Development and assessment of Computer Aided Detection (CAD) software for assisting diagnosis in cervical spine projection radiography

Submitted by Michael Gundry to the University of Exeter
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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or
any other University.

Signature: ……..

ABSTRACT

Introduction

Cervical spine injuries are a major burden on hospital services and have serious consequences for morbidity and mortality; this also affects society due to the associated high care and medical costs. These injuries have the potential to be missed or misdiagnosed, although it must be stated that this phenomena is not unique to cervical spine injuries, and has been seen throughout most imaging services. One possible method to counter this is the use of computer aided detection (CAD) software integrated into the imaging process. This can help increase sensitivity and specificity scores (and thus area under a curve (AUC) scores) by indicating any injuries/pathologies using a pattern recognition algorithm.

Methods

Lateral cervical spine images were collected from clinical cases and anonymysed by the hospital. These were segmented using a Matlab script to develop ground truth images for the computer scientists to develop cervical spine CAD (CSPINE-CAD) software using machine learning algorithms. The CSPINE CAD software was then assessed in a number of studies as described below.

Participants were a convenience sample recruited at the University of Exeter and the Royal Devon and Exeter hospital, and were involved in three tests. These tests all investigated the AUC differences when making a diagnosis without, and with the CSPINE-CAD software. These three tests were:

The first test involving five third year radiography students each diagnosing the same five lateral C-spine radiographs, first without and then with the use of the CSPINE-CAD software. Answers were provided by the students via a comments box in which they would make an original diagnosis, then apply the CAD software and then make a re-diagnosis. Upon completion a questionnaire was filled in about their opinions, feedback and confidence whilst using the software.

The second test involved 11 third year radiography students from the same cohort each diagnosing 30 lateral C-spine radiographs. This involved using a

representation of the CSPINE-CAD software, and followed the same method of diagnosis (a comments box) as in the first test, concluding with a questionnaire.

The third test involved 26 participants made up of junior doctors and qualified radiographers, each diagnosing 30 radiographs without and with CSPINE-CAD. This third test did not utilise a comments box, but instead used an answer sheet which contained blank boxes representing each vertebral body and each vertebral junction. These boxes were filled in by the participant using a number between one and six (one representing no injury, and six being 80-100% confident there is an injury). These boxes would all be filled for each image twice; once without CAD and once with CAD. The next image was loaded and the process repeated. Upon completion a questionnaire was again provided to allow the participants to give feedback and confidence about the software.

Due to the ambiguity in the language used in the comments boxes of the first and second tests, it was concluded to analyse and produce two results per test. The first analysis was a benefit of the doubt analysis in which the diagnosis provided by the participants would receive some latitude (e.g. misalignment of C5 would be accepted if the “true” answer was misalignment C5/C6). The second analysis was more verbatim and received no latitude. All three tests were compared against the gold standard of a radiologists report, and calculated for AUC scores without and with CSPINE-CAD.

Results

None of the three test results were statistically significant. The first test showed an AUC increase of 1.39% (with latitude) and 9.54% (no latitude) when using CAD. The second test showed an AUC increase of 1.64% (with latitude) and a loss of 0.25% (no latitude) when using CAD. The third test showed that across all confidence values (2-6) the AUC is higher 1.65% without CAD. Additionally when reviewing only the highest confidence value (6) the AUC increases with CAD by 0.66%. Questionnaire data showed an increase in average confidence when using CAD across all three tests by 12%, 20% and 9.24% respectively, with the majority of participants agreeing that CAD was helpful as a second “pair of eyes” with scores of 100%, 100% and 73%.

Conclusion

Due to sample sizes and the amount of images being small a statistical significant result could not be reached. Although CSPINE-CAD has shown to be a possible method to reduce missed or misdiagnosed cervical spine injuries, further investigation and development is needed into this CAD software.

ABBREVIATIONS

ALL..... Anterior longitudinal ligament
AAPM ..... American Association of Physicists in Medicine
ACD..... Automated computer diagnosis
AP ..... Anteroposterior
AUC..... Area under a curve
C1..... First cervical vertebra (The atlas)
C2..... Second cervical vertebra (The axis)
C3..... Third cervical vertebra
C4..... Forth cervical vertebra
C5..... Fifth cervical vertebra
C6..... Sixth cervical vertebra
C7..... Seventh cervical vertebra
C7-T1 junction ..... cervico-thoracic junction
C-spine..... Cervical spine
CAD..... Computer Aided Detection
CARS ..... Computer Assisted Radiology and Surgery
CCSR ..... Canadian Cervical Spine Rules
CEMPS..... College of Engineering, Mathematics and Physical Sciences
CI..... Confidence intervals
cm ..... Centimetres
CPD..... Continuing professional development
CSI ..... Cervical spine injuries
CSPINE-CAD ..... Cervical Spine Computer Assisted Detection
CT ..... Computed Tomography
DICOM ..... Digital Imaging and Communications in Medicine
DXA..... Dual energy X-Ray Absorptiometry
EAM..... External auditory meatus
EDJ..... Emergency department junior doctor
EDSG ..... Emergency department staff grade doctor
F1's..... Foundation year 1 doctors
F2's..... Foundation year 2 doctors
FPR ..... False positive rate
GCS..... Glasgow Coma Scale

kVp ..... Kilovoltage peak

L4 ..... Forth lumbar vertebra

mAs ..... Milliamp seconds

mm ..... Millimetres

MRI..... Magnetic Resonance Imaging

MS ..... Microsoft

MSK..... Musculoskeletal

NEXUS ..... National Emergency X-Radiography Utilization Study

NHS..... National Health Service

NICE..... National Institute for health and Care Excellence

OPT ..... Orthopantomography

PDF ..... Portable Document Format

Peg ..... Odontoid process also known as the dens in the cervical spine

PIS ..... Participant information sheet

PLL..... Posterior longitudinal ligament

QM ..... Quantitative Morphometric

ROC ..... Receiver operator characteristics

RD&E ..... Royal Devon and Exeter Hospital

RILD ..... Research, Innovation, Learning and Development Centre

RMSSD ..... root mean square of successive differences

RMSCV ..... root mean square of coefficient of variation

SID ..... Source to image distance

SQ ..... Semi-Quantitative

T1 ..... First thoracic vertebra

T4 ..... Fourth thoracic vertebra

UK ..... United Kingdom

UOE..... University of Exeter

VFA..... Vertebral Fracture Assessment

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AUTHORS DECLARATION

I the author Michael John Gundry declare that the cervical spine computer aided detection (CSPINE-CAD) software used within this research, was developed by City University's team consisting of: Dr Greg Slabaugh (principle investigator), Dr Michael Philips (researcher), Dr Joes Staal (optasia medical), S M Masudur Rahman Al-Arif (research student) Benjamin Narang (intern), Beyrem (intern) and Moad Mellah (intern). This team developed the CAD software throughout the research and provided several updates to versions of the CSPINE-CAD. For my part in developing the CAD software I provided accurate segmentation and alignment data (subsequently sent to the city university team) to allow the software to "learn" from manual segmentations, this type of segmentation and alignment data were also provided by Professor Karen Knapp. Additionally a team at the RD&E; Dr Adam Reubens and Dr Andy Appelboam provided discussion points during the meetings held by the team, and helped gather junior doctor participants during testing. It must also be stated that City university team provided analysis and measurements of vertebral segmentations and alignment data used within this thesis as part of the interoperator and intraoperator studies (Chapter 5).

The actually testing of this CSPINE-CAD software on third year radiography students (first and second test), and on doctors and radiographers (third test) was conduct by myself the researcher.

CHAPTER 1. INTRODUCTION

1.1 MOTIVATION FOR STUDY

Cervical spine (C-spine) injuries (CSI) may result from traumatic injuries to the neck region and can involve fracture, subluxation or dislocation of the vertebra with associated ligamentous injury [1]. This type of injury can lead to instability of the C-spine leading to spinal cord compression and resultant neurological disability. CSI account for 55% of all spinal injuries suffered [2], and make up approximately 4.3% of all trauma patients [3].

They are most commonly seen in males; peaking at the age range of 15-24 years, and then again in the over 55s [4]. They are normally caused due to high energy impact, involving road traffic collisions (50%), falls (43%), and dives into shallow water [5, 6], although there are other causes such as assaults and sporting injuries [7]. CSI can also occur in elderly patients, in the form of fragility fractures from minor trauma, these tend to be due to pre-existing bone abnormalities such as osteoporosis; a disease that is characterised by reduced bone mineral density and microarchitectural deterioration of bones that decreases the physical strength of the skeleton, increasing fracture risk [8].

The majority of C-spine fractures occur at the upper or lower ends of the C-spine. 10% involve the first cervical vertebrae (C1 also named the atlas) [9], 33% involve the second cervical vertebrae (C2 also named the axis); with 15% of those fractures through the odontoid process (also called the peg or dens) of C2 (See Figure 3 for clarity). Approximately 50% of all C-spine fractures involve the sixth (C6) or seventh cervical vertebrae (C7) [2].

The pattern, frequency, and distribution of CSI depend on both the mechanism of the injury and the patient's age, for instance CSI in children are uncommon [10]. C-spine fractures can result from several biomechanical mechanisms, including flexion and extension, compression, lateral bending and axial rotation [11, 12]. Adults tend to have injuries affecting C1 and C2, and C5 and C6, whereas children tend to be affected more by C1 and C2 CSI.

A delayed or missed diagnosis of the C-spine can result in motor and/or sensory neurologic deficits, paralysis, or even death [7]. Studies have shown that 67% of patients with missed cervical fractures suffered neurological deterioration (such as: inability to extend their arms, weakness in muscles, loss of pain or temperature sensation, loss of proprioception, and loss of bowel or bladder control [13, 14]), and nearly 30% who suffered a delayed C-spine injury diagnosis developed a permanent neurological deficit [15]. Due to this CSI are a major source of morbidity and mortality across all age groups.

Due to CSI being such a high risk injury with the potential for life changing repercussions their correct diagnosis is extremely important. Platzer et al research showed that up to 20% of CSI have a delayed (not detected in the first 24 hours) or incorrect diagnosis [7]. Studies have also shown that the most common cause (accounting for between 44% - 47%) of missed or delayed diagnosis CSI was due to misinterpretation of the radiographs [7, 16]. With C6 being the most commonly missed fracture [16].

As well as the implications of delayed and misdiagnosed fractures to the patient, the repercussion of such errors leads to a significant economic burden on the National Health Service (NHS). In the United Kingdom (UK) 1200 people per year are paralysed due to spinal cord injury [17], with an injured person incurring between £1M - £3M in lifetime medical expenses [18]. It is estimated that the cost of caring for people in the UK paralysed by spinal cord injury is more than £500M per annum [17]; however, this estimate is conservative as it only based on patients that accessed a spinal cord injury centre. According to the National Institute for health and Care Excellence (NICE) the NHS spends over £1 billion per annum looking after patients with neurological deficits and long term disabilities, however this figure also includes brain injuries [19].

The cost associated with CSI to the NHS means that preventing disability is likely to be highly cost effective. It is estimated that 21% of people discharged from spinal cord injury centres go into nursing homes, hospitals or other institutionalised settings rather than their own homes [17]. For many spinal cord injury patients; education, career, marriage, and independence are disrupted and sometimes never restored. The human cost is such that around 20% of

patients leave spinal cord injury centres clinically depressed [20]. These reasons are the motivation for this research, as if there is a way the percentage of missed or delayed diagnosed CSI can be reduced then this could not only improve and save patient lives, but also reduce the financial burden on the NHS.

This study assessed how technology such as Computer aided detection (CAD) software could be developed and utilised in musculoskeletal (MSK) imaging especially that of the C-spine; in order to reduce the previously stated missed or misdiagnosed injuries on lateral C-spine radiographs. Currently there is no such software for the detection of CSI, but it is postulated that a C-spine CAD system could help reduce the percentage of missed or misdiagnosed fractures.

1.2 C-SPINE ANATOMY

The C-spine is made up of seven vertebrae (C1, C2, C3, C4, C5, C6, C7), which are the smallest vertebrae in the human spine and make up the uppermost part of the spinal column, starting with C1 beginning at the base of the skull and going down to C7 (Figure 1). The vertebral bodies of the C-spine are classified as irregular bones (i.e. they do not fit into any of the other categories of bone), and form part of the central axis of the skeleton, they are made of cancellous bone covered with compact bone [21]. In between these seven vertebral bodies are a total of six intervertebral discs, (there is no disc between C1 and C2) with the sixth intervertebral disc between C7 and the first thoracic vertebrae (T1). These are made of a tough exterior annulus fibrosus, with an interior nucleus pulposus; these help distribute force and pressure, and give flexibility to the C-spine [22].

The cervical vertebrae are made up of a collection of different components; and thus are all slightly different. C3-C7 are very similar in construction and tend to only vary in size, but C1 and C2 are unique in their shape and as such will be discussed separately. Together, the vertebrae support the skull, move the spine, and protect the spinal cord.

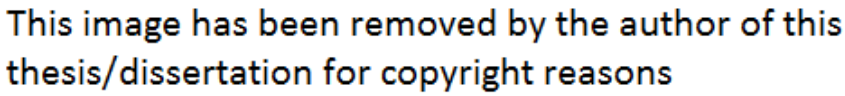


Figure 1. *Anatomy of the C-spine [23]*

C3-C7

The main part of the C3-C7 vertebra is the vertebral body, this lies anterior to the spinal cord and works with the muscles, joints, ligaments, and tendons to provide support, structure, and stabilise the neck. Each cervical vertebra has a protrusion on its posterior aspect called the spinous process; it extends backwards and slightly caudally. These processes increase in size as you go inferiorly, with C7 usually having the largest process of the cervical vertebrae. The spinous process is also where certain muscles attach to the vertebra (for example the Semispinalis cervicis [24]). The vertebrae also articulate with each other via the inferior and superior articular facets forming the joints of the vertebral arches [21], this allows movability and stability but as with any joint can be a source of injury due to dislocation. The pedicles project back from the postero-lateral aspect of the body and connect the laminae to the vertebral body [25]. The laminae project back from the ends of the pedicles; and fuse in the midline [21], connecting the transverse process to the spinous process which helps with stability of the C-spine [26]. The cervical vertebrae also contain a foramen; a hole that allows the spinal cord through, this is posterior to the vertebral body. The vertebrae also have two much smaller intervertebral foramina (one either side) to allow the root of each spinal nerve through (as shown in Figure 1). These common components are seen in cervical vertebrae C3 to C7, with a labelled example of C4 and C7 shown in Figure 2.

Figure 2. *The similarities in anatomy of the cervical spine vertebrae [27]*

C1 and C2

C1 and C2 are both unique, although they contain similar components to the other cervical vertebrae such as; spinous processes, transverse processes, articular facets and a foramen. C1 is a ring structure (as shown in Figure 3), and articulates with the occipital condyles at the base of the skull to form the atlanto-occipital joints [21] (this can be seen in Figure 1 where the skull sits on C1). C1 also articulates with the peg (referred to in Figure 3 as the dens), as C1 fits over C2 to form the median atlanto-axial joint. In order to accommodate the peg, C1 has a facet on the posterior aspect of the anterior tubercle, this allows the peg to fit comfortably and articulate with C1 [21].

C2 as stated has a peg/dens, this projects from the upper aspect of the vertebral body, it also has a facet to compliment the facet on C1, this is to aid articulation and rotation between C1 and C2 [21]. Together C1 and C2 allow the head to rotate and turn.

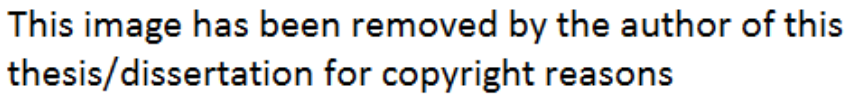


Figure 3. *The anatomy of C1 and C2 [28]*

In addition to the vertebrae, there are ligaments that connect and support the spinal column, these are made up of connective tissue and wrap around the vertebrae. The anterior longitudinal ligament (ALL) arises from the anterior tubercle on C1 and travels inferiorly and anteriorly to the vertebral bodies firmly attached to the annulus of the intervertebral discs [29]. The posterior longitudinal ligament (PLL) arises from the back of C2 and travels inferiorly, and is posterior to the vertebral bodies (attached loosely) and intervertebral discs (firmly attached to the posterior annulus) [29]. These ligaments and additional muscles help support and protect the C-spine, and prevent any excessive movement that could damage the spinal column [30].

1.3 TYPES OF INJURY TO THE C-SPINE

1.3.1 COMMON MECHANISMS OF INJURY

Understanding the types of injuries that a C-spine can receive, and appreciating the skill needed to determine, deduce and classify that injury may give greater comprehension as to why CSI can be missed or misdiagnosed.

As stated, the most likely injury sustained is caused by a motor vehicle collision. This causes either hyperflexion or hyperextension to the C-spine as the head and neck hit the dash board, due to either being hit behind by another car, or as their own car comes to a sudden stop. This type of injury is the most common; with approximately 80% of CSI involving flexion [31]. The other types of mechanism are distraction injuries, rotational injuries and compression injuries [31, 32], with compression injuries seen mostly in people who dive head first into shallow water [32]. Many injuries can result from a combination of these mechanisms; this section will cover some of the most common.

1.3.2 FLEXION INJURIES

Anterior subluxation

Also called hyperflexion sprain, this occurs when the posterior ligaments are damaged causing anterior subluxation of the vertebral body (Figure 4). There may also be increased intervertebral space [32].

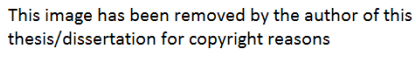


Figure 4. [33] *Lateral radiograph showing an anterior subluxation of C4 on C5 (arrow) with widening of spinous processes*

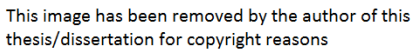


Figure 5. *Lateral radiograph showing an anterior wedge fracture of C7 (arrow) [31]*

Wedge fracture

A wedge fracture happens when a vertebra is compressed between adjacent vertebrae during flexion [34]; the posterior elements including the ligaments remain intact [34]. There is relatively minor loss of height at anterior section of vertebral body [35], an example of this is shown in Figure 5.

Unilateral interfacet dislocation

Unilateral interfacet dislocation is due to a combination of hyperflexion, distraction and rotation [35]. This injury causes the facets to ride up, with the superior facet on one side sliding over the inferior facet, becoming locked [35]. This results in the vertebra being anteriorly displaced by 25% [31], an example of this is shown in Figure 6.

Figure 6. *Lateral radiograph showing a unilateral facet dislocation [32] of C5 on C6 (arrow)*

Figure 7. *Lateral radiograph sho a bilateral facet dislocation [32] on C6 (arrow)*

Bilateral interfacet dislocation

This is the result of extreme flexion and distraction; this causes the related facets to override each other so they become disarticulated [35]. When the dislocation is complete, the upper dislocated vertebra is displaced 50% anteriorly compared to the lower vertebrae [35]; this is shown on the lateral radiograph in Figure 7. Because of its extensive soft tissue damage and dislocated facet joints, bilateral interfacetal dislocation is unstable and is associated with a high incidence of spinal cord damage.

Flexion teardrop fracture

This fracture is the result of a combination of flexion and compression, which is usually caused by a motor vehicle collision, and is seen most commonly at the level of C5 [36]. This fracture produces a triangular or teardrop fragment that comes from the antero-inferior aspect of the vertebral body [35] as shown in Figure 8. The posterior part of the vertebral body may become displaced backwards into the spinal canal, resulting in neural damage [35]. It is the most severe form of flexion injury to the C-spine causing anterior cervical cord syndrome or quadriplegia [36].

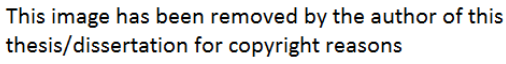


Figure 8. *C-spine lateral radiograph [37] showing a flexion teardrop fracture to C5 (arrow)*

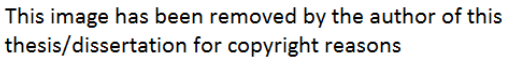


Figure 9. *C-spine lateral radiograph [31] showing a spinous process fracture to C4 (arrow)*

Spinous process fracture

Involves an avulsion fracture caused by the supraspinatus ligament being pulled off the spinous process usually involving C6 or C7 [31] (this is also called a Clay shovellers fracture). This type of fracture is caused following excessive muscular load during a flexing movement [35]. It is usually undisplaced and therefore only seen on the lateral radiograph [31]. An example of a spinous process fracture is seen in Figure 9.

1.3.3 EXTENSION INJURIES

Hangmans fracture

Approximately 15% of all cervical fractures involve C2 [35], and 25% of these are hangmans fractures [35]. The remainder are fractures of the body, lateral mass, spinous process or single neural arch fractures [35]. A hangmans fracture occurs following hyperextension of the head and neck but may also occur following hyperflexion and compression [35]. Typical causes are through hanging (hence the name), and in motor vehicle collisions when the chin hits the dashboard. A hangmans fracture is defined as traumatic spondylolisthesis of C2 [31, 35] and involves a fracture of the neural arch of C2 or fractures of the ring of C2. The fracture happens when transmission of the force travels through the C2 pedicles, this results in an oblique fracture originating anteriorly to the inferior facet joint of C2 and extending supero-posteriorly [31]. This injury is unstable, and best visualised on the lateral view as shown in Figure 10 [31].

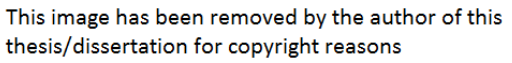


Figure 10. *C-spine lateral radiograph [31] showing a Hangmans fracture of C2 (arrow)*

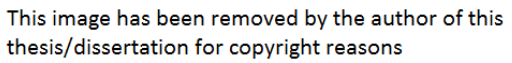


Figure 11. *C-spine lateral radiograp [31] showing an extension teardrop fracture to C2 (arrow)*

Extension teardrop fracture

This is caused by hyperextension and occurs when the ALL pulls a bony fragment away from the inferior aspect of the vertebral body causing an avulsion fracture [31], as shown in Figure 11. The fragment is a true avulsion, in contrast to the flexion teardrop fracture in which the fragment is produced by

compression [38]. This type of fracture is commonly seen in diving accidents and tends to occur at lower cervical levels. This injury is stable in flexion but highly unstable in extension [38].

1.3.4 COMPRESSION INJURIES

Jefferson fracture

C1 fractures represent 2% of all vertebral spine fractures [39]. This injury occurs when an axial (vertical) compression of the skull forces C1 onto C2, compressing the lateral masses, this is normally associated with a diving injury. This results in a burst fracture of the ring of C1 at the anterior and posterior arches [31] (called a Jefferson fracture [35, 39]). A Jefferson fracture can be seen on the peg view (a particular type of radiograph view: see Figure 13 and 21), which shows displacement of the lateral masses of vertebrae C1 beyond the margins of the body of vertebra C2 as shown in Figure 13 [31]. The lateral view can also indicate a Jefferson fracture by presenting with prevertebral soft tissue swelling anterior to C1. The predental space may be widened to greater than 3 millimetres (mm) if there is damage to the transverse ligament [40]; if the transverse ligament is damaged this creates an unstable fracture [31].

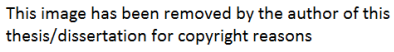


Figure 12. *C-spine lateral radiograph showing a Jefferson fracture (arrow) [41].*

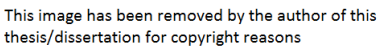


Figure 13. *A peg radiograph showing a Jefferson fracture [41].*

1.3.5 OTHER TYPES OF INJURIES

Peg fractures

Peg fractures represent 5-15% of all cervical spine fractures, and 55% of all C2 fractures [35]. The mechanism of these fractures is not clear [42], it may be caused by flexion or extension and usually results in ligamentous injury [31]. Peg fractures usually occur through the base of the peg [35] and may be visualised either on the peg view or on the lateral view [31] as shown in Figure 14; in which it can indicate a peg fracture via soft tissue swelling anterior to C1 [31].

Figure 14. *C-spine lateral radiograph showing an peg fracture of C2 (arrow) [31]*

Figure 15. *C-spine lateral radiograph showing a Atlanto-occipital dislocation (arrow) [43]*

Atlanto-occipital dislocation

These injuries are usually fatal due to disruption of the medulla oblongata [35]. Although an uncommon injury it is reported to occur in 31% of all fatal motor vehicle collisions [44]. The injury is characterised by complete disruption of all ligaments between the occiput and C1, with subluxation or complete dislocation of the occipitoatlantal facets. This can result in dislocation of the head anterior to the cervical spine [35] as shown in Figure 15.

1.3.6 CONCLUSION

This is just a selection of the most common injuries the C-spine can suffer from, the examples used here clearly show the type and style of injury sustained, and it must be noted these injuries can come in a more subtle form. Due to the difficulty in assessing subtle injuries a true C-spine diagnosis can be delayed or misdiagnosed in plain radiographs. Additional evidence supports this stating; 61% of all C-spine fractures are missed in plain radiographs; including 36% involving missed subluxations (an incomplete or partial dislocation [45]), and 23% involving patients being incorrectly identified as having normal spines [46]. These figures may have been influenced due to poor positioning technique, but even with the best possible technique there may be difficulty in excluding a CSI in trauma patients.

As such it was concluded that the standard technique for C-spine plain imaging be stated. It must be noted that some hospitals image trauma patients with Computed Tomography (CT) instead of projection (plain) radiography, although this is reserved for major trauma since the radiation dose for such an examination is significantly higher; with CT delivering a dose of 2.2 milliSieverts compared to plain radiograph of just 0.07 milliSieverts [47]. It has been argued that CT should replace plain radiograph imaging completely for C-spine trauma [48], whilst other researchers have argued against it [49, 50]. So CT is still not considered routine practice.

1.4 C-SPINE IMAGING

1.4.1 CLINICAL ASSESSMENT AND GUIDELINES FOR IMAGING

If a patient is suspected of having a C-spine injury most hospitals will use one of two ways to determine if C-spine imaging is required following that trauma; the Canadian Cervical Spine Rules (CCSR), or the National Emergency X-Radiography Utilization Study (NEXUS). The CCSR were developed for use on alert patients with a Glasgow Coma Scale (GCS) of 15 and stable cervical spinal trauma patients. (The GCS provides a practical method for assessment of the level of conscious impairment in response to defined stimuli [51]), The CCSR method was developed by evaluating 8,924 cases [52]. It includes three

high risk factors in all alert and stable trauma patients where CSI are a concern [53]:

- age ≥65 years
- dangerous mechanisms of injury such as: fall from an elevation greater than three feet or five stairs, axial load to the head, motor vehicle collision at high speed 100km/hr rollover or ejection, motorised recreational vehicles, and bicycle struck or collision
- Paresthesias in the extremities. Which can be caused by a focal neurological deficit; these are problems restricted to a particular part of the body or a particular activity, for example, loss of balance; general weakness; abnormal reflexes; and problems walking [54]

It also includes five low risk factors allowing safe range of motion assessment:

- simple rear-end collisions
- able to sit in the emergency department
- ambulatory at any time
- delayed onset of neck pain (not immediate)
- absence of midline cervical tenderness.

Additionally, the CCSR suggest that if the patient is unable to rotate the neck to 45 degrees to the right and left, then C-spine imaging is required [53].

The second method the NEXUS guide is also used; it was first described in 1992 [55], and subsequently validated in a study involving 34,069 patients [56, 57]. This requires patients to meet the following five criteria to be classified as having a low probability of injury [53]:

1. No midline cervical tenderness
2. No focal neurologic deficit
3. Normal alertness
4. No intoxication (intentionally not defined)
5. No painful, distracting injury (also intentionally not defined)

Patients who suffer CSI go through a process of clinical evaluation following either the CCSR or NEXUS guidelines. This leads them to undergo a series of radiographic imaging of the trauma area. As is shown from the NICE guidelines

flow chart in Figure 16, the UK incorporates the majority of the CCSR guidelines into its C-spine imaging protocols. This may be due to the NEXUS criteria missing almost 10% of CSI when compared to the CCSR [58], or that the CCSR was shown to be more sensitive and specific than the NEXUS criteria, making it the more accurate of the two [58]. Following the NICE guidelines flow chart means C-spine imaging is divided into two types of primary imaging, either CT or a series of plain radiographs. The extent and type of injury determines the type of imaging required [59].

1.4.2 CT

Adults in the UK will have a CT C-spine scan recommended within an hour of the issues being identified: If they have sustained a head injury and have any of the three high risk factors from the CCSR, or additionally; have a GCS of less than 13 on initial assessment, have been intubated, or have suspicious or inadequate radiographs (see figure 16 for flowchart).

1.4.3 MRI

Magnetic Resonance Imaging (MRI) is also used depending on the type of C-spine injury, although CT and plain radiographs are still the primary imaging services. MRI is used if there is suspicion of vascular injury (for example, vertebral malalignment, or posterior circulation syndrome) and is used to assess spinal cord injuries [60]. MRI can add important information about soft tissue injuries associated with bony injuries, and has a role in the assessment of ligamentous and disc injuries suggested by x-ray, CT or clinical findings [54].

1.4.4 PLAIN RADIOGRAPHS

If the patient does not have any of the risk factors for CT then they are reassessed to see if they require plain radiograph imaging. This protocol (Figure 16) incorporates the five low risk factors (from the CCSR), including the assessment involving the rotation of the patients neck 45 degrees to the right and left.

Figure 16. *National Institute for health and Care Excellence guidelines showing the flow diagram of the protocol used for imaging C-spines [59]*

1.4.5 C-SPINE PLAIN RADIOGRAPH IMAGING

NICE guidelines state that for adults who have sustained a head injury and have neck pain or tenderness but no indications for a CT C-spine scan, then three C-spine radiograph views should be performed, this includes: a lateral view, an Anteroposterior (AP) view, and a peg view [61] as shown in Figure 17. This should be performed within one hour of the risk factors being identified [54]. The radiographs should then be reviewed by a person clinically trained in C-spine interpretation, within one hour of being performed [54].

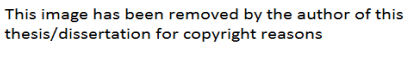


Figure 17. *Shows the standard three radiographs taken in a C-spine radiograph series (this includes: a Lateral view (left) [62], a Peg view (middle) [31] and an Anteroposterior (AP) view (right) [31])*

The first radiograph in the three plain radiograph series involves a lateral of the C-spine; this is the most important image containing the greatest information of the three projections [63, 64, 65], and should always be done first and reviewed by the radiographer prior to progression of the other projections. After the lateral, an AP is performed. In some cases of C-spine imaging two projections might be enough, in trauma cases an additional view called an odontoid process or “peg” projection is required in order to look for peg fractures of C2. If any clinical information is missing from the radiographs then repeats or additional views must be performed. One additional view is called a swimmers view and is sometimes performed when the cervico-thoracic junction (C7-T1 junction) cannot be seen on the lateral view. These radiographs are then diagnosed and further imaging requested if required.

1.4.6 LATERAL PROJECTION

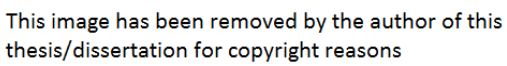


Figure 18. *Lateral C-spine radiograph [62]*

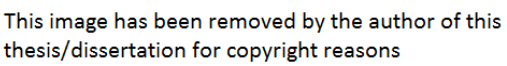


Figure 19. *Lateral C-spine radiograph (from Figure 18) labelled with the anatomy of the C-spine [62]*

An optimum lateral C-spine radiograph should be performed at a source to image distance (SID) of 180 centimetres (cm) [68] with a broad focus, on a cassette 24x30 cm [66] (although some digital radiography setups have the cassettes built in, and thus the cassettes "size" is dictated by the collimation), The centering point of the midline of C4 should be used to direct the central x-ray beam, and collimated to the soft tissue borders laterally [65]. The radiograph should be taken on suspended expiration to reduce blurring on the image and to draw the shoulders caudally; to allow better visualisation of the C7-T1 junction which should be visualised on the lateral radiograph. There should be no rotation of the shoulders, head or pelvis, and the mandibular rami (the posterior portion of the jaw) should be superimposed on the radiograph as over rotation can obscure vertebral bodies [63].

This should produce a radiograph consisting of the external auditory meatus (EAM, the ear canal) superiorly (so the whole of C1 is visualised) to the C7-T1 junction inferiorly, including the top half of T1. The radiograph should include all soft tissue borders laterally and medially in order to assess the prevertebral tissues for indications of trauma. Contrast of the radiograph should be optimum in order to visualise the proper bone density of the cervical bodies and air columns, so the correct Kilovoltage peak (kVp) and Milliamp seconds (mAs) should be used. There should be no avoidable artefacts such as hair pins, earrings and hearing aids obscuring the C-spine, as this would impair the quality of the radiograph by obscuring important anatomy. Due to positioning of the patients head on the cassette an air gap between the cassette and the C-spine is inevitable, this increases contrast by removing scatter, but also creates magnification of the anatomy [64]. An example of a lateral C-spine radiograph is shown in Figure 18, with a labelled diagram in Figure 19.

The lateral radiograph provides a side view of all seven cervical vertebrae and the C7-T1 junction, and is considered to be the most useful view for detecting dislocations or subluxations via the misalignment of the vertebral column; it also allows the visualisation of possible cervical vertebral body fractures. It can also be carefully analysed for fractures of the spinous processes, as well as the spacing between the anterior and posterior parts of the vertebral bodies. The lateral view can also convey information due to prevertebral soft tissue swelling that can indicate trauma such as ligamentous injury [3]

1.4.7

ANTEROPOSTERIOR PROJECTION

The optimum AP view (Figure 20) should be conducted at a SID of 100 cm, on broad focus, using an 18 x 24 cm portrait cassette [66] (unless using some digital radiography setups) with a moving or stationary grid. The central ray should be aimed at the level of C4 with approximately the level of the angle of the mandible 15 to 20 degrees cephalad to match the lordotic curve of the C-spine to penetrate the intervertebral disc spaces [68]. Collimation should include the outer skin margins laterally and medially, superiorly should be C3, and inferiorly should be the second or third thoracic vertebra [68]. This should be done on suspended expiration to reduce blurring. With the posterior portion of the patient in contact with the cassette (optimally this would be with the patient in the erect position, but in trauma cases this is likely to be in the supine position so make sure the patient is parallel to the floor).

Figure 20. *C-spine AP radiograph with anatomy labelled [67]*

The midline of the patient should line up with the midline of the cassette, and the central ray. There should be no rotation of the shoulders, and all avoidable artefacts should be removed (e.g. necklaces) [66]. The AP projection although not as important as the lateral view, can convey fractures and dislocations that are not shown on the other views, as well as giving additional spatial information [31].

1.4.8 PEG VIEW

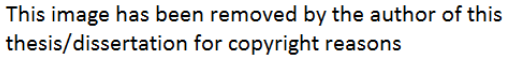


Figure 21. *Peg view of C-spine radiograph series with anatomy labelled* [67]

Finally the peg view (Figure 21), taken through the patient's mouth, provides a view of C1 and C2, including the peg, and is examined for fracture and asymmetry. The optimum peg view is conducted on an 18x24 cm cassette [66] (unless using certain digital radiography setups), with fine focus, a grid, and at a SID of 100 cm [68]. The patient is in nearly all cases supine on a trolley due to it being a trauma case, the cassette is placed as close to the posterior portion of the patients head and neck as possible. The patient then opens their mouth as wide as possible (without causing further injury) and then the central beam is aimed at the centre of their open mouth (roughly the peg) [68]. This should be parallel to the occlusal plane of the top teeth and the base of the skull to avoid superimposition of the peg (the x-ray tube may be angled cephalad, caudal or perpendicular depending on the patient's presentation). Superiorly, the collimation should include the peg and vertebral body of C2, the lateral masses of C1 and apophyseal joints between C1 and C2 [68].

The patient's head should remain parallel to the floor at all times. All avoidable artefacts should be removed (e.g. tongue jewellery, dentures), there should be no rotation of the patient, with the exposure made on suspended respiration to avoid blurring. The main information gathered from a peg view is if there is a peg fracture or a possible burst fracture to C1.

1.5 ASSESSMENT OF THE C-SPINE

In order to assess plain C-spine radiographs for fractures and injuries and thus understand how these can be missed or misdiagnosed an A, B, C'S approach should always be used:

- Adequacy and Alignment
- Bones
- Cartilage and Joints
- Soft tissue

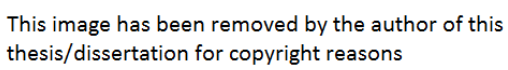
1.5.1 ADEQUACY

This relates to the radiograph being clinically diagnostic; is all the information on as described in the optimum imaging technique. Does the lateral show the base of skull to the endplate of T1? Does the AP show C3-T1? Is the C2 spinous process visible? Does the peg view show C1-C2 articulations?

1.5.2 ALIGNMENT

Lateral Alignment

One of the most important actions to take is to assess the stability of the C-spine; this again uses the most important radiograph the lateral. On the lateral the alignment and stability of the C-spine can be determined, this happens by dividing the C-spine into three "columns" called the Theory of Denis [69] (Figure 22), or by using three lines as shown in Figure 23.



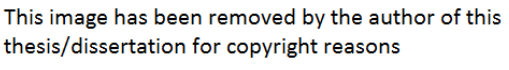


Figure 22. *The theory of Denis applied over two vertebrae to show the designated (shaded) columns [70]*

Figure 23. *Three lines (anterior, middle and posterior) applied over a lateral C-spine radiograph [71]*

Theory of Denis (three columns)

Anterior column (1) – Involves the anterior half of the vertebral body/intervertebral disc, and the ALL [69, 72]

Middle column (2) - Involves the posterior half of the vertebral body/intervertebral disc, and the PLL [69, 72]

Posterior column (3) – Involves the posterior elements - the lamina, facet joints, spinous processes, and the associated ligaments. [31, 69, 72]

The three lines uses a similar approach with the anterior (black) line involving the anterior portion of the vertebral body and the ALL, and the middle (red) line using the posterior portion of the vertebral body and the PLL. The only difference being that the three lines uses the spinolaminar line (blue) as its posterior, and the theory of Denis uses the spinous processes.

With reference to Denis' three-column theory of spinal stability [69], fractures of the spine can be classified based on the pattern of injury and the forces involved [73]. The mechanism of the injury sustain reflects the mechanical injury to the vertebral bodies [72]. An injury to the C-spine is thought to be unstable if

two of the three columns are disrupted. Generally, if the middle column is disrupted, either the anterior or posterior columns will also be involved, or the injury is therefore unstable. Signs of instability include [74]:

1. More than one vertebral column involvement
2. Increased or reduced disc space height
3. Increased interspinous distance
4. Facet joint widening
5. Vertebral compression greater than 25%

The middle column is the fulcrum from which the spine pivots into flexion and extension. It is generally thought that the middle column remains intact, and is therefore stable in simple flexion and extension injuries [31]. Axial compression, distraction and rotational injuries, or a combination of these with flexion or extension will usually disrupt the middle column [31].

AP Alignment

When looking at the alignment of the AP radiograph; the spinous processes should be followed inferiorly to make sure they are consistently in the midline [66]. If one of the spinous process is in malalignment then a unilateral facet dislocation should be suspected [31]. The pedicles should be evaluated so that they are equal distance from the vertebral body edges [66]. The height of the cervical vertebral bodies should be approximately equal on the AP view, and the height of each joint space should be roughly equal at all levels. Also the intervertebral disc spaces should be more open due to the caudal angulation, and the mandible should be superimposed on the base of the skull [66].

Peg Alignment

The lateral aspects of C1 should line up with the lateral aspects of C2. If they do not line up, there may be a burst fracture of C1 [31, 61]. There should be symmetry between the peg and the lateral masses of C1 [61], if there is asymmetry this may suggest a fracture, although this may just be due to rotation of the patients head [31].

1.5.3 BONES

All cortical margins should be checked for fractures across all three projections, especially of all the bones shown on the lateral (C1-C7) [68]. The vertebral bodies should all approximately be equal height, and should be regular cuboids, similar in size and shape to the vertebral body immediately above and below (not including C1 and C2); any loss of height to a vertebral body can indicate a compression or wedge fracture [75]. The spinous processes should be checked, and if there is angulation of the spinous process above eleven degrees at any level of the C-spine then a ligamentous injury or fracture should be assumed [61]. On the peg view the bony margins of the peg should have uninterrupted cortical margins, and be completely seen without superimposition of other anatomy or artefacts [68].

1.5.4 CARTILAGE

The lateral and AP view should asses the intervertebral disc spaces, which should be uniform, as should spaces between spinous processes. The Predental space (the space between the anterior arch of C1 and the anterior aspect of the peg) should not measure more than 3 mm in adults [76]. If the space is increased, a fracture of the peg or disruption of the transverse ligament is likely.

1.5.5 SOFT TISSUE

On the lateral C-spine radiograph an abnormal prevertebral soft tissue shadow (secondary to haemorrhage) may be the only indicator of a C-spine injury. A normal prevertebral shadow does not however exclude an injury. The airway and pharynx should be checked for swallowed foreign bodies such as teeth or dentures and also any supporting airway device position.

Typically soft tissue at C2 should measure less than 6 mm, or less than 50% of the width of the adjacent vertebral body [61]. At the level of C6 it should measure less than 22 mm [61]. The AP and peg view do not really add any more additional information to prevertebral swelling except for better understanding of spatial positioning (i.e. the exact position of a swallowed item for instance).

Due to the types of severe injuries a C-spine can sustain, it must be concluded that anything that can help a diagnosis, and thus reduce the possibility of injuries being missed, or misdiagnosed must be considered. One of these possible considerations is a piece of technology called Computer Aided Detection (CAD) software. This type of software could be integrated over the lateral C-spine radiographs and visually apply (via software) the systematic assessment approach already in place (the three lines), consequently highlighting or indicating injuries, thus reducing missed or misdiagnosed injuries.

1.6 COMPUTER AIDED DETECTION SOFTWARE (CAD)

1.6.1 AN OVERVIEW

Even the best human observers make errors in the interpretation of radiographs. These errors may be due to tiredness, inexperience, or environmental disturbances [77]. Although a perfect human observer might never be possible, computers and software can facilitate in reducing these errors [77]. One of these facilitators is Computer Aided (or Assisted) Detection software more commonly referred to as CAD, a technology that is used in medical imaging; designed to increase true positive rates (also called its sensitivity), and to increase true negative rates (referred to as its specificity) [78]. This simply means the higher these two values (sensitivity and specificity), the greater the accuracy of the medical test. Sensitivity is the more important of the two in this context as it refers to the true positive rates; this means the amount of times the test concludes a patient has a disease/injury (when they truly do). If this sensitivity rate is low then a patient with an injury/disease might be allowed to be discharged due to a test incorrectly revealing the absence of the injury/disease. CAD software has shown to increase this sensitivity and thus helps physicians/radiologists at interpreting medical images [78].

Computer aided detection does this by using pattern recognition software, and reviews the image/radiograph identifying anything it deems suspicious bringing it to the attention of the radiologist/operator. A standard CAD system will start first with the radiologist making a diagnosis, after which they will activate the

CAD software which will then highlight any suspicious findings. These finding are re-reviewed by the radiologist, who can modify their original diagnosis (should they wish) before submitting their report [78].

1.6.2 DEVELOPMENT OF COMPUTER AIDED DETECTION SOFTWARE

In 1955 Lee Lusted described the possibility of computers reading and automatically interpreting radiographs [79]. Early studies were conducted throughout the 1960s [80-85], these provided interesting results but were unsuccessful; this was due to several factors: lack of computing power, not having advanced image-processing software, and the lack of digital imaging.

The first published works regarding computers examining radiographs was reported in 1976 by Winsberg et al [79]. Winsberg and his team examined the use of computers to analyse the detection of breast lesions on mammograms [79]. This stimulated a number of further research studies [79]. These ideas created a concept called automated computer diagnosis (ACD); this was intended in time to replace radiologists in interpreting the radiographs. However, in the 1980s, with the concept of computer analysis evolving, another approach emerged. This approach postulated that the computer could work with the radiologists, and not replace them; this concept was known as computer aided detection (CAD) [86].

1.6.3 COMPARISONS BETWEEN AUTOMATED COMPUTER DIAGNOSIS AND COMPUTER AIDED DETECTION

These two concepts of ACD and CAD exist even at present; with some researchers working seriously on the development of ACD systems. For example in 2011 ACD software was tested to diagnose coronary stenosis in CT angiography against an expert human interpreter [87]. There is also the possibility that CAD systems in the future could be used to conduct a primary diagnosis, and thus take on the role similar to an ACD [86], this idea may be due to the recent technological advances of computing and digital imaging. In 2002 during two panel discussion sessions, one at Computer Assisted Radiology and Surgery (CARS) meeting in Paris, and the other at the American Association of Physicists in Medicine (AAPM) in Montreal, about half of the participants voted for the possibility that CAD would be shifted to ACD within 50

years, whereas the other half voted against this prediction [88]. Due to these reasons a comparison between the two systems must be conducted.

Firstly both CAD and ACD analyse images quantitatively via computer software, which means the development of computer algorithms was required for both CAD and ACD systems. Although the major difference between CAD and ACD is the way in which this software is utilised in assisting the diagnosis; with CAD, radiologists use the software as a “spell checker” with radiologists reviewing the information highlighted by the software, and making the final decision. With ACD the software decides the diagnosis entirely on its own using standard modelling strategies [89].

Due to these modelling strategies not being very successful, and the unrealistic expectation of higher performance from computer vision than human vision [90], the evolution of ACD became more tempered, and CAD systems became more dominant. In 1990, Chan et al [91] provided the first statically significant scientific evidence for the benefits of CAD in the detection of lesions in mammography. The main reason the CAD system was seen as the superior was due to the radiologist having the final decision in the diagnosis. This meant if the radiologist was confident in their diagnosis, then they may agree or disagree with the CAD software’s diagnosis, knowing their experience and skill is greater than that of the CAD software. However, for cases in which the radiologist is less confident or unsure, the clinical decision making process could be supported by use of the CAD software indicating the injury/disease.

This improvement depends on the ability and performance of the CAD software being used; the higher the performance of the software the greater the diagnostic accuracy. However, the performance level of the CAD software does not have to be equal to or higher than that of radiologists, as the radiologist can dismiss the diagnosis, unlike in ACD which must equal or exceed the radiologist’s performance. An example of this would be detecting pulmonary nodules, if the sensitivity for detection of the nodules was lower than that of average sensitivity score of the radiologist it would be difficult to justify the use of ACD. Therefore, high sensitivity and high specificity are required for implementing an ACD system [86]. In comparison a CAD system can have a

low sensitivity and low specificity and can still be used effectively. For example, if the CAD software could detect subtle pulmonary nodules which might be difficult for radiologists to detect, yet had poor sensitivity on the larger nodules, the radiologist could disregard CAD false negatives (the missed large nodules), and still utilise the CAD software successfully. However, this sort of system could not work with an ACD, due to such poor sensitivity. By combining the radiologist's competence and the computers capability the best of both worlds can be realised. Because of this, CAD software has become widely used in practical clinical situations.

Commercial CAD systems for detection are now available for clinical use, and have shown a steady increase in sensitivity and specificity. An example of this is in 1993 microcalcifications in mammography scans scored 87% sensitivity at 1.0 false positive per radiograph. Yet their most current CAD system scores an estimated 98% sensitivity at 0.25 false positive per radiograph [86]. It is obvious from these results that a substantial improvement and evolution has happened in CAD systems.

Due to CADs dominance, it has been integrated into some of the most important medical imaging scans. From its early use in mammography CAD systems have evolved with the software becoming ubiquitous and integrated into many services. For example:

- Mammography it has improved the detection of microcalcifications [92, 93, 94]
- Chest CT scans; CAD identifies pulmonary nodules via their density and shape [95]
- CT colonography CAD identifies colorectal polyps [96]
- MRI CAD is used in prostate cancer screening [97]
- CT cardiac scans looking for coronary artery stenosis [98]
- Nuclear medicine whole body scans, where CAD helps identify bone metastases [99]
- CT spinal imaging CAD is used in detecting sclerotic bone metastases in the spine [100,101]

These CAD programs have been shown extensively to improve diagnostic

accuracy and sensitivity in these fields, and are a clinically proven technology [78, 92-96]. But it must be acknowledged that there are data that suggest that CAD systems do not statistically improve the diagnosis [102], and that CAD systems increase recall rates and reading times [103], although the majority of research shows positive results of CAD systems there seems to be a lack of research regarding CAD software being used in C-spine imaging looking at vertebral fractures and injuries.

1.6.4 VERTEBRAL FRACTURES

Although there is a lack of spinal CAD software in plain radiographs, it has been utilised in measuring lumbar and thoracic spine imaging in calculating bone mineral densities in Dual energy X-Ray Absorptiometry (DXA) scans [104], and also used on lateral chest radiographs [86]. Both techniques looked at (thoracic and lumbar) vertebral fractures due to osteoporosis. Vertebral fractures are a common outcome of osteoporosis so early detection of these fractures is extremely important due to the possibility of additional fractures [105-108].

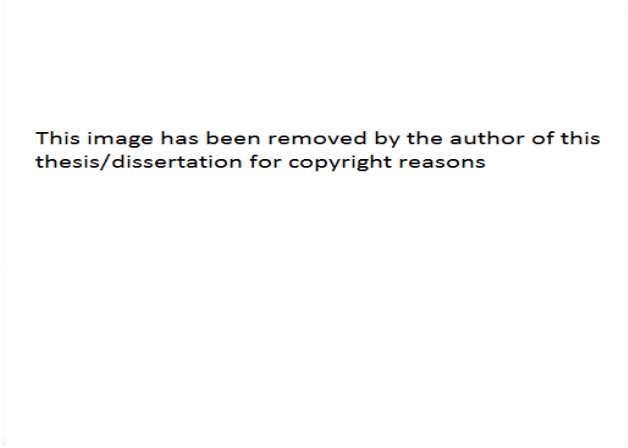


Figure 24. *Genant SQ classification of vertebral fractures [109]*

To determine the severity of vertebral fractures objectively, there are currently two widely accepted methods these are; the visual semi-quantitative (SQ) assessment, and the quantitative morphometric (QM) approach [110]. The first method, the SQ approach involves a radiologist classifying each vertebra by means of visual examination of the vertebral body height at the anterior, middle and posterior portions, and stating any morphologic changes [111]. The most successful of these is the Genant SQ scale [112] (Figure 24); which shows the scale classifications and their associated diagnosis based on visual assessment.

The second approach, the QM approach is where six (or more) points are placed manually on the vertebral body edges and are used to calculate the

anterior, middle and posterior heights, which are then used to categorise fracture type. However, the point placement on the vertebrae is still manual and thus subjective to bias; this introduces variability into the process of detecting vertebral fractures, additionally it is also time consuming [113]. Three examples of CAD software being used in spinal imaging are shown on the next few pages.

CAD method for vertebral fractures in lateral chest radiographs

Kasai et al [114] developed a CAD method for detection of vertebral fractures on lateral chest radiographs in order to assist radiologists' image interpretation, and thus the early diagnosis of osteoporosis. This CAD system used the QM approach, utilising a combination of techniques including feature analysis, which was used to identify the vertebral end plates [114]. The height of each vertebra was determined from locations of identified vertebral end plates, and fractured vertebrae were detected by comparison of the measured vertebral height with the expected height, with any fractures indicated with an arrow, as shown in Figure 25.

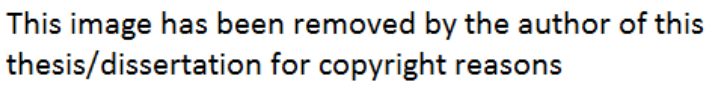


Figure 25. [86] *Detection (arrowhead) by CAD software of a fractured vertebra (dotted circles)*

Preliminary results indicated that the sensitivity of this CAD method for detection of vertebral fractures was 95%, with 1.03 false-positive fractures per image. For a validation test, the detection accuracy of the CAD system was examined by use of additional fracture cases which were selected independently from the training cases. The sensitivity for these cases was 75% at 1.03 false-positive fractures per image. This demonstrates a successful CAD system, although the vertebral analysis was time consuming.

A lateral vertebral assessment on a DXA scan

This CAD research explored unrecognised vertebral fracture in patients who presented with back pain. In this research patients underwent a DXA scan evaluation, using a Hologic bone densitometer (Discovery W model, Hologic, New York, NY, USA) [115]. A lateral vertebral assessment evaluation was performed on the DXA scans from the fourth Thoracic vertebrae (T4) to the fourth Lumbar vertebrae (L4) [115], with the Genant's SQ method being utilised. An example of one of the lateral vertebral assessment DXA scan is shown in Figure 26.

Figure 26. *A) Dual energy x-ray absortiometry scan from T4 to L4. B) Normal vertebral body of T10. C) A Grade one wedge fracture at T11. D) A Grade two wedge fracture at L2. E) A Grade three biconcave fracture at L3. [115]*

The research concluded that the lateral Vertebral Fracture Assessment (VFA) DXA scans can be a standard method for evaluating patients with osteoporosis and vertebral fractures [115]. In the study, approximately 39% of the patients presenting with back pain had an unrecognised vertebral fracture (including single and multiple vertebral fractures), of which 62.6% were multiple, and 37.4% were single vertebral fractures that were detected by lateral vertebral assessment DXA. This again shows a successful CAD system with this one being a combination of both methods SQ and QM.

Semi-automated quantitative morphometry measurements assessing vertebral fractures

This third CAD example (Figure 27) shows the use of semi-automated QM measurements. This involved using a model-based shape recognition technology that provides standard six-point morphometry [113], plus detailed annotation to define the shape of each vertebra between T4 to L4 (Figure 27). Digital Imaging and Communications in Medicine (DICOM) images were loaded and displayed, and vertebrae of interest from T4 to L4 were labelled by the operator by manually placing points in the approximate centre of each vertebral body [110]. Using these points, the algorithm then automatically identifies vertebral body margins, draws contours, and places points for standard

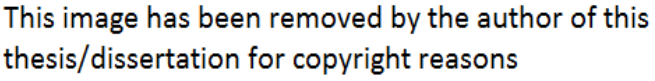


Figure 27. T*he method used to conduct semi-automated QM measurements on a lateral CT radiograph [113]*

six-point morphometry. The operator reviewed the images, and if necessary, manually adjusts the point placement. The CAD program computes vertebral heights, height ratios, and deformities indicative of vertebral fracture [113]. Vertebral fractures were then identified based by fracture percentages derived from morphometry alone, using Genant's SQ scale as shown in Figure 24.

This CAD method was reliable for vertebral fracture assessment based solely on QM, and was comparable to previous reports for SQ vertebral fracture grading by radiologists. Furthermore, the average time to complete the semi-automated QM analysis was approximately 9 minutes and 40 seconds less than previously reported for manual morphometry analysis 116].

These last two examples of CAD systems combine both approaches (the SQ and QM) achieving good results. There seems to be an increasing collection of semi-automated software solutions, which have been commercialised in DXA systems, such as those produced by GE Lunar and Hologic [117, 118] these systems argue that the QM approach is not consistent enough in vertebral fracture assessment, and the SQ method is too subjective [118], therefore they utilise a combination of these two approaches.

1.6.5 CONCLUSION

In conclusion, CAD has been seen as the superior method over ACD due the benefits of a complimentary system which can be overridden by an experienced professional, as such the evolution and dissemination of CAD systems has accelerated, and divided into multiple imaging technologies. As for the CAD systems in vertebral imaging the QM method relies on direct measurements of vertebral bodies by placement of six or more points, and thus incurs a large time commitment, combined with the fact of subjective variability in the point placement. With regard to the SQ method this lacks objectivity due to only being a visual assessment, and with the accuracy determined by the experience of the reader and not a piece of software. With the success of other CAD systems merging both approaches, it was concluded that a combination of the two approaches (SQ and QM) should be utilised to enhance the strengths of each technique, while minimising their limitations, and possibly improving the identification of vertebral fractures [90, 113, and 119].

1.7 AIMS OF THESIS

In summary, this thesis is going to assess the research question regarding what the effect of a newly developed piece of C-spine CAD software has on diagnosing accuracy on lateral C-spine radiographs

Due to the impact that a C-spine CAD system could have in improving the lives of patients, and reducing the financial burden on the NHS, it was decided to help develop and test a piece of cervical spine computer aided detection (CSPINE-CAD) software. This software was created by City University (consisting of Dr Greg Slabaugh and his team), with developmental help from myself (the researcher), Professor Karen Knapp and a team at the RD&E. This software was designed to utilise a combination of the SQ and QM approaches, and was taught via segmented lateral C-spine radiographs. As the software evolved it developed the ability to indicate vertebral fractures and misalignments via its own shape analysis. This CSPINE-CAD software was then tested for its efficacy; with the main aim being: how does CSPINE-CAD software effect diagnosing accuracy on lateral C-spine radiographs. This aim is addressed in the forthcoming chapters summarised below:

- Chapter 2. Co-creation of CSPINE-CAD software; its evolution and adaption. The creation of the software was addressed due to possible limitations in its design and creation, which might affect its overall efficacy performance during testing.

- Chapter 4 and 5. The use of the Genant SQ scale within the CSPINE-CAD software on radiographs, and the level of precision from separate operators in teaching the CSPINE-CAD software. These chapters address the use of the Genant scale in creating an accurate diagnosis via the software, and if the software's learning source is reliable. Both of these reflect upon the software's efficacy and reliability.

- Chapters 3 and 6. The first test; one to one testing of the CSPINE-CAD software on lateral C-spine radiographs using third year radiography students. These chapters address the first test of the software, and

provide useful feedback into how helpful, accurate and effaceable the software was. This is presented in the form of diagnosis (without and with the software) and questionnaire data.

- Chapter 3 and 6. The second test; 20 radiographs tested on a static version of the CSPINE-CAD software on lateral C-spine radiographs using third year radiography student. These chapters again address the efficacy of the software, albeit by proxy due to the use of static image. This was justified in order to upscale the previous test numbers.

- Chapter 3 and 7. The third test; 30 radiographs, one to one testing of the CSPINE-CAD software on lateral C-spine radiographs using junior doctors, and qualified radiographers. These chapters use the latest version of the software and test it in an environment closest to its real life application. As such these results via diagnosis and questionnaire data give the fairest representation of the CAD software's acceptability and efficacy.

These methods will be discussed more in depth in later chapters, but should provide adequate information to answer the aim regarding if CSPINE-CAD software can help reduce the missed and misdiagnosed injuries on lateral C-spine radiographs.

1.8 FUNDING AND ETHICS APPROVAL

A grant application was submitted to the RD&E. This was funded and provided the cost of staff time, consumable costs, travel expenses, and accommodation for conferences. The project was reviewed and given ethical approval by the UOE CEMPS (Appendix 1 with amendments made in Appendix 2) for testing the CSPINE-CAD software on third year radiography students; both in the first and second test. For the third test additional ethics approval was required, ultimately being approved by the UOE medical school research ethics committee (ethics application number Apr15/B/064) (Appendix 3).

CHAPTER 2. CSPINE-CAD SOFTWARE; ITS DEVELOPMENT AND APPLICATION

2.1 INTRODUCTION

This chapter will outline how user inputs supported the development of Dr Greg Slabaugh's (and his team at City University) CSPINE-CAD software; the manual segmentation of the vertebral bodies will be discussed along with the manual inputting of the alignment curves. How the software evolved, improved, and the issues experienced will also be discussed.

2.1.1 BACKGROUND

Patients who suffer C-spine trauma normally undergo a series of three radiographs as stated in Figure 17 of section 1.4.5. One of these is the lateral image which was chosen as the radiograph to develop the CSPINE-CAD software on, due to it being the most valuable projection in the series [63, 64].

A)	B)	C)
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Figure 28. *Shows an Illustration of originally proposed software. (Key: Orange contours show vertebral segmentations (A). Green, blue, and purple lines show alignment patterns (B). CAD would then indicate potential alignment issues (red arrows) or fractures (yellow arrows) (C)).*

A feasibility project was proposed by Professor Karen Knapp, Dr Greg Slabaugh and his team, and a team at the RD&E to develop CAD software to assist physicians in interpreting lateral radiographic images of the C-spine; the

concept is illustrated in Figure 28 from the original “case for support document” (Appendix 4). This software was designed to act as a “spell checker” and would be activated by the physician after the radiograph had first been reviewed. The original idea was that the CSPINE-CAD software would semi-automatically perform a segmentation of the vertebral bodies of C2-C7 (Figure 28 A). This segmentation would then provide spatial data (i.e. the software would then know the location of the contours of the vertebral bodies) allowing subsequent processing and highlight any vertebral body fractures via an arrow (Figure 28 C). In addition to this, three alignment curves would then be overlaid onto the radiograph along the anterior and posterior parts of the vertebral bodies, as well as the spinolaminar junction (as discussed in section 1.5.2 Figure 23 and shown in Figure 28 B). Any suspicious misalignments would then be indicated with a red arrow by the software, as shown in Figure 28 (C).

2.2 METHOD OF CREATING THE CSPINE-CAD SOFTWARE

2.2.1 CREATING THE CSPINE-CAD SOFTWARE THROUGH LEARNING

In order to develop the proposed CSPINE-CAD software, approval was first sought for the study, from the University of Exeter (UOE) College of engineering, mathematics and physical sciences (CEMPS) ethics committee (Appendix 4), and from an NHS research committee in order to collect the radiographs from the RD&E. This was to make sure it complied with confidentiality and personalisation issues.

In total a collection of 183 C-spine radiograph files were gathered from the Royal Devon and Exeter Hospital (Wonford) (RD&E). Each file contained one to six images depending on additional/multiple projections taken. All data within the file had been de-identified of personal information except age and gender. Each file was then sorted into their projections of laterals, swimmers, APs and peg images, with the pegs, swimmers and APs being deleted. This left 183 images of lateral C-spines; although three radiographs were corrupt, and one radiograph was missing. So in total 179 lateral C-spine radiographs were collected. The reports for all radiographs were also recorded into an MS Excel

spreadsheet in order to compare later (Appendix 5).

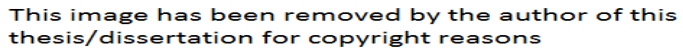


Figure 29. *Screen grab of the CSPINE-CAD software and its layout.*

The first chosen lateral C-spine radiograph was loaded into MATLAB (version R2014a 8.3.0.532 Mathsworks, Natick, MA), which in turn contained version 1.0 of the CSPINE-CAD software (Figure 29), this software was developed by the computer science collaborators at City University (consisting of Dr Gregory Slabaugh and his team).

In order to get the CSPINE-CAD software to segment the vertebral bodies and apply the alignment curves it first had to learn how. This meant that the software had to learn from manually segmented vertebrae, and manually applied alignment curves. This manual input was provided by two radiographers; researcher 1, and researcher 2. This way the software could develop and learn how to accurately segment both the vertebral bodies and apply the alignment curves, leading to software that could indicate any deviations from the norm as suspicious, such as possible fractures or misalignments.

In order to manually input the segmentations and alignments, the software provided a collection of options on its control panel as shown in Figure 30. The 'load' button allowed lateral C-spine radiographs to be imported into the CSPINE-CAD software. The radiograph could then be manipulated and segmented. After loading the radiograph it was rotated (if needed) using the 'rotate' button, so C1 and the EAM were at the top part of the screen, and C7 and T1 were near the bottom. This allowed consistent and repetitive viewing, and is considered the standard orientation for interpreting lateral C-spine radiographs.

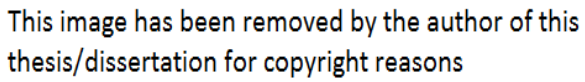


Figure 30. *Control panel of the CSPINE-CAD software*

Additional options on the control panel included:

- 'Zoom settings', allowing zooming in and out, which facilitated more precise segmentation and identification of injuries or pathologies.

- Windowing or contrast adjustment (represented on the control panel as a MIN and MAX figure and a black to white scale), this was extremely helpful when viewing C7 which was sometimes superimposed over dense tissue, and thus harder to visualise and segment with just the default contrast.

- A 'comments' box was also available to allow comments regarding the quality of the radiograph such as '*poor visualisation of C7'*, '*parallax distortion'*, '*artefact*', '*osteophytes*', '*degenerative change'* or *'C7/T1 junction missed'* this helped elaborate on any idiosyncratic or substandard segmentation.

The main two buttons on the control panel were; the ‘plot alignment curves’ start button, which was used to create manual alignment curves on each radiograph, and the ‘segment vertebrae’ start button which was used to manually segment each vertebral body on each image. Both procedures also used the buttons ‘remove last point’ as a an undo button, a ‘cancel’ button which dismissed what had been done, and a ‘delete’ button in which a particular alignment curve or vertebral body segmentation could be deleted. An ‘end’ button was also used after either an alignment curve was completed or a vertebral body segmented. The completed radiographs were then saved as MATLAB files (the file type the MATLAB software utilises which allows it to be analysed by the City University team) using the ‘save’ button and exported to a dropbox account or emailed to the City University team.

Of the 179 lateral C-spine radiographs collected approximately 118 were manually segmented by the researcher, in addition researcher 2 segmented approximately the same number from the same set of 179. For every lateral C-spine radiograph segmented, each vertebral body was physically outlined using a strict set of coordinates; for vertebral bodies C3-C7 these were segmented using a 20 point system. The number of points used had a direct influence on the quality of the segmentation results, with a greater number allowing better representation of the vertebral bodies. Nevertheless a good compromise was needed, so the number 20 was reached. This figure was calculated by the computer science team in the formation of the programme by using the mean number of points used by researcher 2 in testing the segmentation software, along with evidence from the literature [120]**.**

The 20 points were administered in a dot-to-dot system going in the clockwise direction starting at the superior left corner, producing six dots along the superior border, five along the anterior, five along the inferior border, and four along the posterior, this process is shown in Figure 31 and 32. A “special” dot was used to designate each corner dot (this dot is shown clearly in Figures 31 and 32 as a white circle with a black outline). The corner dot system made the segmentation and alignment more accurate as the software used the corner dots to determine the placement of the anterior and posterior alignment curves, and the more accurate the manual segmentation, the more accurate the

machine learning algorithm would be in producing a true representation of the vertebral bodies and alignment lines. An example of a completed manual segmentation is seen in Figure 33 below.

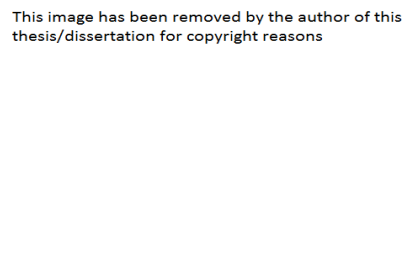


Figure 31. *Started segmentation of C6*

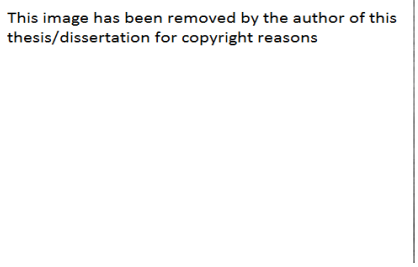


Figure 32. *Completed segmentation of C6*

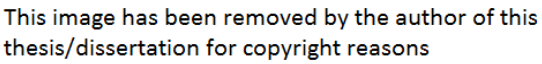


Figure 33. *Lateral C-spine radiograph with vertebral body segmentation. (Key: C1 in blue, C2 in green, C3 in red, C4 in cyan, C5 in pink, C6 in yellow and C7 in black).*

2.2.2 ISSUES WITH SEGMENTATION AND ALIGNMENT

Due to degenerative and osteoporotic changes (Figure 34), poor or incomplete radiographs (Figure 35), spinal fusions (Figure 36), parallax effects, magnification issues, and suboptimal radiographic positioning, some of the radiographs were difficult to segment. Although the CSPINE-CAD software had the ability to zoom in, rotate, and change the windowing of the radiograph, in a small number of cases the radiographs were inverted or facing in a different directions (Figure 37) and could not be flipped in the program.

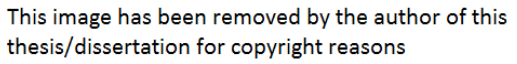


Figure 34. *Radiograph showing a high amount of degenerative change and calcification posterior to spinous processes*

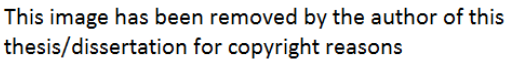


Figure 35. *Radiograph only visible to C4*

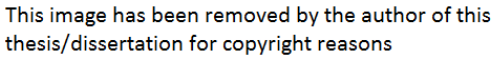


Figure 36. *Radiograph showing a spinal fusion*

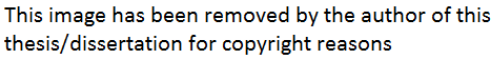


Figure 37. *Radiograph showing a completed segmented inverted image*

2.2.3 C1 AND C2 SEGMENTATION AND EVOLUTION

As well as the issues with the C-spine lateral images, there were issues with the segmentation of C1 and C2. Due to the odd shapes and superimposition of C1 and C2 (See section 1.2.1) they were not given stated limitations of dot numbers, this meant there was more freedom in their segmentation. The first method employed segmented C1 and C2 into their most visually defined borders; this made the segmentation more consistent across multiple images,

but was anatomically incorrect as shown below in Figure 38.

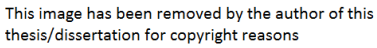


Figure 38. *A true representation of C1 and C2 (left) [122], compared to a radiograph showing the segmentation of C1 (blue) and C2 (green) (right)*

2.2.3.1 MODIFICATIONS TO THE SEGMENTATION METHOD

Upon discussing this first segmentation with the research team it was proposed that due to the occurrence of peg fractures the segmentation process method should change to reflect its true anatomy. This was done so that the C1 segmentation would just constitute the anterior arch of C1 (shown as blue in Figure 39), with the segmentation of C2 including the peg as well as the body (as shown as the green outline in Figure 39) (for comparison the previous segmentation technique is shown in Figure 40).

Figure 39. *New segmentation style*

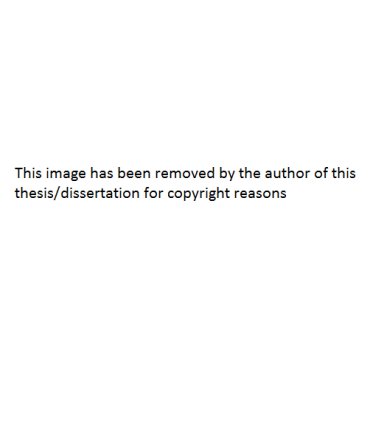


Figure 40*. Previous segmentation style*

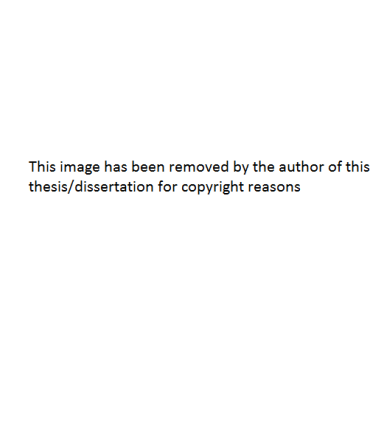


Figure 41. *C1 and C2 without segmentation*

After many attempts to discern the peg from the body of C1 on multiple radiographs, it was deemed unachievable due to superimposition, and thus impractical. The radiograph in Figures 39-41 is one of the clearer radiographs in showing the peg. This segmentation method was reviewed, and it was concluded that any damage to the peg would cause the displacement of the

anterior arch of C1, and thus this would be seen more clearly on the peg view. Due to the idea of this displacement it was concluded that a new segmentation method of C1 and C2 would be needed. The displacement of the anterior arch of C1 became the primary issue, and new segmentation methods of C1 and C2 were produced by the researcher (Figure 42) to try and address this.

This new method was also unsuccessful, this was due to the magnification of C1 (because of the air gap as stated in Chapter 1 section 1.4.6 [123]), and issues between the ambiguity between distinguishing C1 and C2.

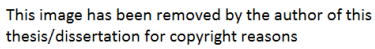


Figure 42*. Radiograph with the new segmentation*

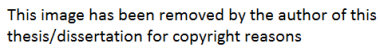


Figure 43. N*ew C1 segmentation (blue), with original C2 segmentation (green)*

A final attempt was made to segment the anterior arch of C1. This segmentation method divided C1 into two separate sections; the body of C1 and the anterior arch of C1, (blue in Figure 43). C2 was segmented as it was originally in Figure 38, and is shown in green in Figure 43.

This again proved unfeasible, and after many attempts to segment C1 and C2 in a way in which diagnostic information would be maximised yet still allow consistency through automated segmentation, it was concluded due to the issues and time restraints that the aspects of C1 and C2 would be removed from the current segmentation process and thus the CSPINE-CAD software, and to just concentrate fully on segmenting C3-C7 and producing the alignment curves.

2.2.4 ALIGNMENT CURVES

The other part of the CSPINE-CAD software that needed development were the alignment curves; these curves allowed the later versions of the software the ability to indicate possible misalignments in the vertebral column. The alignment curves used three main lines; the anterior column line which follows the anterior aspect of the vertebral bodies (shown in blue in Figure 44), the posterior column line which follows the posterior aspect of the vertebral bodies (shown in green in Figure 44), and the spinolaminar line which follows the spinolaminar of each vertebrae (shown in red in Figure 44) [124]. Any misalignment in these three lines can indicate dislocations, subluxations or spondylosis.

In order for the CSPINE-CAD software to learn where to place the alignment curves, they had to be first manually placed on the C-spine radiographs. Initially the type of alignment curve to plot was chosen (anterior, posterior or spinolaminar), via the 'plot alignment curve' start button on the control panel, after selection, a dot was then placed on each vertebrae at the designated place (anterior, posterior or spinolaminar position on the vertebra) based on the type of alignment curve.

At each dot placement a line joined the dot landmarks together, and after all seven vertebrae had been marked a completed line was created (as in Figure 44 which shows all three completed alignment curves)

After completion of the alignment curves the radiographs were saved as MATLAB files using the 'save' button on the control panel and then placed in a dropbox account, and accessed by the City University team who analysed the images.

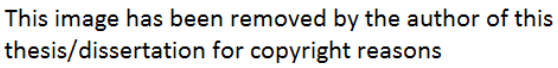


Figure 44. *lateral C-spine radiograph with alignment curves*

2.3 VERSIONS OF THE AUTOMATED CSPINE-CAD SOFTWARE

2.3.1 THE FIRST VERSION OF CSPINE-CAD SOFTWARE

During the process of manually segmenting the vertebral bodies, and manually applying the alignment curves the CSPINE-CAD software was updated. This update included a new control panel with more options (Figure 45) which now addressed the issue of flipping the image. More importantly this new version also had the option to perform semi-automated segmentations for the first time and thus was the first major step in creating a true piece of CSPINE-CAD software with limited manual input.

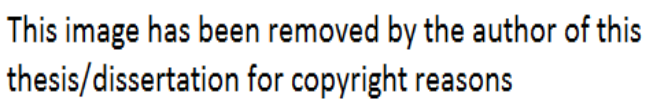


Figure 45. *New CSPINE-CAD control panel options of the first version of the CSPINE-CAD semi-automatic segmentation software*

This was the first version of the CSPINE-CAD software that could conduct semi-automatic segmentations of vertebral bodies on a lateral C-spine radiograph. In order to activate the segmentation an individual had to click on the centre point of each vertebral body from C1 to C7, and then click the 'perform segmentation' button on the control panel (see Figure 45). The CSPINE-CAD software then automatically segmented the vertebral bodies of C3-C7. This version of the CSPINE-CAD software was tested by the researcher, on six random test radiographs (out of the originally collected 152 radiographs from the RD&E).

2.3.2 THE SECOND VERSION FO THE CSPINE-CAD

The second version in the CSPINE-CAD software's evolution was the integration of the Genant SQ scale within the CSPINE-CAD software; this was used to determine if the vertebral bodies were fractured.

The CSPINE-CAD would semi automatically segment the vertebral bodies as per the first version of the software, but would now apply a measurement algorithm to calculate the height of each vertebral body (C3-C7), at the anterior, posterior and middle aspects, these three heights would then be compared to each other and a percentage for each comparison would be calculated. The software would then apply the Genant SQ scale (Figure 24) to determine, based on the percentage, if there was a fracture to a vertebral body, and if there was how severe it was.

Segmentation indicating an injury

The new CSPINE-CAD software would then indicate the fracture type using a simple coloured word linked to that vertebra, as shown in Figure 46 where both C5 and C6 are stated as having mild biconcave fractures. This increased the information given to the operator compared to the much simpler indication arrow as first proposed.

2.3.3 THIRD VERSION OF THE CSPINE-CAD SOFTWARE

The third version of the CSPINE-CAD software (version 1.0.1) included the first automated application of the alignment curves, and the revised indication arrows.

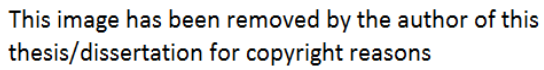


Figure 47. *Vertebrae segmented with the third version of the CSPINE-CAD software*

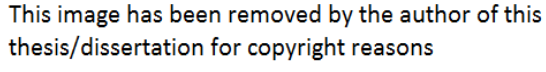


Figure 48. *Arrows indicating possible fractures of vertebral bodies (C3, C4, and C5)*

Figures 47 and 48 show the third version of the CSPINE-CAD software with the new red arrows replacing the wording, and indicating anything suspicious (i.e. any moderate/severe/mild wedge/crush/biconcave vertebral fracture have now been replaced with a red indication arrow at the anterior aspect of the vertebral body). As stated the software still used the same measurement algorithm and the Genant SQ scale but without the classification, so the arrows did not indicate the severity of the fracture, leaving the diagnosis more ambiguous, but still indicating the suspicion of a possible fracture.

The third version of the CSPINE-CAD software also applied alignment curves automatically for the first time as shown in Figure 49. This included orange indication arrows at the posterior portion of the vertebral body, similar to the ones used to highlight possible vertebral fractures. These orange indication arrows were used to highlight any misalignments of 3 mm or more as shown in Figure 49 (where C5 is being indicated as misaligned). Based on the radiographers' report there was a retrolithesis of C5 on C6, this is in keeping

with what the third version of the CSPINE-CAD software was indicating in Figure 49.

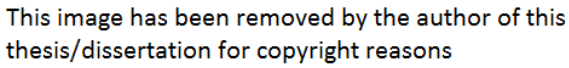


Figure 49. *Lateral C-spine radiograph with CSPINE-CAD automatic alignment curves indicating C5*

2.3.4 FOURTH VERSION OF THE SOFTWARE

The fourth version of the CSPINE-CAD software (version 1.0.2), was an update in order to work with the new MATLAB software R2014b (8.4.0.150421 Mathsworks, Natick, MA) and as such offers no new corrections or additions except compatibility with the new version of MATLAB software.

2.4 RESULTS

Only the first version of the software was tested via six random images, with later versions used in the main body of the research testing. This basic test was conducted in order to visualise the robustness of the software and highlight what needed improving before it could be properly utilised in testing the participants. These six random segmentations show the ability of the software, as shown in Figures 50 and 51. Figure 50 shows an almost perfect segmentation yet Figure 51 is noticeably incorrect. (These two images were chosen as a representation of the best and worst of the six tested radiographs).

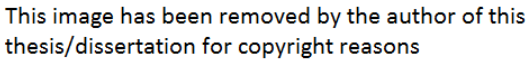


Figure 50. *Example of good CAD segmentation*

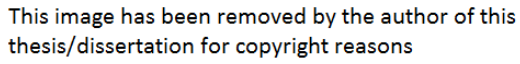


Figure 51. *Example of poor CAD segmentation*

2.5 DISCUSSION AND LIMITATIONS OF ALL VERSIONS OF CSPINE-CAD

In the first version as well as the inaccuracy in segmentation (shown in Figure 51), the CSPINE-CAD software would also only segment an image when the C-spine radiograph was facing to the right. If not, the segmentation would be inaccurate due to the software expecting the C-spine to be a right lateral and not a left lateral as shown in Figure 52 (C3 being the most poorly segmented). Due to this issue all C-spine radiographs had to be right laterals before the CSPINE-CAD software would be applied. This was also important in any horizontal beam supine C-spine radiographs that had not been rotated correctly; again this confused the software, so the radiograph had to be rotated until C1 was at the superior aspect of the image.

Figure 52. *Poor segmentation effect on the radiograph when not facing to the right*

After improvements were made to the software the second version was released. This version had the Genant scale integrated into it to indicate fractures, but it was realised that after automated segmentation of the vertebral bodies via the CSPINE-CAD software, several vertebral bodies were determined to have fractures even though the original diagnostic reports used as the 'gold standard' deemed that they had no fractures. An example is shown in Figure 46 where two mild/biconcave fractures (C5 and C6), are indicated even though the radiographers' report did not state such an injury. It was concluded that the Genant SQ scale within the second version of the software may have caused overcalling in cervical vertebral fractures.

Due to this it was concluded that in the third version of the software not only would the wording of the type of fracture be removed, going back to the original idea of an indication arrow, but that the mild grade one (20-25%) Genant classification would be reviewed, and the Genant SQ scale would be investigated further in order to optimise the CSPINE-CAD software using it (discussed in Chapter 4). The third version was the first version to introduce the

alignment curves, but due to limitations in the software regarding consistent segmentation of C1 and C2 and the lack of data for T1, this version of the software did not pick up certain misalignments. These include: any C1-C2 misalignments, C2-C3 misalignments, and any C7-T1 misalignments.

By the final fourth version of the software there were still several problems. These include the alignment curves not indicating above C3 or below C6, the Genant SQ scale overcalling fractures, the segmentation issues of C1 and C2, and the lack of a spinolaminar line. None of these issues could be rectified, although it must be stated that the segmentation of C3-C7, and the application of the anterior and posterior alignment curves achieved the aim of indicating injuries.

2.6 CONCLUSION OF ALL VERSION OF CSPINE-CAD

The final result of software version 4 was close to what was originally envisaged with the inclusion of the indication arrows making it faithful to the original idea moving it towards its goal of being a competent piece of CSPINE-CAD software. It can segment vertebral bodies, apply alignment curves and indicate injuries.

The problem of the Genant SQ scale overcalling fractures needs to be addressed, and if the Genant SQ scale could be modified for use with the C-SPINE-CAD software. It was also concluded that due to the difficult nature to segment C1 and C2 these vertebrae should be tackled separately, with future developments using CT scans (in a sagittal plane) to build accurate shape models for C1 and C2 which could then be applied to CSPINE-CAD.

Additionally the CSPINE-CAD software needs to extend its alignment curves; both superiorly to include any C3-C2 misalignments, and inferiorly to include any C7-T1 misalignments. The method of testing this CSPINE-CAD software in its capacity as a “spell checker” in identifying fractures and misalignments is discussed in the next chapter, with the results of the testing stated in chapter 6 and 7.

CHAPTER 3. METHODOLOGY

3.1 INTRODUCTION

This chapter describes the participants involved, their recruitment, and the methods and analysis used to test the CSPINE-CAD software. The safety and ethical considerations associated with the crossover study.

The main part of the study involved three tests utilising version 3 or 4 (no difference except compatibility with latest MATLAB update) of the CSPINE-CAD software on a variety of participants, including:

- One to one testing on third year radiography students using CSPINE-CAD (version 3) (first test)
- Static radiograph testing on third year radiography students using CSPINE-CAD (version 3) (second test)
- One to one testing on junior doctors and qualified radiographers using CSPINE-CAD (version 4) (third test)

These tests were designed to answer the research question:

- What effect does CSPINE-CAD software have on diagnosing accuracy on lateral C-spine radiographs

The primary outcome measure for the three tests was:

- Differences in sensitivity, specificity, and area under a curve (AUC) scores for before and after the use of CSPINE-CAD for all three tests

The secondary outcome measures for the three tests:

- Changes in confidence level when diagnosing lateral C-spine radiographs with and without CSPINE-CAD software
- What examination/body part participants would like to see this sort of CAD software applied to
- Features the participants would like to see in the current version of the CSPINE-CAD software
- Was the CSPINE-CAD software useful as a second pair of eyes to the participants

The feasibility study was designed to test the efficacy of the CSPINE-CAD software in identifying and highlighting CSI on lateral C-spine radiographs. These three tests focused on the ability of participants to discern CSI from C-spine lateral radiographs, both with and without the CSPINE-CAD software via sensitivity and specificity scores produced without and with the use of CAD.

Results from the study helped to identify the need for CSPINE-CAD software in reducing missed or misdiagnoses CSI and possibly save lives. The issues of developing the software (Chapter 2), what it utilised to state a fracture (Chapter 4), and the accuracy of the data it learnt from, was also investigated (Chapter 5).

3.2 PARTICIPANTS

3.2.1 RECRUITMENT

For the first and second testing participants were recruited via convenience sampling using an internal university email to all third year radiography students at the UOE (Appendix 6), and by word of mouth via lecturers and direct discussions with the researcher. With a follow up email reminder sent out closer to the date of testing.

For the third test, participants were recruited via convenience sampling from the RD&E with additional radiographers recruited from the UOE. This was achieved in various ways:

- A presentation to the RD&E F1s and F2s at the Research, Innovation, Learning and Development Centre (RILD) (where a lot of research, training, and teaching is conducted) onsite next to the RD&E
- A presentation to the radiographers at the x-ray department at the RD&E
- An article discussing the research opportunity, uploaded onto the RD&E internal intranet (Figure 53)
- A Leaflet handed out (Appendix 7) (this was handed out to all prospective participants after each presentation)
- This Leaflet was also placed around the RILD on poster boards and left in the x-ray department

- Word of mouth via two RD&E Doctors who helped recruit the junior doctors for the research testing
- Word of mouth from a newly qualified radiographer who had qualified from the UOE and been involved testing a previous version of the software on second year radiography students
- Internal email sent to all radiographers within the medical imaging department of the UOE, including clinical tutors (Appendix 8).

3.2.2 INCLUSION CRITERIA

For the first and second test:

- Third year radiography students from the UOE

For the third test:

- Radiographers from the RD&E or the UOE
- Junior Doctors only F1s and F2s from the RD&E

3.2.3 EXCLUSION CRITERIA

For the first and second test:

- First or second year radiography students
- Students from other medical disciplines e.g. Nursing, physiotherapy

For the third test:

- Radiologists
- Radiography students
- Health Care Assistants
- Nurses
- Radiographers working for the UOE who have already been involved in any capacity with the research (this is due to the possibility of bias)
- Senior Doctors

The exclusions made for all studies was due to the possibility of cofounding variables in reducing generalisability, such as a lack of specific knowledge in interpreting the C-spine radiographs (e.g. first and second year radiography

students), or lack of relevance to their job (e.g. nurses). Although these exclusion criteria hindered recruitment numbers, the reason to exclude certain groups was justified. For the additional investigations (Chapters 4 and 5) participants were experts, radiographers or third year radiography students, with all of these groups being from the UOE.

3.2.4 PARTICIPANTS FOR FIRST AND SECOND TESTS

The first and second tests were conducted on third year radiography students from the UOE. This group was selected because of their high level of knowledge, and their known training level in image interpretation of C-spines (due to knowing when they had received lectures covering such topics), giving a consistent baseline for comparison. One other reason for their recruitment was also due to their availability onsite, as the testing was conducted at the UOE. It was also concluded that they would be of a similar ability in analysis and thought to fully qualified radiographers, due to them being near the end of their studies, and having completed 52 weeks of placement at three different hospitals. So any issues/feedback they raised with either the CSPINE-CAD software or questionnaires/answer sheets, could be reviewed and changed before the third test on junior doctors and qualified radiographers.

3.2.5 PARTICIPANTS FOR THIRD TEST

The third and final test of the CSPINE-CAD software was conducted on radiographers, and junior doctors (mainly foundation year 1 (F1s) and foundation year 2 (F2s)), recruited from the RD&E. These groups were chosen as they occupy the front lines of C-spine imaging, and thus are likely to be the first people to see the lateral C-spine radiographs, either due to requesting, reviewing, or performing the projections. As such they will have the most to gain (other than the patient) from any C-spine CAD software in helping them interpret the radiographs. This is also important due to a stronger shift towards radiographic commenting, where radiographers are actively encouraged to make any diagnostic comments identifying anything. This makes the CSPINE-CAD software extremely relevant to this group due to its possible ability to aid a radiographer's original diagnosis by agreeing, or by highlighting, an injury. These groups were also chosen due to them being a representation of the target population; this means if the CSPINE-CAD software is implemented in

future it will most likely be used by junior doctors (especially F1s and F2s) and radiographers. So by testing a portion of the target group this helps increase its validity and generalisability.

3.2.6 RESPONSE RATES

The response rate for the various recruitment methods for the three tests is summarised in Table 3.1.

Table 3.1. *Participant for all three tests (Key F1 = Foundation doctor year 1, F2 = Foundation doctor year 2, EDJ = Emergency department junior doctor, EDSG = Emergency department staff grade*)

First test	Third year student radiographers		**Second test**	Third year student radiographers
Word of mouth			Word of mouth	
Contacted	Unknown		Contacted	Unknown
Volunteered	1		Volunteered	0
Suitable	1		Suitable	0
Direct mailing (Appendix 4)			Direct mailing (Appendix 4)	
Contacted	56		Contacted	56
Volunteered	4		Volunteered	11
Suitable	4		Suitable	11
Total who conducted the test	5			11

Third test	Radiographers	Junior Doctors			
Leaflet/email/Article on intranet/ Word-of-mouth (Appendix 5 and 6 and Figure 29)		F1s	F2s	EDJ	EDSG
Contacted	Unknown	Unknown			
Volunteered	10	9	6	4	1
Suitable	10	9	6	4	1
Unable to test the software	1	1	1	0	0
Did not complete the test	3	0	0	0	0
Presented to					
Contacted	4	20	4	0	0
Volunteered	1	0	1	0	0
Suitable	1	0	1	0	0
Total who volunteered	11	21			
Total who conducted and completed the test	7	19			

Recruitment of the third year radiographer students for the first and second testing was slow. Ultimately out of the 56 third year radiography students contacted (via email and word of mouth), a total of five (for the first test) and 11

(for the second test) responded and agreed to do the testing. The main reason for the low turnout was most likely due to other commitments such as exams, assignments, interviews (both real and mock), and additional workloads for the students. The testing also had to be done after the imaging interpretation lectures (to make sure their knowledge of C-spine interpretation was at its highest); meaning there was a greater time restraint, and ended up being conducted closer to deadline dates/exams.

For the third test, recruitment was initially sedate and difficult, with presentations to the F1s and F2s not being very successful, this may have be due to the F1s and F2s coming to the end of their placements and lacking interest. The presentations were also added on to the end of teaching sessions at the RILD, so were limited in time. Also as shown from the Table 3.1 I presented to only four F2s, this was due to it being the last teaching session for that group's year, with a new group of F1s and F2s arriving a couple of months after this presentation. The timing of the presentation between group changes was a factor in the low recruitment. To help counter this, leaflets (Appendix 7) were put up in the RILD, and an article regarding the CSPINE-CAD software (Figure 53) was published on the RD&E internal intranet.

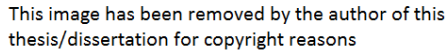


Figure 53. *Royal Devon and Exeter internal intranet recruitment article for CSPINE-CAD testing*

Additionally the researcher contacted the postgraduate medical research team at the RD&E to forward the message on to any interested F1s, F2s and radiographers.

The most successful strategy in recruiting the junior doctors (F1s and F2s respectively), was word of mouth by the two RD&E doctors involved in helping conduct the study (Dr Adam Reubens and Dr Andy Appelboam), this may have been due to their seniority within the group, or they may have expressed the CSPINE-CAD software's relevance more clearly than myself, highlighting the specific benefits to junior doctors. This may also have been due to the timing of recruitment, as this increase in number coincided with the new group of F1s and F2s and was seen as an opportunity to start their portfolios. The F1s and F2s were also more incentivised due to the possibility of having one of their work based assessments signed off.

Although the target of 30 participants (15 junior doctors, and 15 radiographers) was difficult to achieve, participants, especially radiographers, demonstrated a high level of interest and engagement with the project. Any interested participants emailed the researcher directly, and having met the inclusion criteria were emailed a participant information sheet (PIS) providing additional information about the testing (Appendix 9). Some participants after having shown initial interest in testing the CSPINE-CAD software were then unresponsive via email follow ups so did not test the software (as seen in Table 3.1), this may have been due to them finishing their training, or due to them realising they did not have the time. The testing required all the participants to test the CSPINE-CAD software on a designated encrypted laptop; as one F2 had asked if it possible to do the testing online, but due to the uniqueness of the software it was not possible to do this. This also meant the participant had to conduct the study at one specific block of time for between an hour and two hours at the RD&E or at the UOE St Luke's medical school. This time complication was also the reason three participants did not finish the testing. In total 32 participants volunteered but only 26 conducted and completed the testing. The inability to conduct the research remotely and being unable to divide it into smaller sections of time may have influenced the recruitment numbers.

3.3 METHOD USED FOR TESTING CSPINE-CAD SOFTWARE

3.3.1 PRELIMINARY ADMINISTRATION

- Positive respondents to the recruitment campaign were sent a PIS (Appendix 9, 10 or 11) and their details (email address, name, and in the third test job title i.e. medical doctor or radiographer) were recorded and placed in a locked filing cabinet.
- Participants were considered for the study if they met the inclusion criteria
- Appointments were made that were suitable for the participants (except in the second test in which there was a set date and time, due to room booking)
- The testing conducted on third year radiography students was conducted at the UOE, with the third test being conducted at the RD&E and the UOE.
- All three tests were conducted in locations where noise and distractions were at a minimum, additionally all blinds were closed prior to any testing to avoid issues with subjective brightness, and all rooms were adequately heated

3.3.2 SAFETY AND ETHICAL CONSIDERATIONS

The following safety and ethical issues in all three study designs were addressed to minimise any potential adverse effects, pain, discomfort, distress, confusion, or inconvenience to participants:

- All participants were given a PIS form both prior to testing (via email) and in paper on the day to enable them to thoroughly read and understand the contents before volunteering.
- An opportunity to ask further questions regarding the study was offered before the informed consent form (Appendix 12 and 13) was signed.
- All participants were informed that they had the right to stop or withdraw at any point in the study should they wish to.

Due to the possibility of long time periods of testing (two hours), comfort and ergonomics were addressed, this included a comfortable chair adjusted correctly, computer screens being placed at a reasonable height, and some participants even brought snacks and drinks with them. To minimise the time

burden on participants the talk through was kept brief and to the checklist, and the questionnaires were succinct, precise, and straightforward to complete.
All testing was done in the presence of the researcher (myself) and thus meant there were no health and safety issues regarding lone working, it also meant any issues regarding the software were addressed first hand. Although I was present I was not directly viewing any screens; this was in order to reduce any possible subconscious influence or bias I might express.

Confidentiality issues were addressed by employing the following safeguards:

- The lateral C-spine radiographers originally collected from the RD&E were de-identified and only their age and gender remained.
- Data gathered during testing at the UOE were stored on the UOE servers behind password protect accounts, and any off site data were gathered via encrypted laptops, behind password protected accounts.
- Hard copies of the data and material containing participant contact details were stored in a locked filing cabinet in a private office with access only available to authorised personnel.

3.3.3 FIRST TEST

Positional set up

In order to maintain reliability and consistency in the first test all participants used the same office; room 201 of the physics building at the UOE Streatham campus), the photos shown in Figure 54 and 55 show both the set up, and the office. For consistency the office was not changed, the same chair and computer were used. Comfort and ergonomics were addressed with each individual correcting the screen, chair and mouse position to suit their body morphology and eye level. There were no distractions as the door remained closed at all times during the testing.

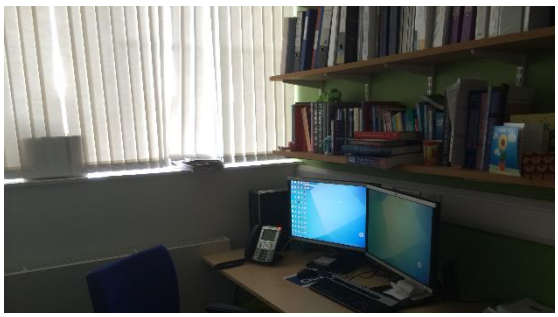


Figure 54. *Office area/computer where the first test was conducted*

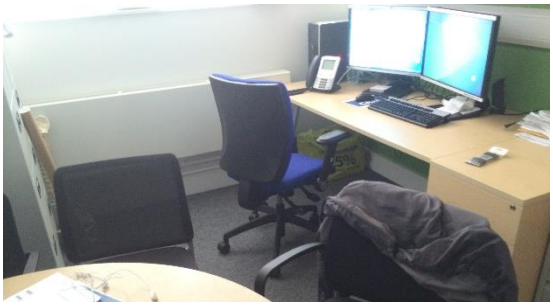


Figure 55. *Same office, showing positioning of the researcher (highlighted by the coat)*

- The same desktop account login was used for all testing; this was tested previously for any issues or loading faults.
- All participants used the same MATLAB program (version R2014a 8.3.0.532 Mathsworks, Natick, MA), with the same version 3 of CSPINE-CAD software.

On the PC desktop lay ten folders (labelled one to ten) each contained the same set of six lateral C-spine plain radiographs, these radiographs were chosen as showing the most promise with the CSPINE-CAD software; out of the 183 radiographs, which had been collected from the RD&E and stripped of all identification except age and gender. The six chosen were:

- 1 example radiograph (which was normal)
- 2 normal
- 1 retrolisthesis C4-C5,
- 1 retrolisthesis of C5 on C6
- 1 with anterior translation of C2 on C3 in keeping with grade one spondylolisthesis, resultant retrolisthesis from C3-C5.

For clarity normal refers to any radiograph without trauma injury; this includes radiographs with degenerative change, osteophyte formation, spondylotic changes and even post-surgery fusions. The order of these six radiographs were randomised in every folder, except for the example radiograph which was always first. These folders themselves were then independently renumbered one to ten without my knowledge. This was to reduce bias in the possibility of me knowing the order and thus influencing the participant through demand characteristics (in this case subconscious cues that they might pick up on). Also due to this concern I positioned myself as to not be in the line of sight of the viewing screen during testing; as shown by the position of the reserchers coat in Figure 55. I was only present in case of any issues or questions arose regarding the software. This along with randomisation of the radiographs reduced researcher bias.

The participant then randomly picked one of the ten answer sheets (Appendix 14) which were all face down. The answers sheets were all identical except for being numbered one to ten, with this number corresponding to the folder on the desktop. Attached to each answer sheet was also a questionnaire (Appendix 15) (with the equivalent number as the answer sheet), this was completed by the participant after the testing was complete.

Answer sheet used for first and second testing

An answer sheet (Appendix 14) was used in the first and second test with an example of a section shown in Figure 56; this was devised to allow maximum diagnostic freedom, as shown the columns consisted of: an Image number box, a Normal? Yes No box, and a Diagnosis box for comments. With an additional row under each numbered image/radiograph labelled “after CAD”. These three columns and two rows were repeated throughout the answer sheet for all image numbers.

Image	Normal?	Diagnosis
1	Yes ☐ No ☐	
1 After CAD	Yes ☐ No ☐	

Figure 56. *The answer sheet used in the first and second testing*

This answer sheet was similar to the ones the third year radiography students had been using in their image interpretation lectures/seminars (using just a commenting diagnosis box in exams), meaning they could use the same method of explanation, this made it similar to radiographic commenting.

Questionnaire for first and second test

The questionnaire (Appendix 15) consisted of seven questions. These seven questions allowed a range of information and data to be collected, and contained both quantitative and qualitative data:

Quantitative data (which consisted of five questions) used a Likert scale, for example:

- On a scale of 1 to 5, where 5 is very confident and 1 is not confident at all, how confident do you feel when interpreting cervical-spine radiographs?

Qualitative data (which consisted of two questions) allowed an opinion to be expressed, for example:

- Are there any other features you would like to see in the CSPINE-CAD software?

These questions were tested then modified after a pilot study that had used an earlier version of the CSPINE-CAD software; this study was conducted by third year radiography students on second year radiography students at the UOE.

Method

Each participant was informed that the images were only lateral C-spine radiographs, and all additional radiographs (APs, pegs, and swimmers) had been removed. The participant then loaded version 3 of the CSPINE-CAD software via MATLAB, and then opened the folder that had the corresponding number to their answer sheet, this then revealed the six lateral C-spine radiographs to be diagnosed. The first radiograph was then loaded; which was always the example radiograph. The CSPINE-CAD software training then began (conducted by myself) and included discussions on how to rotate, change contrast, zoom in and out, and flip the radiograph, as well as the proper use of the answer sheet and questionnaire.

As well as the basic controls to view the radiograph correctly the main portion of this training was the details of applying the actual CSPINE-CAD software, this was done to the first/example radiograph. Participants were first asked to make a diagnosis of the example radiograph (Figure 57), in order to save time, this was conveyed verbally as to what they would tick and write (during the actual test radiographs their diagnosis was written on the answer sheet next to the corresponding image number).

Figure 57. *The example radiograph loaded into version 3 of the software but without CSPINE-CAD software applied*

After stating their diagnosis participants were then instructed to use the CSPINE-CAD software, this was done via choosing the “choose vertebral centres” button and clicking on the centre of each vertebral body from C1 to C7, thus labelling them C1-C7 (Figure 58). They then clicked the “perform segmentation” button. The CSPINE-CAD software then showed the vertebrae segmented (Figure 59); this segmentation could be turned off and on using the “show segmentations” button. They were informed that the CSPINE-CAD software also applied a red arrow to indicate any suspicious looking vertebrae; this could be turned off via the “show Genant scale” button. It was then stated to the participant that if they saw anything diagnostically important or wished to change their original diagnosis, that they should write it in the “after CAD” box on the answer sheet (as seen in Figure 56), and not amend their original diagnosis, this was to be done for all additions. If they wanted to delete their original diagnosis or part of it, they were told to state it in the “after CAD” box as “delete…” and again make no corrections or crossing out of the original diagnosis.

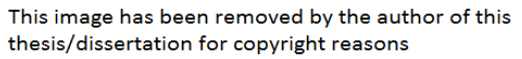


Figure 58. *The participant labelling the vertebral centres C1-C7*

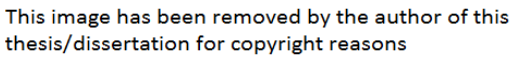


Figure 59. *The part of the CSPINE-CAD software that segments the vertebral bodies*

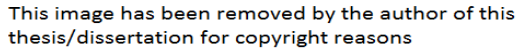


Figure 60. *The alignment curve part of the CSPINE-CAD software applied over the lateral C-spine radiograph*

The participant was then trained on the "show alignment curve" button, and how this applied lines to the anterior and posterior portions of the vertebral bodies (Figure 60), and how this indicated any malalignment in excess of 3 mm via an orange arrow. Again, any revisions to the participant's original diagnosis was made and placed in the same "after CAD" box. This entire process was repeated twice on the same example radiograph, once with the researcher directing them and talking through where to click, and again with them completely on their own but with me watching in silence. This was done for each participant in order to establish that everything was fully understood. After the participant was comfortable in their understanding of the CSPINE-CAD software they then clicked on the "next" button to load the first radiograph for the actual testing.

This process was repeated for the next five additional radiographs, with each radiograph; loaded, diagnosed, CSPINE-CAD applied, and then re-diagnosed. With the participants looking at the vertebral segmentation and then the alignment curves with all corrections, additions or deletions being written below

the original diagnosis in the “after CAD” box of the answer sheet.

3.3.4 SECOND TEST

Positional set up

The second test took place at the UOE in the Harrison building room 207 on the 10th March 2015 from 9am-11am (an image of the setup of the room is shown in Figure 61-64).In total 43 computers were loaded with a 67 page portable document format (PDF), the same procedure as described in the first test was followed, this covered; noise, blinds, and account settings. The same consent form, answer sheet (extended to 20 radiographs being reviewed rather than five) and questionnaire were used from the first test. All answer sheets and questionnaires were linked together via a number (1-56) so no personal data (other than the consent forms) were collected; these were then placed randomly next to each of the 43 computers. It must be stated that the door was left open, to allow a more optimum temperature, so some intermittent ambient noise did enter the room from small groups of occasional passing students.

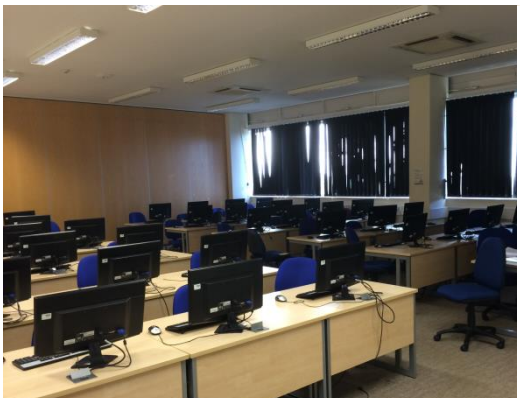


Figure 61. *Front of the room (left side) showing testing set up*

Figure 62*. Front of the room (right side) showing testing set up*

Figure 63 *Back of the room showing the computer screens and paper set up (left side)*

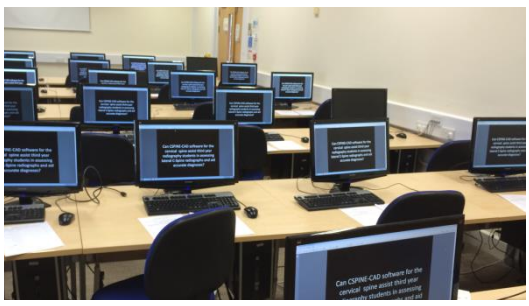


Figure 64*. Back of the room showing the computer screens and paper set up (right side)*

PDF and testing

The main difference between test 1 and test 2 was that this second test involved a larger number of participants and a higher number of radiographs, and as such the CSPINE-CAD software could not be used; this was due to only a few select computers having MATLAB installed. This would mean each participant would have to use the same computer, and be trained individually on the software like in the first test. This, combined with the additional radiographs to be reviewed, and the availability of the participants, would have made it too time consuming. To rectify this a PDF was created; this consisted of a selection of slides, starting with how the CSPINE-CAD software worked, and then included screen shots of the CSPINE-CAD software (in use) after it had segmented vertebral bodies and applied alignment curves. This PDF was loaded (via adobe reader version XI 11.0.10) onto all 43 computers, this was done prior to the arrival of any participants. The first six pages of the PDF are shown in Figures 65-70, explaining the principles of the software and the images to the participants.

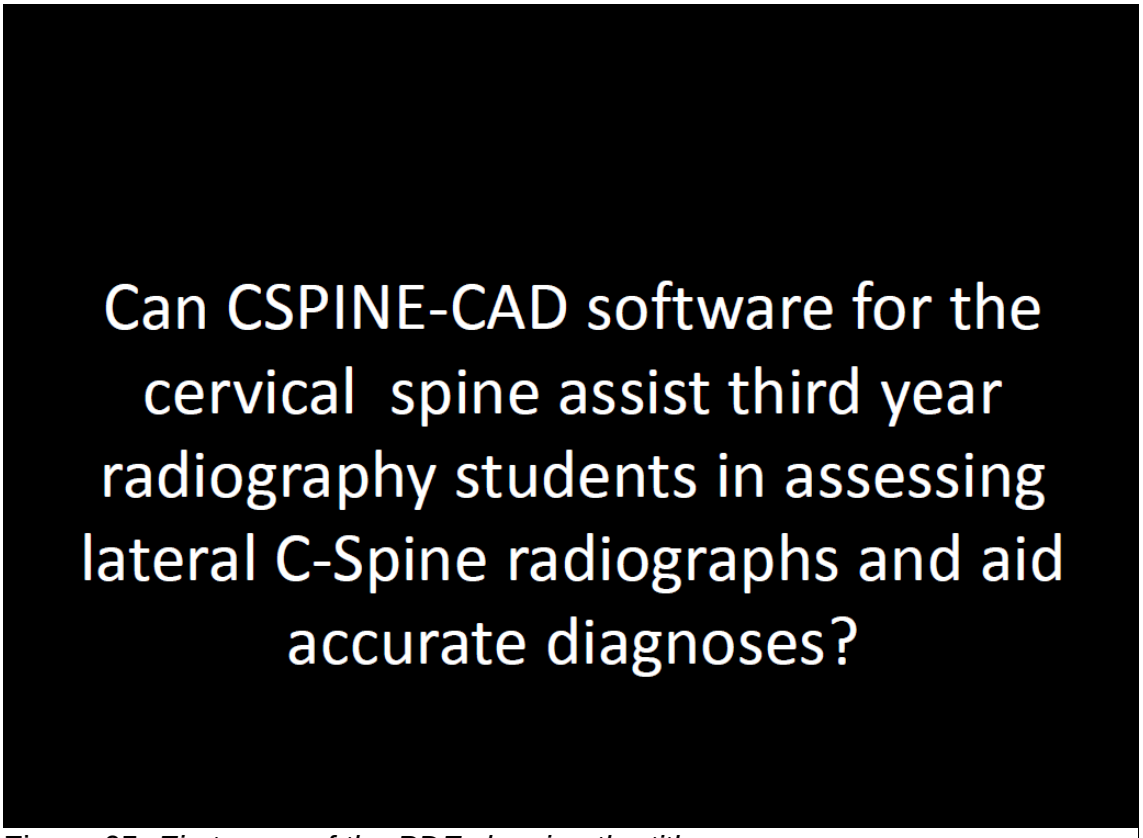


Figure 65. *First page of the PDF showing the title*

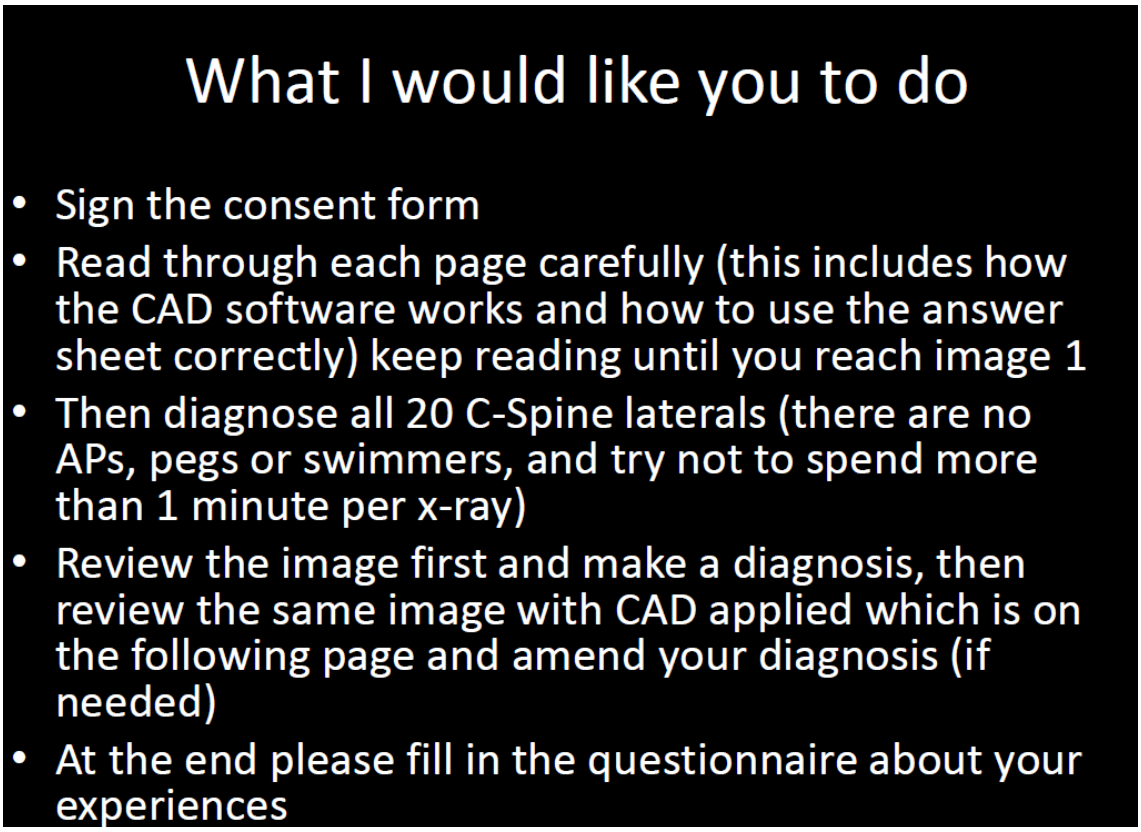


Figure 66. *Second page of PDF giving an overview of the project, and the actions required*

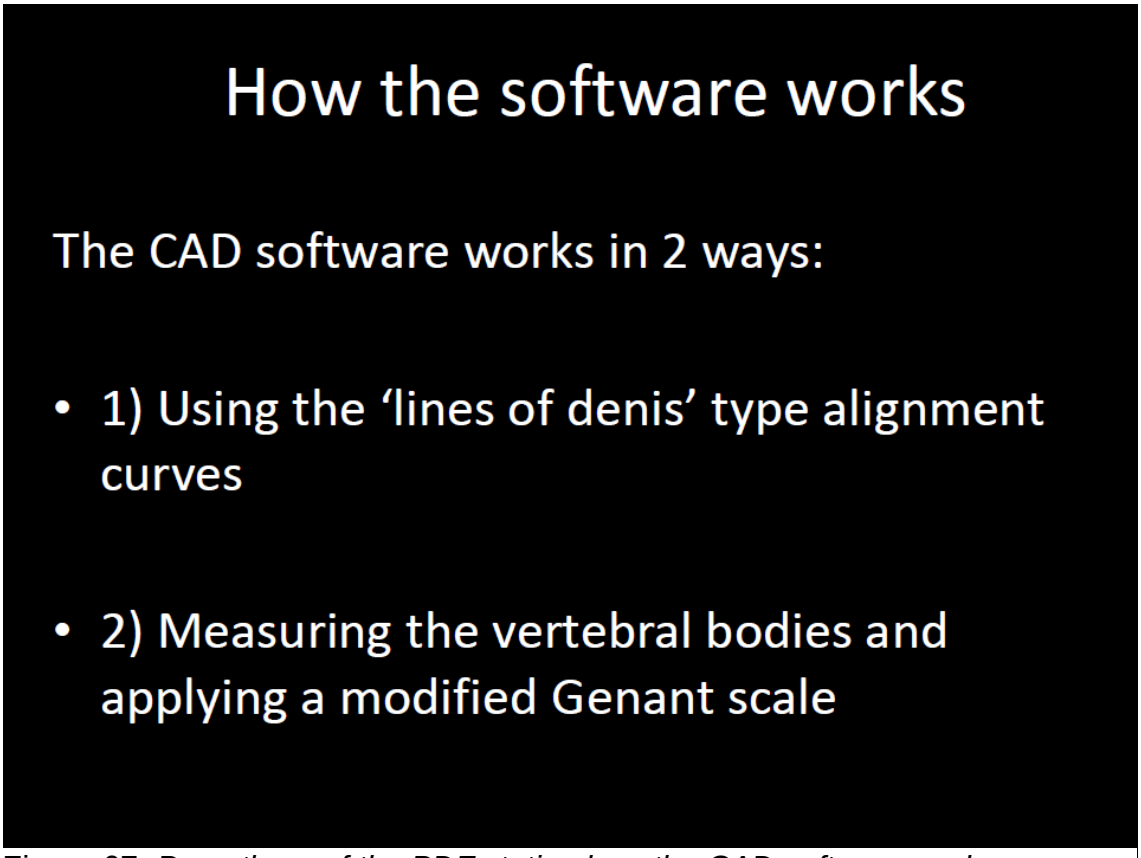


Figure 67. *Page three of the PDF stating how the CAD software works*

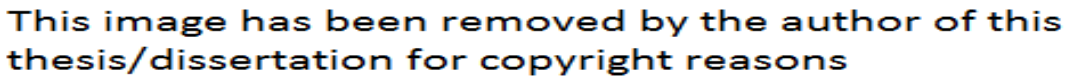


Figure 68. *Page four of the PDF showing the example image*

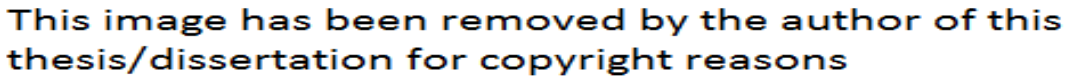


Figure 69. *Page five of the PDF showing the first screen grab of how the CAD software works*

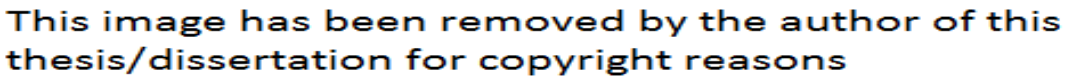


Figure 70. *Page six of CAD showing the second part of the CAD software*

From page seven each PDF contained the same set of 20 radiographs from an original 183, these were chosen as best representing the CSPINE-CAD software. They were also chosen based on their original radiology reports indicating injuries, these reports are shown in Table 3.2 and were treated as the "true" answer.

Table 3.2. *20 lateral C-spine radiograph radiologist reports (abridged), used in the second test*

7	Normal C-spines
1	Airgun pellet
3	Retrolisthesis of C5 on C6 (2 minor)
1	Retrolisthesis of C4 on C5
1	C1 peg fracture
1	C6 spinous process fracture (subtle)
2	Spondylolisthesis of C2 on C3
1	C2 Fracture
1	Anterior translation of C2 on C3 in keeping with grade 1 spondylolisthesis, resultant retrolisthesis from C3-C5
1	Retrolisthesis of C6 on C7
1	Anteriolisthesis of C2-C3, Fracture posterior of body of C2

As stated in the examples of the PDF (Figures 65-70) each participant was presented with an image similar to that shown in Figure 71. The participant then followed the same process as in the first test and made a diagnosis on the answer sheet (Appendix 16). It must be noted participates could only zoom in and out and were not able to change contrast or rotate the image (although all radiographs were rotated and orientated before being screen grabbed). As this was a screen grab of the applied software and not the actual software, the participant then loaded the next page of the PDF.

Figure 71. *Image 2 of the PDF before CSPINE-CAD was applied*

The next page of the PDF (Figure 72) showed the original image on the left (also shown in Figure 71) next to a screen grab of the same image; this image showed part of the CSPINE-CAD program over it (the alignment curves).

Figure 72. *Image 2 of the PDF after CSPINE-CAD alignment curves have been applied*

This is where the original image had been loaded into the CSPINE-CAD program and had its vertebral centres chosen (like in the first test), and then the CSPINE-CAD software was applied. This image was then screen grabbed and saved as a JPEG image, edited in Microsoft (MS) paint (removing the image of the control panel), and pasted into the PDF. This technique was used for all 20 images as a representation of the CSPINE-CAD software. The participant then looking at this CSPINE-CAD image then followed the same procedure as the first test and re-evaluated their diagnosis placing it in the 'after CAD' box on the answer sheet. The participant then loaded the next page of the PDF

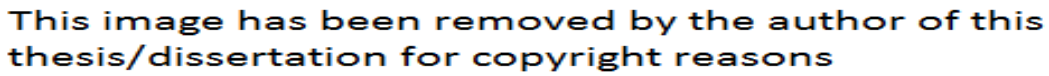


Figure 73. *Image 2 of the PDF after CSPINE-CAD vertebral segmentation have been applied*

The next page contained the second part of the CSPINE-CAD software; the segmentation of the vertebral bodies, in which the same technique to screen grab the image was used. This page of the PDF is shown in Figure 73, as can be seen this time there is no original image for comparison. The image on the left is showing the segmented vertebral bodies, and the image on the right shows an arrow indicating possible vertebral anomalies. The diagnosis procedure was repeated with any additions placed in "after CAD" box. The next page was then loaded showing the next image, and the whole process was repeated until all 20 images had been diagnosed. After conclusion of the testing the questionnaire was completed.

3.3.5 THIRD TEST

Positional set up

The third test took place at UOE (St Luke's medical school) (Figure 74) and at the training room at the RD&E (Figure 75), and followed the same procedure regarding the testing area as stated in the first two tests.

Figure 74. *University of Exeter St Luke's*

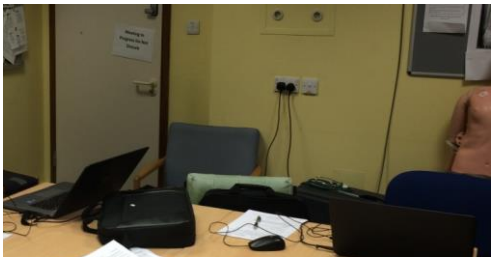


Figure 75*. Royal Devon and Exeter training room*

The same login account was used, and two encrypted laptops (HP EliteBook) were used to conduct the study, these were installed with version 4 of the CSPINE-CAD software (updated to work with the new MATLAB software otherwise exactly the same as version 3) and loaded with MATLAB sR2014b (8.4.0.150421 Mathsworks, Natick, MA). The same procedure from the first test was followed regarding PIS (Appendix 9) and consent forms (Appendix 13). Additionally the questionnaire (Appendix 17) and an answer sheet (Appendix 18) were used, but were first modified.

Answer sheet for third test

Due to issues experienced in the answer sheet during the analysis of both the first and second tests (See section 3.4.1), it was decided to modify the answer sheet for the third test; this modification addressed several issues such as the ambiguity of language, errors in miscommunications, and the inability to discern handwriting of participants. An example of the new modified answer sheet is shown in Figure 76.

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
EXAMPLE	1 C1 1 C1-C2 1 C2 1 C2-C3 1 C3 3 C3-C4 1 C4 1 C4-C5 1 C5 1 C5-C6 1 C6 1 C6-C7 1 C7 1 C7-T1	1 C1 1 C1-C2 1 C2 1 C2-C3 1 C3 5 C3-C4 1 C4 1 C4-C5 1 C5 1 C5-C6 1 C6 1 C6-C7 1 C7 1 C7-T1	Minor degenerative changes noted C3 to C6.

Figure 76. *Example of new modified answer sheet*

The answer sheet also used a new set of confidence scores to determine fractures and misalignments. The participants made their diagnosis prior to applying CAD, but this time rather than state it in writing in a comments diagnosis box, they had to state it numerically with a confidence level for each vertebrae and each alignment. For every normal alignment/vertebral body the participant put in a 1 (i.e. there is no fracture/misalignment), this states they are clearly confident that there was no injury. The confidence levels of 2-6 were then used to determine how confident the participant was, with 2 being 0.01-19.99%, 3 being 20-39.99%, 4 being 40-59.99%, 5 being 60-79.99% and 6 being 80-100%. In the example in Figure 77 as can be seen in the original diagnosis it states there was a misalignment at C3-C4 but were only 20-39.99% confident, now "With CSPINE-CAD" it has moved up to a 60-79.99%. This change would not have been seen in the previous version of the answer sheet as in this example both answers would be deemed the same and would not address the link in confidence. There was also a comments box in order to still allow participants some diagnostic freedom, to state things such as: foreign bodies, osteophytes and degenerative changes (these were not scored or analysed). This new answer sheet allowed for more quantitative marking, and the use of thresholds addressed the possible issue that participants were guessing at times in the previous two tests.

Questionnaire for third test

After the first two tests slight modifications were also made to the questionnaire; these included adding questions like: "What is your professional background?" and "How many years have you worked full time (37.5 hours or more) or part time (please state hours worked)?" (These questions would be superfluous in the first and second tests due to not needing to know their professional background as they were all third year radiography students). Additionally one question modified from the first and second test was "Did any of your assessments on placement involve doing a C-spine?" to "Do you have any postgraduate qualifications in image interpretation or reporting? If yes, please state what and when you obtained the qualifications." This was changed to reflect upon the change in participants, in total there were now nine questions (from the original seven) with six being the same from the first and second test.

Images/Radiographs

Thirty-one radiographs (30 for testing plus an example practice radiograph) were chosen (Table 3.3) out of 270; this included: eight (seven plus example) "normal" (this refers to any radiograph without trauma injury so this includes radiographs with degenerative change, osteophyte formation, spondylotic changes and even post-surgery fusions) these seven were chosen out of a total of 165 "normal" radiographs. The additional 23 radiographs were chosen out of 105 trauma radiographs from the RD&E:

Table 3.3. *30 lateral C-spine radiograph radiologist reports* (abridged), *used in third test.*

7	Normal C-spines
1	Airgun pellet
1	Slight posterior subluxation of C4 on C5
2	Mild Anteriolithesis of C3 on C4
2	Anteriolithesis of C3 on C4
1	Retrolisthesis of C5/C6 and C6/C7
1	Retrolisthesis of C3 on C4 and C4 on C5
1	Minor Anterolisthesis of C4 on C5
2	Mild Anteriolithesis of C4 on C5
1	Minor grade 1 Retrolithesis of C6/C7
1	Retrolisthesis of C5 on C6
1	Retrolisthesis of C4 on C5
1	Anterior translation of C2 on C3 in keeping with grade1 spondylolisthesis, resultant Retrolisthesis from C3-C5
1	Slight Retrolisthesis and minor slip of C5 on C6
1	C7 spinous process fracture
1	C5 compression fracture
1	Grade 1 forward slip at the C4/C5 level
1	Grade 1 slip at C5/C6
1	Anteriolisthesis of C6 on C7
1	Forward slip of C4 over C5
1	5mm Anterior subluxation at C4/C5, C1 and C2 fracture

For transparency it must be acknowledged that all 105 trauma radiographs that were originally gathered were checked for compatibility with the CSPINE-CAD software; this means each radiograph was tested with the CSPINE-CAD software prior to testing to see if it could highlight the injury reported, of course some injuries would not be highlighted due to the software's limitations in

indicating specific injuries (e.g. any C1 and C2 fractures, spinous process fractures and misalignments between C1-C2,C2-C3, C7-T1).This meant these were dismissed from the CSPINE-CAD testing, as this would not "test" the software. Although it must be stated that three radiographs containing injuries that the CSPINE-CAD software could not highlight were included in the study; an airgun pellet radiograph, a C1 and C2 fracture, and a fracture to the spinous processes of C7. These were added to increase variety in the radiographs. Additionally three radiographs used in the test had ambiguous radiologist reports, example "*mild anteriolisthesis of the C4 body*" this does not mention the junction involved, due to this these three radiographs were reviewed independently by a reporting radiographer who only stated the junction involved for each radiograph, so in the example the new report stated "*mild anteriolisthesis of C4 on C5*" these 3 modified reports were treated as the "true" answer like the other 27 reports.

Testing

This experiment followed exactly the same testing as the first test, with the exception that a checklist (Appendix 19) was introduced in order to make the training of the CSPINE-CAD software more repeatable. Thirty-two participants volunteered for the testing, of which 29 participants actually conducted it, with 26 diagnosing all 30 C-spine lateral radiographs. Participants then completed the questionnaire prior to leaving.

3.3.6 COMPLETION OF ADMINISTRATION

- In all three tests participants were awarded a continuing professional development (CPD) certificate on completion of the study
- All participants in the second and third test were emailed a copy of the original radiographs with the reports diagnosis next to each image/radiograph (this was emailed in the form of a PDF).
- All participants were reminded to contact me via email if they had any follow up questions
- Third test participants were sent a copy of their answers along with a C-spine image interpretation package used in the teaching of third year radiography students

3.3.7 TESTING THE REPEATABILITY OF THE CSPINE-CAD SOFTWARE AT INDICATING INJURIES

In addition to testing the 26 participants on all 30 lateral C-spine radiographs, the accuracy of the CAD software in both indicating the correct injury against the true reported pathology, and its repeatability in doing so was tested. This set up was the same as the third test but no answer sheets were involved and only the results of the CAD indication arrows recorded. The only varying factor other than the radiographs was the numbering of the vertebral body centres which had to be done first by the human operator in order to get the CSPINE-CAD to segment and indicate the injuries. Due to this two reviewers (myself and a colleague (who was trained on the software, and holds a higher technician in diagnostic imaging degree from Spain), each numbered the vertebral body centres on all 30 test radiographs allowing CSPINE-CAD to be applied and recording any indication arrows in an MS excel spreadsheet, this was repeated 10 times by both reviewers. Both results were kept independent, although both reviewers had prior knowledge of the true diagnosis, my colleague having practiced on the data set three weeks prior, and myself having chosen the 30 for third test. As this was directly testing the CSPINE-CAD software's ability to diagnose and not the reviewers involved, this prior knowledge was deemed acceptable as the reviewers' only action was to click on the vertebral body centres of C1 to C7 and record the results of the CSPINE-CAD indication arrows.

3.4 DATA ANALYSIS

The primary outcome measures for the three tests:

- Differences in sensitivity and specificity scores for before and after the use of CSPINE-CAD for all three tests

The secondary outcome measures for the three tests:

- Changes in confidence level when diagnosing lateral C-spine radiographs with and without CSPINE-CAD software
- What examination/body part participants would like to see this sort of CAD software applied to
- Features the participants would like to see in the current version of the

CSPINE-CAD software

- Was the CSPINE-CAD software useful as a second pair of eyes to the participants

3.4.1 ANALYSIS OF THE FIRST TEST

The data from the first test were analysed, this involved comparing each answer to the original RD&E report (which was considered the gold standard and "true" diagnosis), this was done across all five radiographs for all five participants, the analysis only involved the comparison of fractures and misalignments (due to the CSPINE-CAD software highlighting only these issues) i.e. osteophytes, fusions, degenerative changes, disc height loss, foreign bodies, were not reviewed or compared.

Each comparison answer was defined into one of four groups; true positive (if there was an injury match between the report and the answer sheet), a true negative (both the report and answer sheet agreed there was no injury), a false negative (the report states there was an injury and the answer states there was not), and false positive (were the answer sheet states there is an injury but the report states there was not). These four groups were represented by the numbers 1= true positive, 2= false positive, 3= false negative and 4= true negative (this number 4 was later replaced by an empty box due to a high number of true negatives that made it difficult to physically visualise the data). This entire process of comparison and numbering was repeated for both with and without CAD, for all radiographs and all participants, the results of the first radiograph in the test are shown in Figure 77.

Participant	**Without CAD Vertebrae**							**Without CAD Alignment**						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7
3				2	2						3	1		
4											1	1		
5											3	3		
6											3	1		
9											1	1		

Participant	**With CAD Vertebrae**							**With CAD Alignment**						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7
3				2	2					2	1	1		
4											1	1		
5											1	3		
6											3	1	2	
9					2						1	1		

Figure 77. *The raw data from the first test. (Key 1= True Positive, 2= False Positive, 3= False Negative and every blank box represents a True Negative)*

During this analysis it was concluded that due to the answer sheets involving a comments box diagnosis (rather than a tick box) the answers received from participants regarding misalignments had a level of ambiguity in not agreeing verbatim with the radiographers' report, this meant a level of interpretation had to be performed before a fair comparison could be reached.

An example of this amibguity is shown in Figure 78 in the before CAD box, it states that there is "*a posterior dislocation of C5*", for the same radiograph Figure 79 another participant states in the before CAD box that there is an "*anterior slippage of C6*". The "true" or reported answer was "*a retrolisthesis of C5 on C6*", so who is right? Both statements imply they saw the injury but did not state it with enough accuracy; this might be due to lack of practice of correct medical terminology and reporting. Due to this ambiguity the results of misalignments were left to always favour the "benefit of the doubt" in which any diagnosis of misalignment mentioning the associating vertebral body (superiorly or inferiorly) would be classed as correct, thus in this example under the "benefit of the doubt" rule both interpretations are correct in their diagnosis.

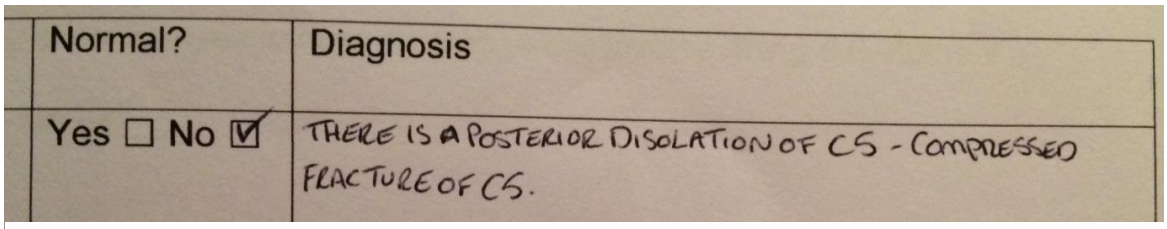


Figure 78. *Answer to question 4 by participant 9 before CAD*

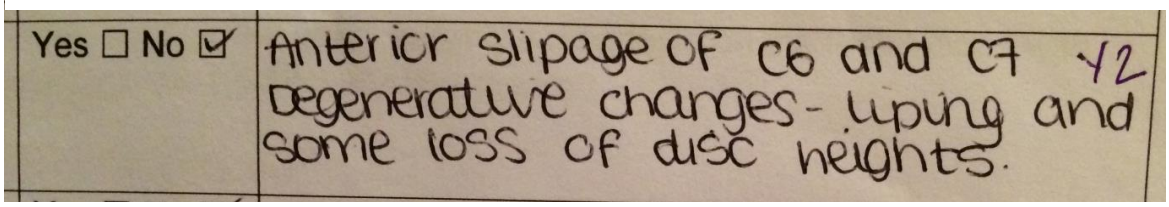


Figure 79*. Answer to question 4 by participant 6 before CAD*

Using the same numbering format this data was reviewed and modified to show the "benefit of doubt" as shown in Figures 80 and 81 and in full in Appendix 20.

Participant	Without CAD	Vertebrae						Without CAD	Alignment more general					
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7
3				2	2						3	1		
4											1	1		
5											3	3		
6											3	1		
9											1	1		

Figure 80. *Full classification based on what the participant has said exactly without ("benefit of the doubt")*

Participant	Without CAD	Vertebrae						Without CAD	Alignment more general					
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7
3				2	2							1		
4											1			
5											3			
6												1		
9												1		

Figure 81*. The same data from Figure 80 but with the "benefit of the doubt"*

3.4.2 ANALYSIS OF THE SECOND TEST

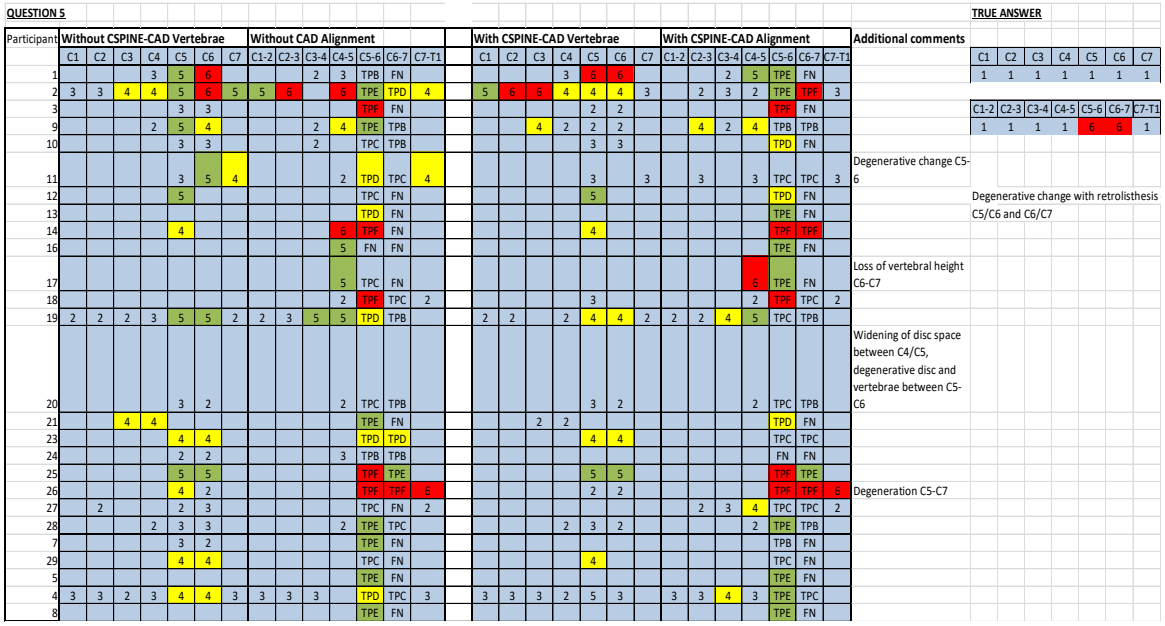
Data analysis was conducted the same way as in the first test including the "benefit of the doubt" technique (shown in full in Appendix 21).

3.4.3 ADDITIONAL ANALYSIS EXACT REPORT DATA

Due to the "benefit of the doubt" modification the analysis did not accurately represent the participants' diagnosis. To balance this, an "exact report" analysis was created. The data from both the first and second test was reanalysed stating that only a diagnosis that mentioned both vertebrae either side of the misalignment or mentioned the specific junction (e.g. C5-C6) would be classified as a true positive. This created a less interpreted piece of data and a fairer reflection of the diagnosis, but lowered the overall true positives.

3.4.4 ANALYSIS OF THE THIRD TEST

Due to the changes in the answer sheet the data produced were not as ambiguous, and as such could be compared directly to a prefilled in answer sheet containing the true radiographers' report answers (Appendix 22). The only difference was the introduction of the threshold confidence levels. Thus any participant who thought there was no injury to either a certain vertebral body (C1 to C7) or vertebral junction (C1-C2 to C7-T1) would write a value of 1 on their answer sheet; thus an answer of all 1s in all boxes would be stating the radiograph as "normal". Any value above 1 placed in the in C1 to C7 boxes indicated a fracture to that particular vertebral body, and any value above 1 placed in the C1-C2 to C7-T1 boxes indicated a misalignment, the higher the number the more confident the participant was in stating that injury, with 6 being the maximum they could state. These numerical values were then compared against the "true" reported answer (as shown in Figure 82). Any boxes left blank in the original diagnosis (before CAD) were deemed to be normal so were defaulted as 1. Any boxes left blank in the "With CSPINE-CAD" box would revert to the original diagnosis number.



QUESTION 5

Participant	Without CSPINE-CAD Vertebrae							Without CAD Alignment							With CSPINE-CAD Vertebrae							With CSPINE-CAD Alignment							Additional comments
	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1	
1				3	5	6				2	3	TPB	FN					3	6	6				2	5	TPE	FN		
2	3	3	4	4	5	6	5	5	6		6	TPE	TPD	4	5	6	6	4	4	4	3		2	3	2	TPE	TPF	3	
3					3	3						TPF	FN						2	2						TPF	FN		
9				2	5	4				2	4	TPE	TPB				4	2	2	2			4	2	4	TPB	TPB		
10					3	3				2		TPC	TPB						3	3						TPD	FN		
11					3	5	4				2	TPD	TPC	4					3		3		3		3	TPC	TPC	3	Degenerative change C5-6
12					5							TPC	FN						5							TPD	FN		
13												TPD	FN													TPE	FN		
14					4						6	TPF	FN						4							TPF	TPF		
16											5	FN	FN													TPE	FN		
17											5	TPC	FN	2											6	TPE	FN		Loss of vertebral height C6-C7
18											2	TPF	TPC	2					3						2	TPF	TPC	2	
19	2	2	2	3	5	5	2	2	3	5	5	TPD	TPB		2	2		2	4	4	2	2	2	4	5	TPC	TPB		
20					3	2					2	TPC	TPB						3	2					2	TPC	TPB		Widening of disc space between C4/C5, degenerative disc and vertebrae between C5-C6
21			4	4								TPE	FN				2	2								TPD	FN		
23					4	4						TPD	TPD						4	4							TPC	TPC		
24					2	2					3	TPB	TPB														FN	FN		
25					5	5						TPF	TPE						5	5							TPF	TPE		
26					4	2						TPF	TPF	6					2	2							TPF	TPF	6	Degeneration C5-C7
27		2			2	3						TPC	FN	2									2	3	4	TPC	TPC	2	
28				2	3	3					2	TPE	TPC					2	3	2					2	TPE	TPB		
7					3	2						TPE	FN														TPB	FN		
29					4	4						TPC	FN						4								TPC	FN		
5												TPE	FN														TPE	FN		
4	3	3	2	3	4	4	3	3	3	3		TPD	TPC	3	3	3	3	2	5	3		3	3	4	3	TPE	TPC		
8												TPE	FN														TPE	FN		

TRUE ANSWER

C1	C2	C3	C4	C5	C6	C7
1	1	1	1	1	1	1

C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
1	1	1	1	6	6	1

Degenerative change with retrolisthesis C5/C6 and C6/C7

Figure 82. *Question five as answered by all 26 participants (Key: answer is shown top right. FN= False Negative, TP=True Positive (confidence level = letter i.e. B=2, C=3, D=4 (yellow), E=5 (green) and F=6 (red) all numerical values are False Positives (FP) and all blank boxes are True Negatives (TN)).*

3.4.5 ANALYSIS OF THE REPEATABILITY OF THE CSPINE-CAD SOFTWARE AT INDICATING INJURIES

Of the 30 radiographs from the third test, 21 images had 24 separate injuries that could be indicated by the CSPINE-CAD software (additional injuries that would not be highlighted by the software were ignored). As stated these radiographs were put through 10 repeats by each reviewer with each indication arrow recorded (Appendix 23 and 24), these data were then compared against the true report. It must be stated that the CAD software only indicated the misaligned vertebral body and not the exact junction; as such the data from the CAD software was treated like the data from the first and second tests, with the "benefit of the doubt" rule. For example a CAD misalignment indication arrow (orange) may have pointed to C5, this would be treated as indicating the C4-C5 and C5-C6 junctions are misaligned. Each diagnosis was marked against the "true" reported injury (with no negative marking) and a tally was collated across all 10 repeats resulting in a score out of 10 per radiograph (i.e. a score of 10/10 would mean the CAD software indicated the injury every time). These scores out of 10 from each reviewer were averaged for each radiograph. These data were then compared to answers provided by the third test participants to see if there was any correlation to repeatability in CAD indicating the injuries correctly, and participants increasing in confidence.

3.4.6 ANALYSIS OF QUESTIONNAIRES

All three tests collected questionnaire data in the form of confidence levels (scoring 1-5) asking participants to rate how confident they felt making a diagnosis without and with the assistance of the CSPINE-CAD software, these figures were then compared. Additionally all qualitative data from the open questions for the first and second tests (for example the question: what additional features the participants would like to see) were combined together, due to both involving third year radiography students. The third tests qualitative data on the contrary were kept separated in order to compare the junior doctors and the radiographers. This was in order to show the prevalent feature/examination requested for each participant group, this was simply done using a tally system were ideas that were the similar/the same were combined. In the third test questionnaire, length of experience was also recorded, this included; the hours, weeks and years participants had worked as either a medical doctor or a radiographer. These data were then correlated against the questionnaire and results to see if more experienced staff members found the CSPINE-CAD less useful.

3.4.7 STATISTICAL METHODS

Data from all three tests were entered into separate MS Excel spreadsheets and the specificity, sensitivity and area under a curve (AUC) were calculated with and without the use of CSPINE-CAD. Furthermore the third test calculated sensitivity and specificity scores for each confidence threshold (from 2 to 6). Sensitivity and specificity scores were also calculated for the CSPINE-CAD repeatability data which were separated into high groups (7/10 or above) and low groups (6.5/10 or below) and compared for before and after CAD scores. Additionally the data from the first and second test was calculated using the “benefit of the doubt” analysis and then again for the additional “exact report” analysis.

For the additional research that looked into the accuracy of the fracture classification (Chapter 4) and the accuracy of the data the CSPINE-CAD learnt from (Chapter 5), two methods of analysis were used. The first method used was calculating Cohens Kappa scores in STATA V14 and Fleiss Kappa scores

in ReCal3 [121], giving a comparison agreement between two independent radiographers reviewing the same radiographs using CSPINE-CAD software, and with a third expert using a different method. The second involved calculating coefficient of variation scores in MS Excel spreadsheets and comparing the results between individuals who had segmented the same radiographs using the same software to compare their inter and intra comparison scores.

CHAPTER 4. DIAGNOSTIC THRESHOLD EXPLORATION

4.1 INTRODUCTION

This chapter describes the testing of the applicability of the Genant SQ scale for C-spine compression fractures. This is due to the use of the Genants SQ scale (Figure 83) within the CSPINE-CAD (version 2, the latest at time of this testing) software being used to assess cervical spine vertebrae fractures, and the issues that arose with it incorrectly diagnosing fractures where there were none; it was concluded to review this scale and to test its diagnostic accuracy. This testing was conducted across three methods; one using version 2 of the CSPINE-CAD software, the second method used a visual measurement assessment, and the final method used the 'gold standard' method in order to compare the other two, this method involved a visual assessment by a reporting radiographer. 152 C-spine radiographs were reviewed and diagnosed by each method including the gold standard in which comparisons and conclusions were drawn. This chapter will cover the background of the Genants SQ scale, the methods used to test it, and results.

4.1.1 BACKGROUND

The Genant SQ scale is a method to determine the severity of compression fractures in vertebral bodies by visual or quantitative determination of the vertebral body height at the anterior, middle and posterior portions, and any morphologic changes [111]. Figure 83 below shows the Genant SQ scale classifications and their associated diagnoses based on the visualise assessment.

Figure 83. *Genants classification of vertebral fractures [109]*

The Genant SQ scale is widely used and known in clinical settings, and is used in assessment of thoracic and lumbar vertebral bodies in patients with osteoporosis and osteopenia to determine the damage (if any) to their spine [111]. This makes its introduction easier to convey; as medical personnel (especially radiographers) should know of the Genant SQ scale, making the "how the software works" easier to grasp, giving operators more confidence in the CSPINE-CAD software's conclusions, as they know it is based on a known and understandable technique.

As well as the Genant SQ scale being more widely known than other techniques, it is also less time intensive and cumbersome than certain other morphometric methods [111]. As these can involve the operator physically measuring each vertebrae using a simply dot and line system, this of course, although quantitatively accurate is extremely time consuming and would affect the waiting time for patients, the throughput times, and the amount of time the radiographer would need to spend reviewing every single image.

Additional arguments for using the Genant SQ scale within the CSPINE-CAD software compared to other possible methods are: that the Genant SQ scale has been shown to be more accurate than non-standardised qualitative assessment [111]. For instance, some methods have shown to only grade the most severe fractures and thus have not included the mild or moderate fractures. If this method was utilised then the mild and moderate fractures would be missed by the CSPINE-CAD software making it a less reliable piece of equipment.

The Genant SQ scale is also highly reproducible [109], and has been assessed and tested in various studies, resulting in high agreement figures of inter observational data ranging from 90-99% agreement, with Kappa scores ranging from 0.69-0.81 [109]. These were the justifications as to why the Genant SQ scale was integrated into the CSPINE-CAD software. So as each vertebral body was segmented by the CSPINE-CAD software (version 2) the measurement algorithm was applied giving an anterior, middle and posterior measurement figure, the software then inter-compared these measurements and calculated a difference in percentage between them. The Genant SQ scale was then applied

via the resultant percentages and a fracture classification (if there is a fracture) was given based on the Genant SQ scale (Figure 83), this fracture type was then placed next to the suspected vertebral body in word form.

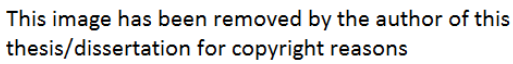
4.2 METHOD

Ethics had already been sought from the UOE (Appendix 1) and the RD&E to collect C-spine radiographs. At time of testing a total of 152 C-spine files had been gathered from the RD&E, these files were sorted with all additional images (AP, pegs, swimmers) removed, leaving 152 lateral C-spine radiographs. These radiographs were then sorted by age removing all below 18 years and all above 50 years, this was due to the possibility of degenerative disease such as osteoporosis which is more present in the over 50 year olds [8]. It must be acknowledged that the CSPINE-CAD software is poor at discerning vertebral bodies in radiographs with degenerative disease, and as this is a test of the Genant SQ scale and not the accuracy in diagnosis of the CSPINE-CAD software, it was concluded over 50s radiographs would be removed. From the original 152 radiographs, that total went down to 48 radiographs (see Appendix 26 for full list of the 48, CS numbers included) of these one file which was corrupt and could not be loaded, leaving 47. Each one of these 47 radiographs were analysed from C3 to C7 by four imaging experts using the three different methods.

4.2.1 FIRST METHOD - CSPINE-CAD SOFTWARE (VERSION 2)

Two radiographers (the researcher and researcher 2) independently applied the CSPINE-CAD software to all 47 lateral C-spine radiographs. First MATLAB (version R2014a 8.3.0.532 Mathsworks, Natick, MA) was opened and the CSPINE-CAD software (version 2) was loaded. Each radiograph was then loaded into the CSPINE-CAD (version 2) software in CS number order. After loading the radiograph into the software the segmentation process outlined in Section 2.2.6 was performed, this software applied the Genant SQ scale as shown in Figures 84 and 85. Any errors in the vertebral body segmentation were manually corrected by the radiographer creating a new segmentation of

that vertebral body, this modification still allowed the Genant SQ scale to be applied.



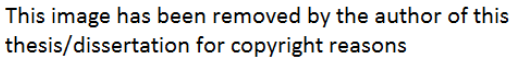


Figure 84. *CSPINE-CAD applied to radiograph (seen with Genant fracture classification)*

Figure 85. *After manual correction segmentation of the CSPINE-CAD software*

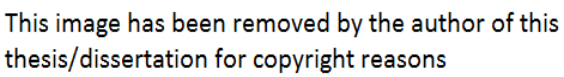
After the application of the CSPINE-CAD software (and any manual segmentation revisions made) any fractures stated by the software were recorded along with their Genant SQ classification, and the vertebral body that was effected (C3-C7). This was repeated for all 47 radiographs, with the data shown in Appendix 27 and 28.

4.2.2 SECOND METHOD - DICOM VIEWER MEASUREMENTS

The second method was utilised by an independent expert (researcher 3) who used a program called ImageJ to view the same 47 radiographs. The radiographs were individually loaded one at a time into the ImageJ program. The expert then proceeded to measure the posterior, middle and anterior height of each vertebral body, starting at C3 and finishing with C7. The exact positioning and type of measuring used was called point placement quantitative morphometry [119], Figure 87 shows the placement of these measurements on different shaped vertebrae.

Figure 86. [119] *Shows the measurement points used to determine if a vertebral body was fractured under the Genants SQ scale criteria*

Each point in Figure 86 shows the placement of either the anterior, middle or posterior points to use during measuring. It also shows the modifications needed if the shape of the vertebral body is not perfectly lateral, these measurements were then applied to the vertebral bodies of C3-C7 for all 47 radiographs. An example of a completed radiograph) with the measuring dots/points in place is shown in Figure 88.



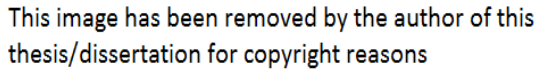


Figure 87. *Radiograph without the manual measurements*

Figure 88. *Radiograph with the manual measurements*

All measurements were recorded in an MS Excel spreadsheet as shown in Appendix 29, an example is shown in Figure 89 showing the measurements of C3 and C4. The measurement taken at the anterior, posterior and middle portions for each vertebral body was then inter-compared with each other to see if there was any loss of vertebral body height at any of the three positions. This inter-comparison was expressed as percentage for each vertebral body in order to give it a Genant SQ classification. An example of this is shown in Figure 90 using the measurements from Figure 89. (For a full list of all the percentages, of all 47 radiographs see Appendix 29).

These percentages were then highlighted depending on their fracture classification based on the Genant SQ scale (Figure 83). The highest

percentage difference determined the type of fracture, for example in C4 in Figure 90 it was known based on the percentages that there was a mild fracture present (A:P), and also a moderate fracture (M:P), due to the middle to posterior inter-comparison percentage being higher than the anterior to posterior percentage, it would be classified under the Genant SQ as a biconcave fracture of C4.

	C3	C3	C3	C4	C4	C4
FileName	A	M	P	A	M	P
CS0065	142.3456	126.8207	164.4544	130.6578	120.8006	165.1274

Figure 89. *The measurements recorded in an MS Excel spread sheet (this example only shows C3 and C4 of one radiograph but in reality it contained C3-C7. Key A=Anterior, M=Middle, P=Posterior)*

						0% to 20%
C3	C3	C3	C4	C4	C4	20% to 25%
A:M	M:P	A:P	A:M	M:P	A:P	25% to 40%
11%	23%	13%	8%	27%	21%	40% to 100

Figure 90. *Shows the figures from Figure 89 converted into a percentage through inter comparison (Key A:M = Anterior to Middle M:P = Middle to Posterior and A:P = Anterior to Posterior).*

4.2.3 THIRD METHOD - VISUAL ASSESSMENT

The third and final method involved a reporting radiographer researcher 4 analysing the same 47 lateral C-spine radiographs. This was done by loading each radiograph into ImageJ and then assessing the image for any abnormalities or injuries. Any injury found was classified by its type of fracture, and recorded in an MS Excel spreadsheet under its CS number (as shown in Appendix 30).

4.2.4 ANALYSIS

All methods were performed blind to the original report, and blind to the other experts' results. Although all results were stated in MS Excel spreadsheets under each CS number, they were all written out differently some using the descriptive terms and others using a number system. So in order to compare these data it was sorted into a new format using a simple conversion; each

classification of fracture would be relabelled with a number between 1-9 (as shown in Figure 91 and 92).

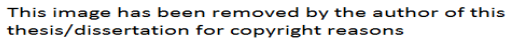


Figure 91. *Genant SQ scale*

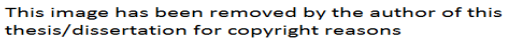


Figure 92. *The Genant SQ scale conversion*

This process of reformatting was done for each classified fracture, until the data from all three methods were in the same format so it could be inter-compared (as shown in Appendix 31). A compressed version of these appendices is shown in Table 4.1.

The data were then analysed using Cohens Kappa calculated in STATA V14 to find out the agreement between the two radiographers using CSPINE-CAD. Additionally the data were analysed using Fleiss Kappa calculated in ReCal3 [121] (a statistical method for comparing multiple raters, not just two) this calculated all three raters' agreement (the two CSPINE-CAD raters and the rater who used the DICOM viewer measurements).

4.3 RESULT

As shown in Table 4.1 out of the 47 C-spine radiographs or a maximum of 235 vertebrae (C7 could not be visualised on certain radiographs, DICOM viewer measurements measured 225 vertebrae and one CSPINE-CAD report stated 228 visualised, the other two data sets did not state which vertebra where poorly visualised); CSPINE-CAD report 1 resulted in 99 fractures (61 mild), CSPINE-CAD report 2 resulted in 77 fractures (33 mild), DICOM viewer measurement resulted in 20 fractures (14 mild) and the visual assessment resulted in a total of three fractures (all three were classified as mild).

Table 4.1. *Reported fracture rates of the 47 radiographs. (Key: CAD1 = CAD report 1, CAD2 = CAD report 2, Meas= DICOM viewer measurement, VA = Visual analysis. The Genant scale has been applied using 1=mild biconcave, 2=moderate biconcave, 3=severe biconcave, 4=mild wedge, 5=moderate wedge, 6=severe wedge, 7=mild crush, 8=moderate crush, 9=severe crush, very empty box means no fracture.)*

			CAD1					CAD2					Meas					VA				
ID	Age	Gender	C3	C4	C5	C6	C7	C3	C4	C5	C6	C7	C3	C4	C5	C6	C7	C3	C4	C5	C6	C7
CS0002	46	M	1		5				7	7	2				5							
CS0003	50	F						1	2													
CS0004	25	F	1	1	2	2		1	2	5	2			1	1	1						
CS0006	19	F		1		1	1	2	4		1		1	1								
CS0007	48	M											1									
CS0011	32	M			5				4						5							
CS0012	20	F																				
CS0014	23	M		1																		
CS0015	37	M		1	2					2					1							
CS0020	29	M	2	2		1			1													
CS0024	44	M	1										4									
CS0034	42	F		4	5	4			5	6				4	4							
CS0035	46	F																				
CS0040	34	M	1	1	1	1		1			1											
CS0044	22	M			1						2											
CS0045	39	M		2	2				2	2					1				4			
CS0047	45	M	1		1	4	2															
CS0048	40	F	1	1		1																
CS0051	45	F	1			1		1			2											
CS0052	43	F						1		2	8											
CS0053	49	M			1	1		4			6											
CS0054	30	F				1			1	1												
CS0060	30	M																				
CS0064	50	M	2	5	2		1	1	5	4				1								
CS0065	48	F	2	2	1	1	2	1	1	1		1	1	2		2						
CS0074	44	M	2	1		2		2	1	1	1		1									
CS0079	44	F			5		4	1		6					5					7		
CS0081	25	M			1	1		1		1												
CS0087	31	M																				
CS0088	18	F			5																	
CS0090	44	F		4		1	1		4	5	2											
CS0092	24	M	1	1	2	1		1		2												
CS0098	41	F			1	2	1			2												
CS0099	41	F	1			1				1	1											
CS0105	42	M	1						2													
CS0114	25	M		1	2	1																
CS0115	45	M		4	5	1	2		2	6					5							
CS0119	39	F				1					4										7	
CS0128	48	F	1	2																		
CS0132	40	M		1	4	2			2	5	5											
CS0133	32	M			5	2	2			7												
CS0140	36	M					1															
CS0141	41	F	1	2				1	1	1	1											
CS0145	43	F	1	1	2		1		5	5		1										
CS0146	50	M			2			1		1												
CS0149	50	M		5	1				7	7												
CS0150	28	F	2	2	2	1		2	2	2	1											
Total fractures			99					77					20					3				

The two experts using the CSPINE-CAD software (version 2) each correctly identified all three mild fractures as stated by the visual assessment (the gold standard), although the DICOM viewer measurement only identified two of the three.

Agreement between the two radiographers using CSPINE-CAD was 59% with a Kappa score of 0.27 ($p<0.001$) (Appendix 32). Excluding the mild fracture category from the datasets improved agreement to 80%, with a Kappa score of 0.28.

Fleiss' Kappa

Fleiss' Kappa	Observed Agreement	Expected Agreement
0.154	0.617	0.547

Figure 93. *Fleiss' Kappa calculation between three raters*

A Fleiss' Kappa score was calculated (between the three raters; the two CAD results and the DICOM viewer measurement) with an agreement of 62% and a Kappa score of 0.15 (Figure 93). All quantitative methods over-classified vertebrae as fractured when compared to visual assessment.

4.4 DISCUSSION AND LIMITATIONS

The Kappa scores were defined as; a fair agreement (a score of between 0.21-0.40) in the two raters comparison, and a slight agreement (a score of between 0.01-0.20) in the three raters comparison. Although these figures are above 0 showing that the results are above "just chance", they are rather low compared to a perfect agreement which has a Kappa score of 1.

The reasons for this low Kappa score between the two raters using the CSPINE-CAD software (version 2) and thus the low agreement between the three raters; might have been due to the scarce amount of injuries, and the low number of radiographs used [125]. That is to say of the 235 vertebrae only three were considered (by visual assessment/gold standard) to be injured. This is expressed more clearly in the fact the "exclude mild category" had a very high agreement (above 80%) yet still a low Kappa score (0.28).

The low score might also be related to the fact that some of the vertebral bodies needed to be manually segmented; this segmentation was a huge issue in determining if there was a vertebral fracture based on the software's measurement algorithm in which it read the point placement. If during segmentation this point placement is off by a millimetre in vertebral height, the

difference between the two measurements could have changed from 19.94% no fracture, to a 20% grade one mild fracture. This manual placement would also affect the classification of the fractures, and there may have been cases where the radiographers agreed on a fracture but one classified it as a high percentage mild and the other classified it as a low percentage moderate so again there would be no agreement. It must be stated if this comparison was done with version 3 of the CSPINE-CAD software utilising the indication arrows both radiographers would have been correct in this instance (as it would only indicate the injury and not define its classification).

Additionally this may have been due to the Genant SQ scale being designed for use in thoracic and lumbar vertebrae and not cervical vertebrae, and the difference in vertebral body shape between the two groups [123] might be the reason there is an incorrect application of the scale and thus overcalling of fractures, this is further supported by the limitation that the Genant method has difficulty in differentiating normal anterior wedging in mid-thoracic and thoracolumbar vertebrae from grade one osteoporotic collapse [126].

It must also be acknowledged that the reporting radiographer stated there were three fractures on the 47 images/235 vertebrae, yet compared to the original reports there were none, this may be due to the fact that a lot osteoporotic fractures go unreported [127]. So it is entirely possible that the CSPINE-CAD software might highlight an unreported fracture and thus be classified as incorrect for flagging it, although such a large number being missed is highly unlikely.

4.5 CONCLUSION

The Genant SQ scale resulted in an over-classification of C-spine vertebrae as having compression fractures. Agreement between experts using CSPINE-CAD showing a fair agreement, and ImageJ measurements were weak to moderate. It is concluded that adapted thresholds are required for the CSPINE-CAD software to improve in accuracy. Interestingly CAD classified the three known fractures as moderate and severe in CAD report 1, and indicated two of them as moderate or severe in CAD report 2. This means if you were to remove

all mild classifications from the CAD 1 report and CAD 2 report and compare those results against the three fractures identified by the visual assessment then five out of six fractures are still picked up, this is due to the three mild fractures as determined by the visual assessment being defined by the CAD software as either moderate or severe fractures (instead of mild). So removing the mild classification from the reports would not really affect the “true” result, except in reducing the overcalling (although one mild fracture would be missed in the process).

Further investigation into the issue of point placement in manual segmentation is needed, given as the comparison between the two radiographers using the same CSPINE-CAD software resulted in different results. Also accompanying research should use a higher rate of images with vertebral fractures when comparing the inter-reliability of CSPINE-CAD software, this will make the kappa scores more reliable.

Additional revisions of the percentage classification are needed with the possibility of the removal of the mild classification, this is in order to create a more ideal piece of software; this could be done by testing the images with the CSPINE-CAD software tweaked each time; the moderate classification could be extended to include 23% then 24% then 25% and so on, this exact cut off could be investigated in order to optimise the fracture classification process, and possibly the overcalling of fractures.

CHAPTER 5. INTEROPERATOR AND INTRAOPERATOR RELIABILITY

5.1 INTRODUCTION

In the previous chapter it was shown that the Genant SQ scale being utilised within the CSPINE-CAD software resulted in overcalling mild fractures. This may be due to how the CSPINE-CAD software learns how to segment vertebral bodies via the information relayed to it by the manual segmentation (provided by just two radiographers, myself and researcher 2). There was the possibility of a lack of agreement in defining the borders of vertebral bodies between radiographers, or a lack of precision between the same radiographer. Any ambiguity of the borders would impede the ability of the software to learn, and thus its ability to discern vertebral bodies correctly, affecting its accuracy, repeatability and classification of fracture. This chapter addresses that, by conducting an interoperator and intraoperator precision test; this type of test has been used in several other studies to test the ability and accuracy of software [104].

The intraoperator and interoperator study involved manual segmentation of C-spine vertebral bodies on ten lateral C-spine radiographs, using the CSPINE-CAD software (version 2). As the software learned from the segmentation it was decided to see how consistent this segmentation was. This was done in two ways; one using the same ten images being segmented week after week by the same trained individual (intraoperator), and the other way was across multiple trained individuals with the same set of ten images each (interoperator).

The intraoperator precision study was conducted by myself and involved no other participants. The interoperator precision testing involved recruiting four third year radiography students (plus myself, so five participants in total: AO, CW, JR, MG, VW) from the UOE. This group was chosen as they were already conducting their own research (as part of their final year project) with the CSPINE-CAD software on second year radiography students, so knew about the software. Also their level of knowledge of C-spine anatomy, and experience of viewing lateral C-spine radiographs was important due to the need to segment vertebral bodies on their own using the CSPINE-CAD software.

5.2 METHOD

For the interoperator precision testing, the five participants selected ten lateral C-spine radiographs from the collection of 152 lateral C-spine radiographs already gathered from the RD&E. These ten radiographs were chosen due to their lack of degenerative disease, lack of injury such as fracture, dislocation or subluxation (as this was a test of segmentation not indication), and being good quality radiographs i.e. the C-spine was visible from C1 to the whole of C7, with minimal lack of rotation and parallax distortion, and lacked any avoidable artefacts (such as glasses and earrings). These were concluded to be the simplest to visualise and thus segment, and were chosen in order to reduce cofounding variables in the possibility of poor quality radiographs being the defining factor, rather than the ability of the participant to subjectively segment the vertebral body.

Prior to starting both the interoperator and intraoperator participants were trained on the MATLAB software (version R2014a 8.3.0.532, Mathsworks, Natick, MA), and shown how the CSPINE-CAD software worked. Any questions raised by the participants during the training were addressed. All participants used the same computer and version of MATLAB, and all were blinded from each other's results and all independently segmented the radiographs without anyone viewing their screen, also no time restrictions were imposed. The testing was conducted at the UOE Streatham campus on the second floor of the physics building, and was conducted in the corner of an open study area, this area was free from: glare (blinds were drawn), distractions, and the area was rarely frequented.

Due to the issues stated in section 2.2.2 and 2.2.3 regarding C1 and C2 and their lack of conclusive segmentation by the CSPINE-CAD software it was decided to exclude these from the interoperator and intraoperator precision tests. Each participant loaded the first radiograph into MATLAB and started to segment the relevant vertebrae from C3-C7 in the process (previously stated in section 2.2.1 (Figures 31 and 32) in which the 20 dot-to-dot system was used. After completion of vertebral segmentation the radiograph was saved as a MAT file under its CS number, with the initials of the participant next to it. The participant then repeated the process for the next nine images (ten images

segmented in total). The next participant then loaded the first radiograph and segmented all ten; this process was repeated until all five participants had segmented all ten radiographs resulting in a total of 250 segmentations (5 participants x 10 radiographs x 5 vertebrae per radiograph).

In conjunction with the segmentation of the vertebral bodies the three alignment curves were also plotted this included the posterior, anterior and spinolaminar lines (using the process as stated in chapter 2, section 2.2.4). This was similar to the segmentation and was repeated for all ten radiographs by each participant. Upon completion of each radiograph the file was again saved as a MAT file under its CS image number and under the initials of the individual participant who had applied the alignment curve. This process was repeated until all ten radiographs had had alignment curves applied by all five participants. An example from each participant of their segmentation, including their alignment curves is shown below in Figures 94-98.

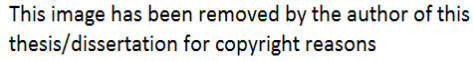


Figure 94. *Radiograph CS0081 segmented by MG*

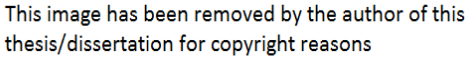


Figure 95. *Radiograph CS0081 segmented by JR*

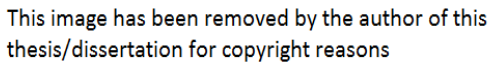


Figure 96. *Radiograph CS0081 segmented by VW*

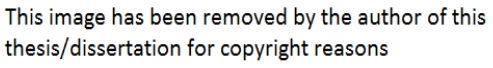


Figure 97. *Radiograph CS0081 segmented by CW*

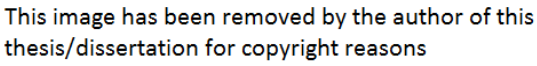


Figure 98. *Radiograph CS0081 segmented by AO*

These ten MAT files from each of the five participants were then sent to the team at City University to overlap and compare for Interoperator precision (50 images in total, 5 participants x 10 radiographs).

For the intraoperator precision testing the same ten radiographs were used, as was the same MATLAB software, computer and segmentation protocol. The main differences between the interoperator and intraoperator were:

- It was only done by one person (myself)
- No alignment curves were plotted
- There was a recognised time gap after all ten radiographs were segmented, this process was then repeated.

In the intraoperator testing all ten radiographs were segmented by myself, then after a period of between 7 to 42 days (with an average of 20 days), the same ten radiographs were segmented again. The wait of at least seven days was to reduce bias of consistency brought about through memory of the previous segmentations. This continued until all ten radiographs had been segmented ten times, resulting in a total of 500 segmentations (1 participant x 10 radiographs x 5 vertebrae per image x 10 separations of time). These images were then sent to team at City University in the same way as the interoperator images, to be inter-compared to see the variation in segmentation.

Thirty processed images were then returned by City University (ten images showed all manual segmentations (interoperator), ten images showed all manual alignment curve (interoperator), and ten images showed all intraoperator manual segmentations). Each image contained all participants manual segmentations (of that image) superimposed as shown in Figure 99, each participant's segmentation was designated and linked to their initials (Figure 99). Or as in the case of the intraoperator test data rather than different colours symbolising different participants segmentations, instead it symbolised different dates those segmentation took place on, as shown in Figure 101. Additionally the alignment curve data from the interoperator data were visualised in the same way (Figure 104 and 105).

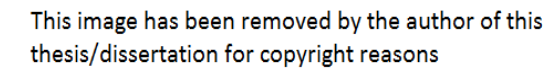


Figure 99. *CS0081 example of interoperator precision, initials are shown in different colours*

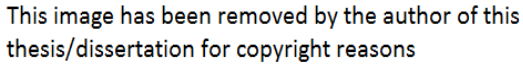


Figure 100. *CS0081 example of intraoperator precision including dates of segmentation*

Of the 30 images produced, a subjective best and worst representation of the precision testing were chosen, these are shown in Figures 101-106 as screen grabs. It consisted of; the best and worst interoperator manual segmentation (Figures 101 and 102), best and worst alignment curves (Figures 103 and 104), and the best and worst intraoperator manual segmentation (Figures 105 and 106). These were chosen to highlight visually the diversity and precision of interoperator and intraoperator errors within the group

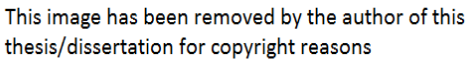


Figure 101. CS0115 *zoomed in example of good interoperator vertebral segmentation*

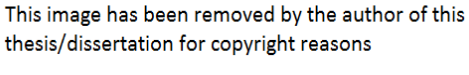


Figure 102. *CS0098 zoomed in example of poor interoperator vertebral segmentation*

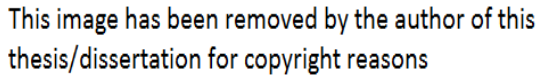


Figure 103. *CS0114 example of good interoperator alignment*

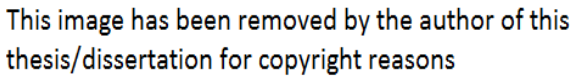


Figure 104. *CS0098 example of poor interoperator alignment*

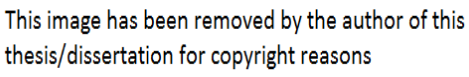


Figure 105. *CS0105 zoomed in example of good intraoperator vertebral segmentation*

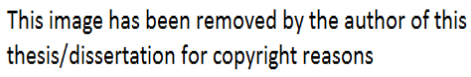


Figure 106. *CS0098 zoomed in example of poor intraoperator vertebral segmentation*

Both the interoperator and intraoperator precision tests involved having the segmentations analysed by the team at City University, in which they calculated the average circumference size of each vertebral body per image in millimetres, and calculated the distance from the mean from all users. This analysis was repeated for the intraoperator data with the difference in participants being replaced by the difference in dates, but ultimately following the same measuring and averaging process.

5.3 ANALYSIS AND RESULTS

5.3.1 THE INTEROPERATOR STUDY

Each vertebral body segmentation made by each participant (AO, CW, JR, MG, and VW) was measured in millimetres, across all ten images. This resulted in each participant having five vertebral measurements per radiograph (C3-C7 equals 5 vertebrae, across 10 images equals a total of 50 sets of data per participant). Each participant's measurement was then compared against the mean value of each individual vertebra (produced by the five participant's measurements); this process was then repeated for all five vertebrae in the image. This produced five new measurement scores (their original measurement minus the mean), the largest of these figures was recorded as it was the maximum amount away from the mean, with the smallest distance recorded as the minimum (see Table 5.1 under Max and Min). These five new measurement scores were then averaged to give a mean score for that image (see Table 5.1 under Mean).

Table 5.1. *Data from the vertebral body segmentation (in millimetres) for the interoperator precision testing.*

In mm	Image No	81	87	88	90	92	94	98	105	114	115
	Mean	0.478	0.491	0.474	0.580	0.566	0.514	0.579	0.604	0.377	0.387
AO	Max	3.015	1.966	2.165	2.382	2.570	4.654	3.482	3.218	1.037	1.424
	Min	0.009	0.011	0.007	0.004	0.019	0.018	0.008	0.010	0.014	0.010
	Mean	0.361	0.363	0.429	0.390	0.534	0.333	0.504	0.498	0.297	0.307
CW	Max	1.970	1.617	2.081	2.240	3.337	1.629	1.804	2.289	1.712	1.538
	Min	0.012	0.017	0.000	0.001	0.013	0.009	0.004	0.004	0.010	0.022
	Mean	0.367	0.393	0.405	0.496	0.553	0.363	0.510	0.510	0.318	0.329
JR	Max	1.548	1.209	2.006	2.753	2.520	1.402	2.867	2.778	1.475	1.768
	Min	0.013	0.033	0.011	0.012	0.009	0.018	0.006	0.005	0.015	0.015
	Mean	0.397	0.366	0.481	0.447	0.676	0.418	0.538	0.549	0.360	0.310
MG	Max	1.603	1.328	2.017	2.167	3.097	1.958	2.343	3.282	1.345	1.058
	Min	0.008	0.011	0.010	0.014	0.008	0.008	0.016	0.009	0.011	0.011
	Mean	0.365	0.429	0.799	0.504	1.055	0.519	0.548	0.917	0.419	0.397
VW	Max	2.313	2.129	4.531	3.972	5.665	3.910	2.645	4.951	1.195	1.430
	Min	0.005	0.009	0.002	0.012	0.014	0.008	0.013	0.015	0.017	0.005

The results in Table 5.1 show that the minimum figure was from participant CW in image 88 who had a minimum difference of 0 mm making it a perfect representation of the mean value. The maximum figure was 4.95 mm by VW in image 105. The highest and lowest mean differences were 0.92 mm and 0.30 mm, with the average of the mean difference across all vertebral bodies calculated to 0.48 mm. Meaning that on average manual vertebral body segmentation was out by 0.48 mm.

As well as this the average vertebral body size via circumference was calculated (Table 5.2).

Table 5.2 *The average vertebral body size circumference calculation across all images*

Average vertebra size in mm										
Image No	81	87	88	90	92	94	98	105	114	115
AO	65.48	80.66	66.46	67.71	79.14	62.60	78.69	78.13	70.04	82.86
CW	67.80	80.49	68.92	71.06	83.39	65.12	81.53	76.95	71.66	82.26
JR	66.79	80.13	68.22	71.45	81.99	65.95	80.62	77.00	71.43	83.19
MG	68.22	81.38	67.85	71.36	82.90	65.91	81.85	76.65	72.48	83.08
VW	65.32	77.46	65.00	69.37	79.88	63.73	77.82	73.77	68.46	80.85
					Average size of vertebral body across all images					74.02

Given as the average vertebral body size circumference is 74.02 mm across all ten images with a range of 62.60 mm -83.39 mm, and that the mean value was out by 0.48 mm that was a percentage inaccuracy of 0.64%. That means on average each segmentation was out by 0.64% when compared to the vertebral body size.

To create a more statistical model each vertebral body segmentation mean value was calculated for a coefficient of variation, this was used to see what variation there was within the segmentation model; with a lower figure suggesting a good fit for the model (0 would imply a perfect fit). This was calculated for both the segmentation mean difference and the vertebral body circumference size (These calculations are shown in Appendix 33).

The coefficient of variation for vertebral body segmentation mean difference was calculated as a root mean square of successive differences (RMSSD) of 0.11 mm, and a root mean square of coefficient of variation (RMSCV) of 23.60%. The coefficient of variance for vertebral body circumference size stated a RMSSD of 1.55 mm and a RMSCV of 2.09%.

The alignment data were treated in a similar way (except the data from images CS0081 and CS0087 was not included; this was due to an error in the processing) this was calculated as a RMSSD score of 0.12 mm and a RMSCV% of 24.85%.

5.3.2 THE INTRAOPERATOR STUDY

First the same ten images from the interoperator study were used, these ten were segmented and saved, this process was repeated again on a different date and repeated again and again until all ten images had all been segmented ten times. This meant there were measurements from five vertebral bodies within ten repeated images within ten image numbers, for clarity this means there are 500 vertebral body measurements to compare. These data were analysed exactly the same way as the interoperator data but instead of having five participants there were ten repeats (on different dates), so rather than AO, MG, VW, JR, CW you had 1, 2, 3, 4, 5, 6, 7, 8, 9, 10. This is shown in Table 5.3.

Table 5.3 *The data from the vertebral body segmentation in the intraoperator precision testing*

In mm	Image No	81	87	88	90	92	94	98	105	114	115
	Mean	0.242	0.262	0.246	0.318	0.419	0.290	0.349	0.287	0.215	0.256
1	Max	1.454	3.182	1.383	1.654	1.327	1.557	2.598	1.729	1.117	0.908
	Min	0.005	0.006	0.005	0.003	0.009	0.000	0.023	0.007	0.003	0.022
	Mean	0.234	0.272	0.220	0.282	0.395	0.269	0.332	0.289	0.208	0.295
2	Max	1.148	1.705	0.972	1.044	3.120	0.896	1.576	1.215	1.100	2.572
	Min	0.002	0.007	0.013	0.011	0.004	0.010	0.005	0.007	0.005	0.002
	Mean	0.182	0.284	0.215	0.301	0.404	0.234	0.395	0.259	0.243	0.276
3	Max	0.750	1.841	1.435	2.032	2.310	0.973	3.688	1.258	1.329	1.592
	Min	0.005	0.013	0.009	0.005	0.008	0.008	0.004	0.006	0.006	0.008
	Mean	0.232	0.248	0.264	0.284	0.550	0.266	0.502	0.276	0.237	0.361
4	Max	0.877	1.528	1.285	1.754	6.492	1.076	2.684	1.443	0.958	2.426
	Min	0.008	0.003	0.007	0.010	0.015	0.012	0.016	0.007	0.003	0.016
	Mean	0.253	0.287	0.230	0.289	0.406	0.307	0.354	0.297	0.229	0.310
5	Max	2.004	1.127	0.880	0.951	1.705	3.640	1.478	1.366	1.137	1.876
	Min	0.013	0.007	0.005	0.003	0.006	0.007	0.008	0.006	0.008	0.011
	Mean	0.234	0.328	0.235	0.260	0.454	0.247	0.355	0.267	0.241	0.299
6	Max	1.415	1.880	0.869	1.257	1.563	0.816	2.585	1.016	0.947	1.873
	Min	0.005	0.009	0.009	0.004	0.005	0.011	0.004	0.003	0.010	0.012
	Mean	0.267	0.313	0.222	0.281	0.428	0.235	0.384	0.350	0.189	0.289
7	Max	2.045	1.237	1.281	1.134	2.422	0.794	1.882	2.328	0.935	1.852
	Min	0.010	0.005	0.010	0.004	0.013	0.001	0.012	0.013	0.009	0.011
	Mean	0.285	0.263	0.225	0.296	0.432	0.326	0.508	0.397	0.266	0.317
8	Max	2.043	1.742	1.056	1.054	3.153	2.414	3.950	2.032	2.205	4.747
	Min	0.008	0.009	0.014	0.006	0.004	0.010	0.008	0.016	0.004	0.002
	Mean	0.258	0.252	0.194	0.293	0.379	0.303	0.417	0.311	0.239	0.262
9	Max	1.911	1.034	0.950	1.695	1.748	1.898	2.794	1.544	1.149	2.748
	Min	0.002	0.013	0.008	0.007	0.017	0.011	0.007	0.009	0.010	0.011
	Mean	0.235	0.427	0.245	0.305	0.388	0.272	0.346	0.297	0.203	0.302
10	Max	1.545	3.580	1.443	1.593	1.346	1.321	2.987	1.134	0.894	1.287
	Min	0.008	0.007	0.002	0.008	0.019	0.010	0.002	0.012	0.008	0.015

As stated the numbers 1 to 10 in the first column represent dates when the segmentations were performed, this gap between segmentations was to reduced memory bias. They were performed on:

1. 29th October 2014
2. 1st December 2014
3. 12th January 2015
4. 27th January 2015
5. 10th February 2015
6. 26th February 2015
7. 12th March 2015
8. 7th April 2015
9. 14th April 2015
10. 19th May 2015

The results in Table 5.3 show that the minimum figure was in number 1, in image 94 which had a minimum difference of 0 mm making it a perfect representation of the mean value. The maximum figure was 6.49 mm in number 4 for image number 92. The highest and lowest mean differences were 0.55 mm and 0.18 mm, with the average of the mean difference across all vertebral

bodies calculated to 0.30 mm (Table 5.4). Meaning that on average manual vertebral body segmentation was out by 0.30 mm (rounded up from 0.297758 mm)

Table 5.4 *Average of all mean values across all images showing the difference in vertebral segmentation*

In mm	Image No	81	87	88	90	92	94	98	105	114	115
1	Mean	0.242	0.262	0.246	0.318	0.419	0.290	0.349	0.287	0.215	0.256
2	Mean	0.234	0.272	0.220	0.282	0.395	0.269	0.332	0.289	0.208	0.295
3	Mean	0.182	0.284	0.215	0.301	0.404	0.234	0.395	0.259	0.243	0.276
4	Mean	0.232	0.248	0.264	0.284	0.550	0.266	0.502	0.276	0.237	0.361
5	Mean	0.253	0.287	0.230	0.289	0.406	0.307	0.354	0.297	0.229	0.310
6	Mean	0.234	0.328	0.235	0.260	0.454	0.247	0.355	0.267	0.241	0.299
7	Mean	0.267	0.313	0.222	0.281	0.428	0.235	0.384	0.350	0.189	0.289
8	Mean	0.285	0.263	0.225	0.296	0.432	0.326	0.508	0.397	0.266	0.317
9	Mean	0.258	0.252	0.194	0.293	0.379	0.303	0.417	0.311	0.239	0.262
10	Mean	0.235	0.427	0.245	0.305	0.388	0.272	0.346	0.297	0.203	0.302

Just like with the interoperator data; the average vertebral body size was calculated (Table 5.5).

Table 5.5 *Average vertebral body size circumference calculation across all images*

Average size mm										
Image No	81	87	88	90	92	94	98	105	114	115
1	69.29	82.22	69.30	72.96	83.08	66.96	82.05	76.83	72.45	84.77
2	69.09	81.97	68.55	72.90	83.83	65.55	80.84	78.15	71.80	84.44
3	67.98	82.53	68.95	73.36	83.33	67.09	82.35	77.37	73.20	84.62
4	67.96	82.06	68.74	73.01	84.75	65.92	81.10	77.39	71.79	84.26
5	68.85	82.82	69.00	72.86	85.54	66.36	81.07	77.36	72.16	83.89
6	68.12	83.32	69.32	72.60	86.27	66.41	81.18	76.89	72.71	84.06
7	67.65	82.47	68.85	72.71	85.13	66.61	81.33	78.05	72.39	83.00
8	67.21	81.67	68.74	72.52	84.46	65.42	80.75	76.97	71.61	83.83
9	68.27	82.71	68.78	72.95	84.17	66.86	82.32	77.54	72.15	84.11
10	68.22	81.38	67.85	71.36	82.90	65.91	81.85	76.65	72.48	83.08

Given as the average vertebral body circumference size is 75.79 mm across all ten images with a range of 65.41 mm – 86.27 mm and the mean value was out by 0.30 mm that was a percentage inaccuracy of 0.39%. That means on average each segmentation was out by 0.39% when compared to the vertebral body size.

As with the interoperator data each vertebral body segmentation mean value was calculated for a coefficient of variance. This was calculated for both the segmentation mean difference, and the vertebral body size (See Appendix 34 for calculations). Coefficient of variance calculation for the segmentation mean

difference stated a RMSSD of 0.039 mm and a RMSCV% of 12.96%. Coefficient of variation calculation for the average vertebral body size circumference stated a RMSSD of 0.63 mm and a RMSCV% of 0.83%. A summary of all the precision errors is shown in Table 5.6.

Table 5.6 *Intraoperator and interoperator precision errors*

Interoperator precision errors	**RMSCV%**	**RMSSD (mm)**
Vertebral segmentation	23.60	0.11
Vertebral body size	2.09	1.55
Alignment curve	24.85	0.12
Intraoperator precision errors	**RMSCV%**	**RMSSD (mm)**
Vertebral segmentation	12.96	0.039
Vertebral body size	0.83	0.63

5.4 DISCUSSION AND LIMITATIONS

The interoperator study yielded RMSSDs of 0.11 mm (vertebral body segmentation), 1.55 mm (vertebral body circumference size) and 0.12 mm (alignment), with a RMSCV% of 23.60% (vertebral body segmentation), 2.09% (vertebral body circumference size) and 24.85% (alignment). The precision data demonstrates extremely small amounts, fractions of a millimetre, with the highest figure being 1.55 mm; this is because that data set deals with larger figures i.e. the average vertebral body circumference is approximately 74 mm, so although these data seem inconsistent it is in line with the measurements used. A similar issue is seen in the percentages, for example 23.60% is a high percentage and as such might lead to being concluded as imprecise, but this is represented as 0.11 mm which is an extremely small figure showing good precision. Thus it is important to know the percentage and the size of the measurement. This type of result is seen in the intraoperator data as well: RMSCV of 12.96% is represented as an RMSSD score of 0.039 mm (vertebral body segmentation) and a RMSCV of 0.83% is represented as 0.63 mm (vertebral body circumference size). Low RMSSD and low RMSCV indicates a high degree of agreement between participants, with Intraoperator being slightly more precise than interoperator. Which is in line with the expectations from the literature [128], this suggests that using manually segmented images is an appropriate source of data for the CSPINE-CAD to learn from.

5.4.1 LIMITATIONS

There are several limitations to the study; firstly the amount of participants was low, with only five recruited, additionally these participants had all the same level of training from the same university, so interoperator figures might be reflecting the best possible result compared to individuals from a collection of different academic institutions. Furthermore four of the five were third year radiography students and not fully qualified radiographers; as such although they had had training there lack of experience might have influenced the results. Additionally the amount of images used, and the quality of the images was a limitation. With a greater number of images and with more diverse range of issues (e.g. degenerative change, normal variants) it could yield a truer representation of the measurements and intraoperator and interoperator results.

5.5 CONCLUSION

Vertebral segmentation in radiographs is of great importance for the assessment of vertebral abnormalities especially when being incorporated into CSPINE-CAD software.

The use of manual segmentation methods in order to teach the CSPINE-CAD algorithm relies on subjective judgement and introduces interoperator variability that limits its performance and accuracy. This inaccuracy is very small and will only affect the CSPINE-CAD software in a minimal way (nearly half a millimetre); although caution should still be used as there were large differences between some segmented vertebral bodies. Due to this a robust CSPINE-CAD automatic algorithm for segmenting vertebrae will be invaluable to help in the assessment of vertebral abnormalities and its continuing learning and input should help achieve this robustness.

<u>Future work</u>

Investigations into overcoming the issues of segmentation with poor quality radiographs are needed to reduce the chances of poorly learned segmentation. Due to such a small amount of data additional research into extending the testing with qualified radiographers both with the interoperator testing and the intraoperator, to see if the differences are as consistent or if the small differences might be reduced further with fully qualified individuals.

CHAPTER 6. RESULTS – FIRST AND SECOND TEST DATA REGARDING CSPINE-CAD'S ABILITY TO IMPROVE LATERAL C-SPINE RADIOGRAPH DIAGNOSES

6.1 INTRODUCTION AND AIMS

This chapter presents the results relating to the first and second tests of the CSPINE-CAD software on third year radiography students. The chapter aims to evaluate differences between a C-spine lateral radiograph diagnosis made without, and with CSPINE-CAD software.

6.2 OBJECTIVES

- To compare the" benefit of the doubt" data sensitivity and specificity scores of without and with CSPINE-CAD software
- To compare the "exact report" data for sensitivity and specificity
- To assess confidence levels from participants both when not using and using CSPINE-CAD software to make a diagnosis
- To assess data from the questionnaire to investigate what features the participants wanted to see in CSPINE-CAD software
- To assess the questionnaire to see what participants wanted the CAD software to be applied to next

6.3 BRIEF METHODS AND STATISTICS

The methods are described in detail in Chapter 3, section 3.3.3 and 3.3.4, analysis methods for first and second testing are described in Chapter 3, section 3.4.1 and 3.4.2.

6.4. RESULTS

6.4.1 RESULTS FOR FIRST TEST

The data from the first and second tests were analysed and calculated creating an overall sensitivity and specificity score of before and after the use of CSPINE-CAD. These data were first compared using the "benefit of the doubt" analysis as described in Chapter 3, section 3.4.1. The result of the first test is shown in Table 6.1 and Figure 107.

Table 6.1 *Statistical analysis of the first test before and after CSPINE-CAD "benefit of the doubt" data (Key Confidence Intervals (CI)*

	Before CAD	After CAD
TP	18	19
TP+FN	18+7	19+6
TN	309	305
TN + FP	309+16	305+20
Sensitivity	72% (95% CI: 50.61% to 87.88%)	76% (95% CI: 54.87% to 90.58%)
Specificity	95.08% (95% CI: 92.13% to 97.16%)	93.85% (95% CI: 90.65% to 96.20%)

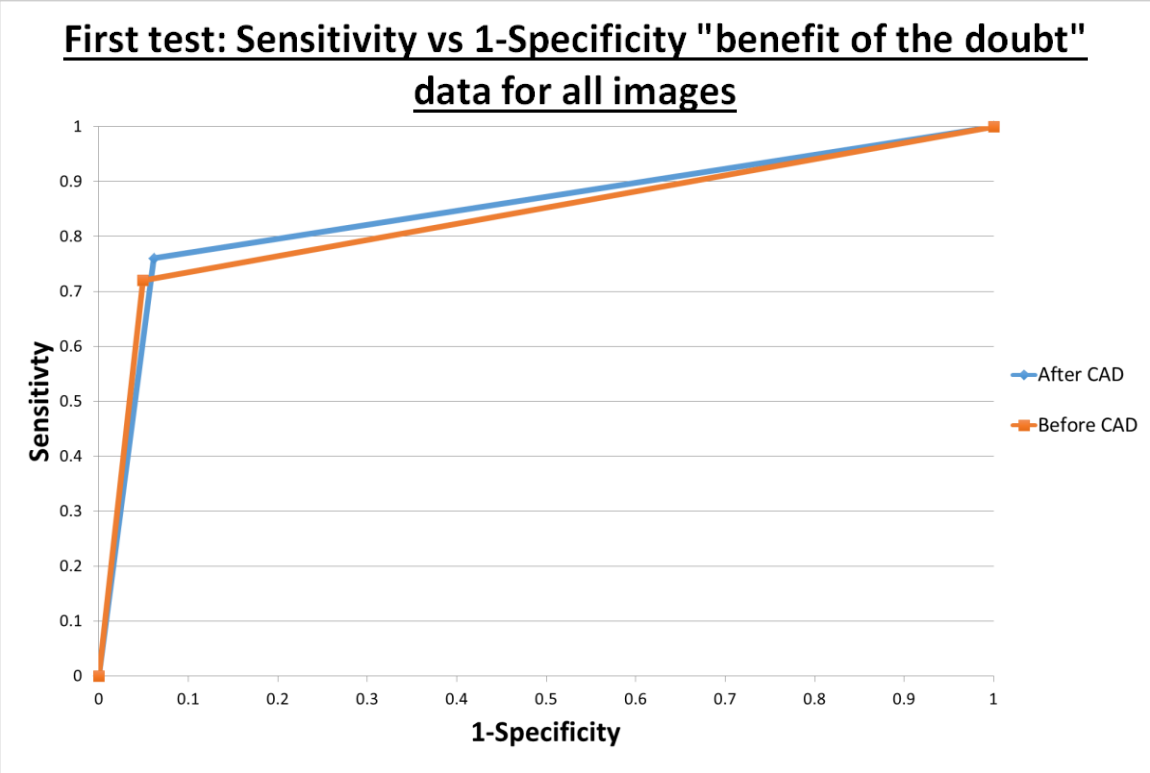


Figure 107. *Sensitivity vs 1-specificity of the "benefit of the doubt" first test before and after CSPINE-CAD across all radiographs*

Table 6.2 *First test before CSPINE-CAD area under a curve calculation*

Before CAD		
1-Specificity	**Sensitivity**	**AUC**
0	0	0.0177
0.0492	0.72	0.8177
1	1	
	Total AUC	**0.8354**

Table 6.3 *First test after CSPINE-CAD area under a curve calculation*

After CAD		
1-Specificity	**Sensitivity**	**AUC**
0	0	0.0234
0.0615	0.76	0.8259
1	1	
	Total AUC	**0.8493**

The results between before and after CAD (Table 6.1, Table 6.2 and Table 6.3) show an increase in sensitivity of 4% and a decrease in specificity of 1.23% when using CSPINE-CAD. Overall the AUC has increased by 1.39%. Although not a large increase, given as this software was tested on such a low number i.e. five participants plus the issue of the "benefit of the doubt" it does show an increase in sensitivity and a decrease in specificity with CSPINE-CAD although the CI shows no statistical significance.

6.4.2 RESULTS FOR THE SECOND TEST

The data in Tables 6.4 and Figure 108 shows the results of the second test of 11 participants across 20 radiographs using the screen shots from the CSPINE-CAD software, compared for sensitivity and specificity of before and after the use of CSPINE-CAD using the "benefit of doubt" analysis.

Table 6.4. *Statistical analysis of the second test before and after CSPINE-CAD "benefit of the doubt" data*

	Before CAD	**After CAD**
TP	83	82
TP+FN	83+91	82+91
TN	2868	2863
TN + FP	2868+38	2863+44
Sensitivity	47.70% (95% CI: 40.09% to 55.39%)	47.40% (95% CI: 39.77% to 55.12%)
Specificity	98.69% (95% CI: 98.21% to 99.07%)	98.49% (95% CI: 97.97% to 98.90%)

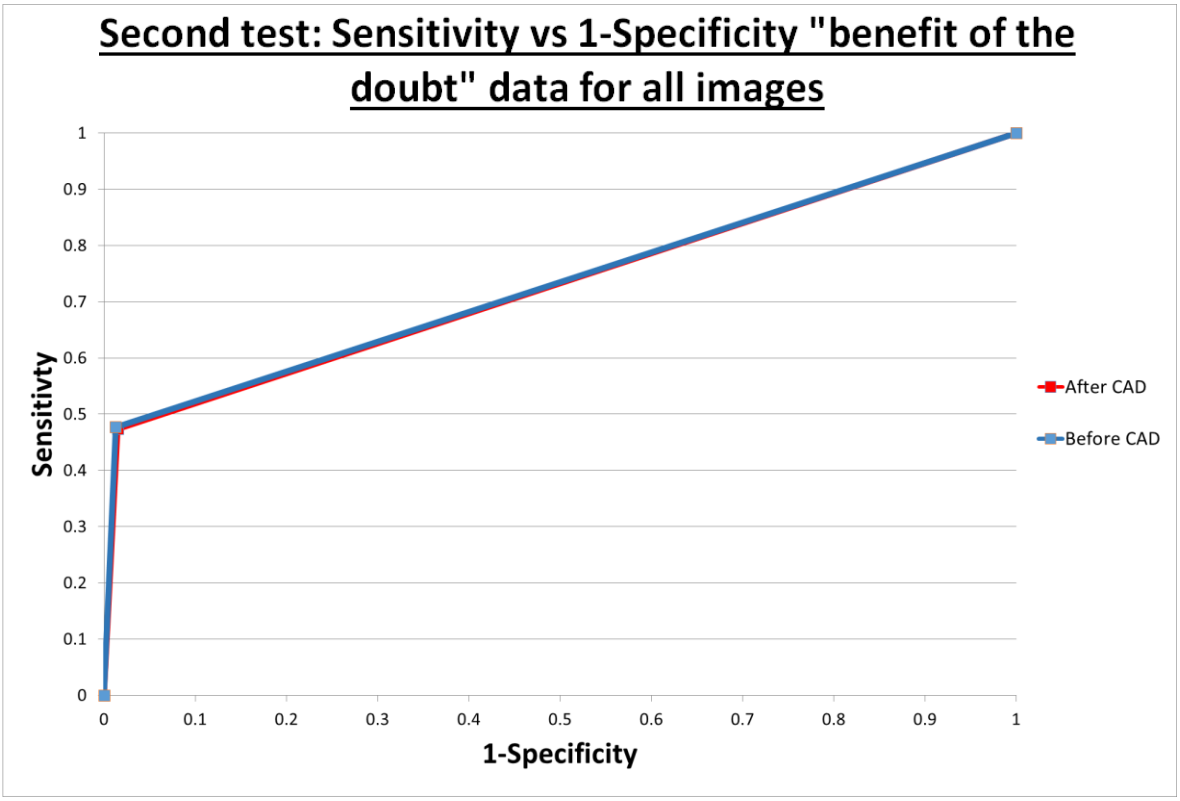


Figure 108. *Sensitivity vs 1-specificity of the second test before and after CSPINE-CAD across all radiographs*

Table 6.5. *Second test before CSPINE-CAD area under a curve calculation*

Before CAD		
1-Specificity	**Sensitivity**	**AUC**
0	0	0.0031
0.0131	0.477	0.7288
1	1	
	Total AUC	**0.7320**

Table 6.6. *Second test after CSPINE-CAD area under a curve calculation*

After CAD		
1-Specificity	**Sensitivity**	**AUC**
0	0	0.0036
0.0151	0.474	0.7259
1	1	
	Total AUC	**0.7295**

Looking at the results between before and after CAD (Table 6.5 and Table 6.6) of the second test, the CSPINE-CAD is shown to have a negative effect on the diagnosis decreasing by 0.3% in sensitivity, and decreasing by 0.20% in specificity, with the AUC difference 0.25% in favour of before CAD, although this is not statistically significant due to the CI.

6.4.3 RESULTS OF THE EXACT REPORT

These data were analysed without the interpretation of the participants' diagnosis, and only data matching the exact report was included; this process of analysis is described in Chapter 3, section 3.4.3. The before and after the use of CSPINE-CAD results are shown in Tables 6.7, 6.8, 6.9 and Figure 109 for the first test data, and Tables 6.10, 6.11, 6.12 and Figure 110 for the second test data.

Table 6.7. *First test of the exact reported data test*

	Before CAD	After CAD
TP	6	12
TP+FN	6+19	12+15
TN	149	145
TN + FP	149+1	145+3
Sensitivity	24% (95% CI: 9.42% to 45.13%)	44.44% (95% CI: 25.50% to 64.66%)
Specificity	99.33% (95% CI: 96.33% to 99.89%)	97.97% (95% CI: 94.18% to 99.56%)

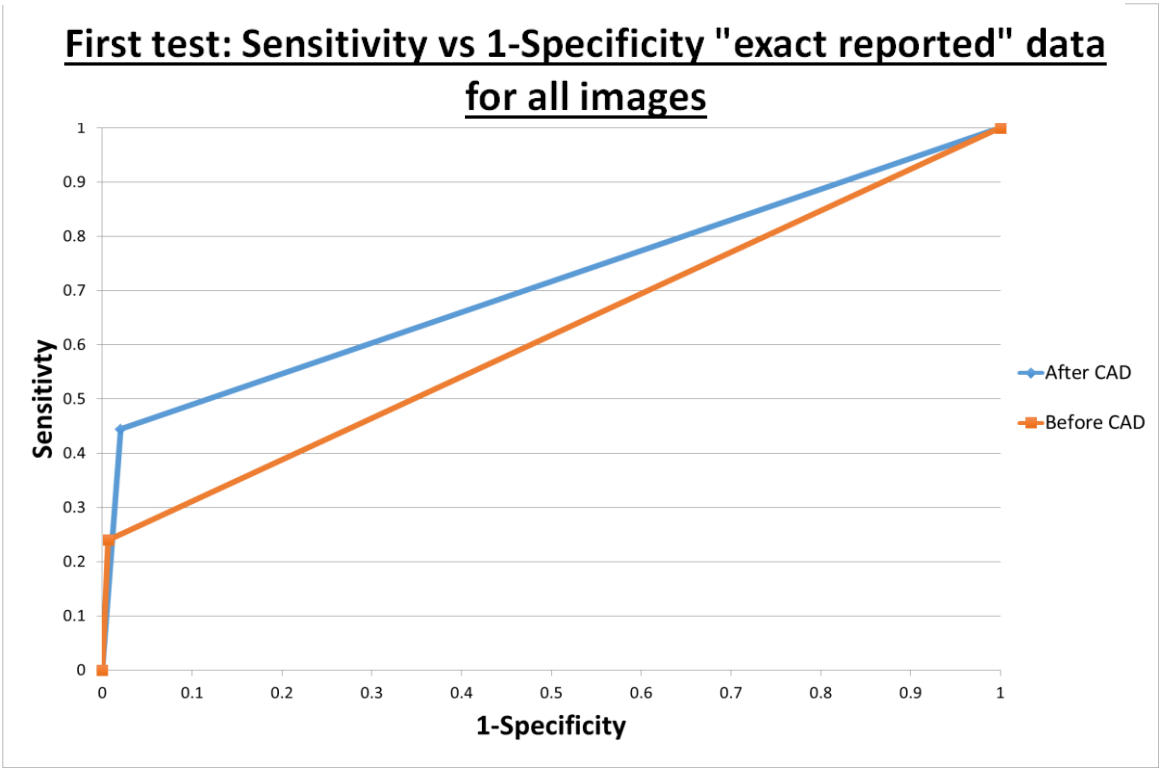


Figure 109. *First test; sensitivity vs 1-specificity for just the data matching the exact reported data*

Table 6.8 *First test data before CSPINE-CAD area under a curve data matching the exact report*

Before CAD		
1-Specificity	**Sensitivity**	**AUC**
0	0	0.0008
0.0067	0.24	0.6158
1	1	
	Total AUC	**0.6167**

Table 6.9 *First test data after CSPINE-CAD area under a curve data matching the exact report*

After CAD		
1-Specificity	**Sensitivity**	**AUC**
0	0	0.0045
0.0203	0.4444	0.7075
1	1	
	Total AUC	**0.7121**

Table 6.10. *Second test data that matches the exact reported data*

	Before CAD	**After CAD**
TP	20	24
TP+FN	20+101	24+97
TN	1415	1414
TN + FP	1415+4	1414+5
Sensitivity	16.53% (95% CI: 10.40% to 24.37%)	19.83% (95% CI: 13.14% to 28.06%)
Specificity	99.72% (95% CI: 99.28% to 99.92%)	99.65% (95% CI: 99.18% to 99.88%)

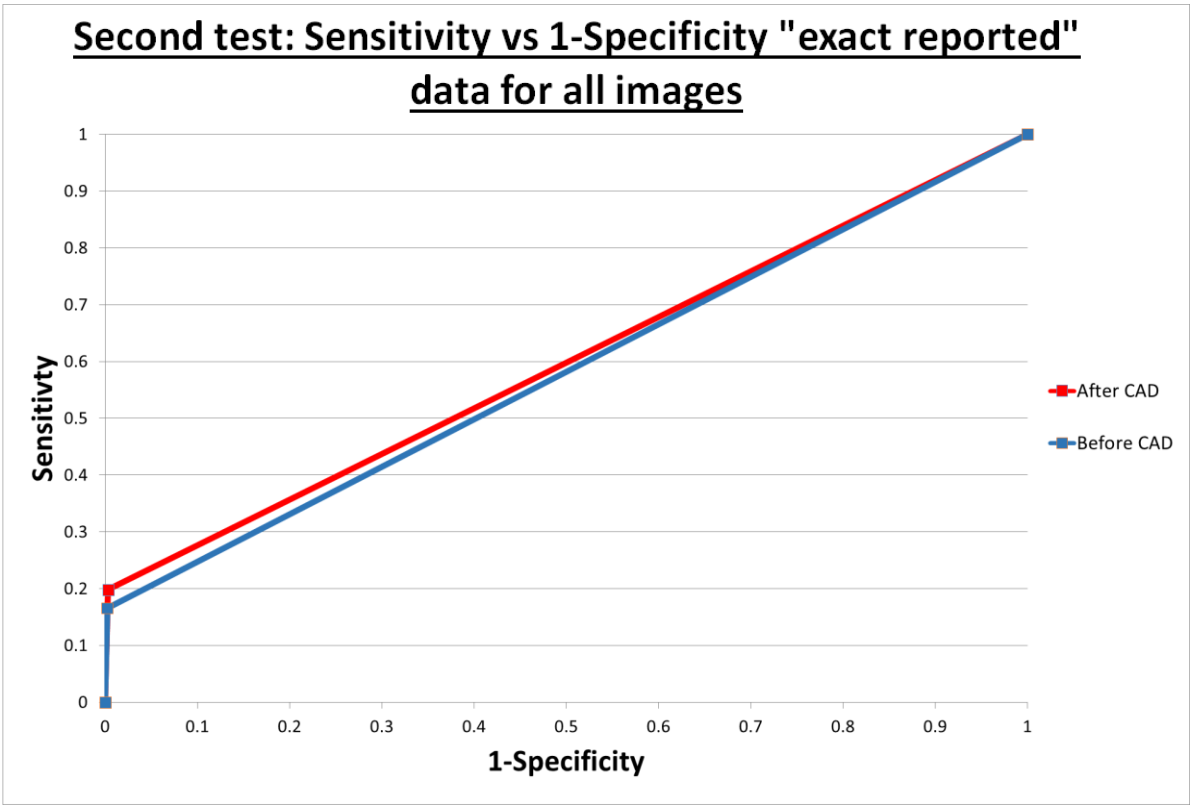


Figure 110. *Second test; sensitivity vs 1-specificity for just the data matching the exact reported data*

Table 6.11 *Second test data before CSPINE-CAD area under a curve data matching the exact report*

Before CAD		
1-Specificity	**Sensitivity**	**AUC**
0	0	0.0002
0.0028	0.1653	0.5810
1	1	
	Total AUC	**0.5813**

Table 6.12 *Second test data after CSPINE-CAD area under a curve data matching the exact report*

After CAD		
1-Specificity	**Sensitivity**	**AUC**
0	0	0.0003
0.0035	0.1983	0.5971
1	1	
	Total AUC	**0.5974**

The results from the first test (exact reported data) (Table 6.7 and Figure 109), shows an increase in sensitivity of 20.44% and a decrease in specificity of 1.36% when using the CSPINE-CAD software, the AUC (Table 6.8 and Table 6.9) shows an increase of 9.54%. However there is a large overlap with the CI demonstrating non-significant results.

The results from the second test (exact reported data) (Table 6.10 and Figure 110) shows an increase in sensitivity of 3.3% and a decrease in specificity of 0.07%. The AUC calculation (Table 6.11 and Table 6.12) shows an increase of 1.61%, however again with large uncertainties due to the CI in the data.

6.4.4 RESULTS OF QUESTIONNAIRES

The data from the first and second test questionnaires were collated and showed very promising results.

Confidence levels without and with the use of CSPINE-CAD

All participants across both tests found that having the CSPINE-CAD software as an additional pair of eyes was helpful. The first test showed a confidence score when using the assistance of CSPINE-CAD increased in 60% of cases, with the rest having no loss of confidence, with an average confidence increase of 12% (0.6) per person (this was on a scale of 1-5, with an average of 3.8 before CAD and an average score of 4.4 after CAD). The confidence correlated with either the same amount of true positives or an increase, although the use of the CSPINE-CAD can lead to an increase in false positives due to overcalling, which may be related to overconfidence and thus higher confidence scores.

The second test showed similar results, the confidence score when using the assistance of CSPINE-CAD increased in 72.72% of participants and stayed the same in 27.27%. This increased confidence by an average of 20% (an average confidence score of 3 out of 5 before CAD to 4 out of 5 after CAD). Looking at confidence scores from the second test compared to the CSPINE-CAD diagnostic accuracy results, most participants were at the same level neither improving their diagnosis accuracy nor reducing it.

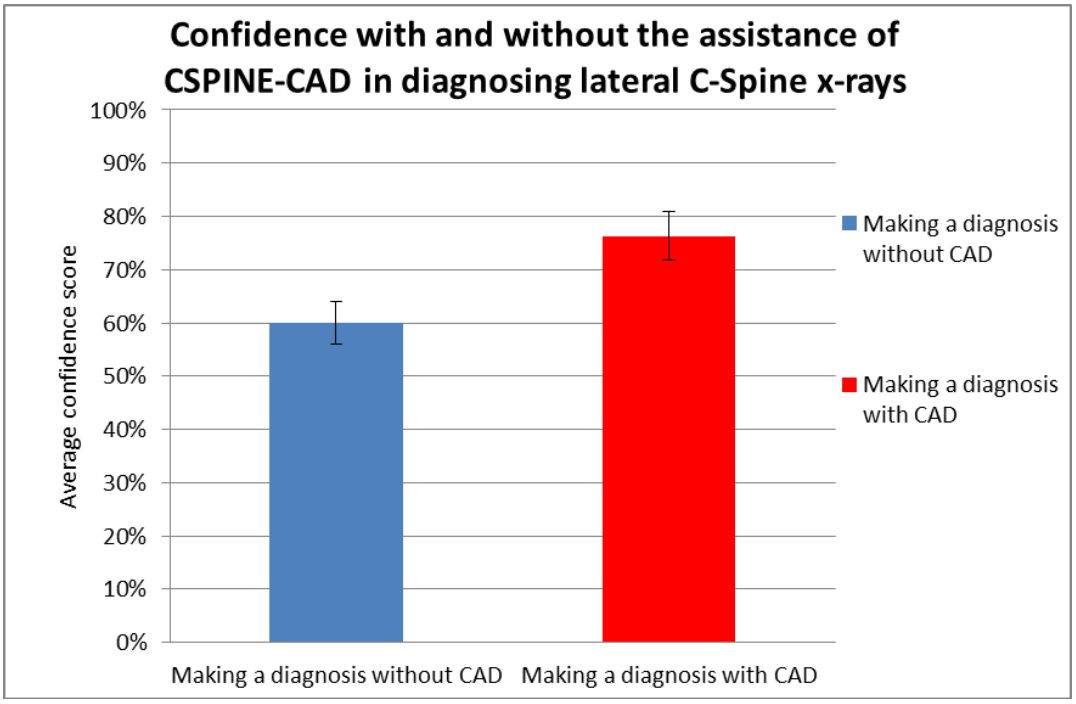


Figure 111. *Percentage changes in for confidence scores during making a diagnosis with CSPINE-CAD, compared without the CSPINE-CAD (combination of all 16 participants from the first and second test, error bars on the graph represent the standard error).*

When combining the first and second the confidence scores it showed an increase in 68.75% of participants, with the rest having no loss in confidence. Increasing confidence on average by 16.2% (an average of 3 before CAD, to an average of 3.81 after CAD) as shown in Figure 111.

Opinions on the CSPINE-CAD software

Additional question asked by the questionnaire was "*Are there any other additions or features you would like to see in the CSPINE-CAD software?*" This was an open question allowing the participant to provide multiple answers.

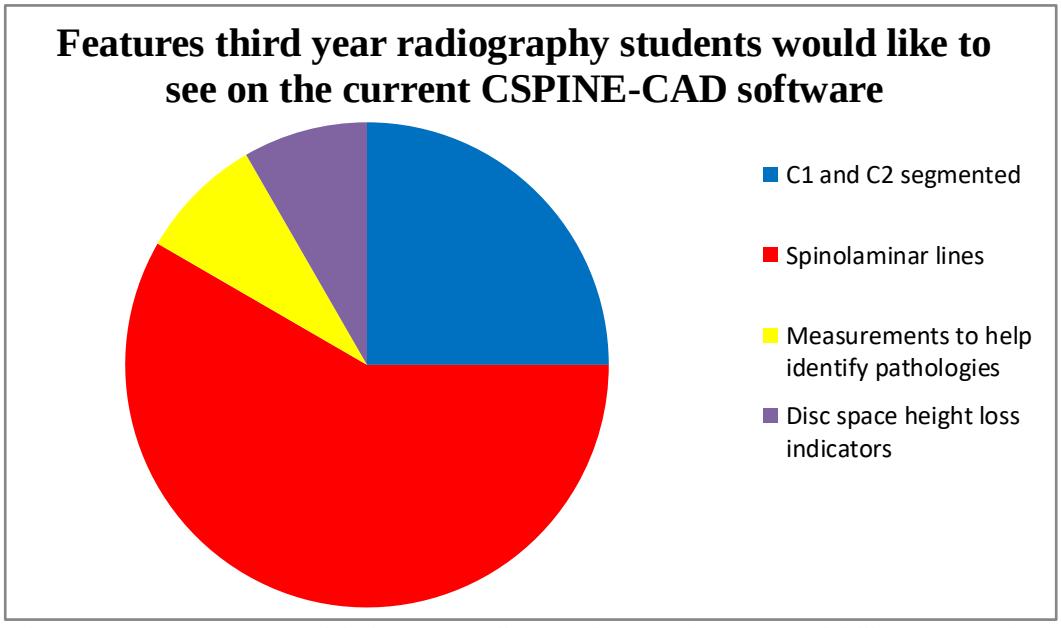


Figure 112. *Features third year radiography students would like to see in the current CSPINE-CAD software*

These data show in Figure 112 the difference in features requested, with the majority (58%) of third year radiography students wanting the addition of the spinolaminar lines as an added feature to the software. Additionally 27% wanted the segmentation of C1 and C2.

The questionnaire also asked: "*If you did find this useful what other types of examination/body part would you like to see this sort of CAD software be applied to?"*

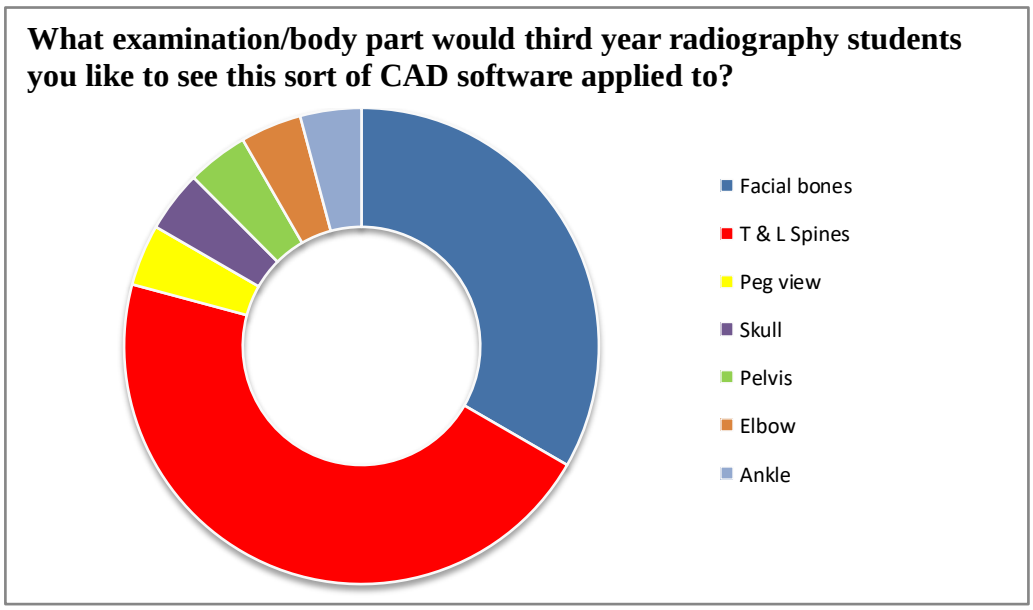


Figure 113. *Combined questionnaire data from the first and second test regarding what body parts/examinations participants wanted the CAD software applied to next*

The data from this question is a reflection upon what the participants wanted to see the CAD software be applied to next, for third year radiography students (Figure 113) 45.83% wanted to see the CAD software applied to the Thoracic and Lumbar Spines, with the second idea (33.33%) wanting to see the software applied to facial bone radiographs.

Time differences

Participants were also timed during the testing. In the first test each participant spent on average 11.4 minutes during the talk through, 13.4 minutes evaluating all five radiographs, and filled in the questionnaire in an average of 3.6 minutes. Due to the differences in the second test set up, only the total time was recorded. This second test took on average 41.8 minutes to complete.

6.5 DISCUSSION

Sensitivity and specificity scores

The preliminary study demonstrated no significant benefit when using CAD but showed some promising results that it might be useful in the future.

The main issue with the sensitivity and specificity scores of the first and second tests were that the two sets of data produced are still not a true representation of what the participants communicated (as stated in section 3.4.1). Although it must be acknowledged that the results of both interpretations across both tests were very similar; showing a trend in the increase of sensitivity, and decrease in specificity after using CSPINE-CAD compared to beforehand. The exception to this is one result out of the four, in the "benefit of the doubt" data from the second test, in which the after CAD sensitivity score decreased by 0.3% (an AUC loss of 0.25% after CAD). When comparing the same data but using the "exact report" analysis rather than the "benefit of the doubt" the sensitivity increases to 3.3% after using CAD agreeing with the tests. It must be stated that all sensitivity and specificity scores produced lack statistical significance as all the figures had overlapping CI, this may be the reason for the 0.3% score in favour of without CAD, likewise this might be the right result, and the other three results might be incorrect..

Additionally other factors might have influenced the results, such as the fact that the second test was conducted on screen grabs of the CSPINE-CAD software and not an applied version, making it less reliable as it was not a true depiction of the CSPINE-CAD software but a representation. This was further exacerbated due to other draw backs of using a screen grabbed version of the software. Simple things such as: the process of applying the software meant consciously numbering the vertebral bodies, turning the software on and off allowing an easier comparison, and the ability to change the contrast. This contrast issue was stated by one of the participants in the questionnaire:

> "*As we could not window our images it can make looking at them on these monitors difficult sometimes*"

This also meant this test had less applicability to the real world, although it was justifed due to time constraits, and the need to assess a larger number of

participants in one sitting. This may have also led to simple errors in defining the correct vertebral body as stated: consciously numbering the vertebral bodies meant less chance of miscounting them, i.e. the screen grabbed image might have indicated C4 and the participant miscounted the vertebrae and classified it as C5, this would result in a drop of sensitivity for the software and an increase in specificity due to the false positive. In the first test with the real CSPINE-CAD software this was less of an issue as the participants had to individually click the vertebral bodies so were more conscious of stating the correct vertebra.

Questionnaire data

The data from the first and second tests show the importance in confidence, especially in an environment where C-spine injuries are life threatening and being confident in your own judgment in order to comment on a diagnosis is especially important, even one that might be incorrect, as it might make the reporting radiographer or consultant look again. The hope is this software could aid this, even adding confidence to a non-injury diagnosis by not indicating an injury. Although we must be wary of overconfidence in the software resulting in participants possibly stating injuries where there are none, increasing the overcalling rate. However with 68.75% having an increase in confidence when using the CSPINE-CAD software, and that confidence level increasing by an average of 16.2% in each participant, it has shown to have a large benefit when making a C-spine diagnosis. One participant even said:

> "*Having the software was useful as it agreed with my original diagnosis and that gave me more confidence that I was right*"

Implications

The implication of using CSPINE-CAD software is the possible reduction in percentage of missed and misdiagnosed C-spine injuries, although the down side is an increase overcalling of injuries when there are none. With further testing with more competent participants this overcalling could be lowered due to the operator having a more experienced final say over the diagnosis. Due to positive increase in confidence scores the implication is that CSPINE-CAD software could be integrated as an extra safety net, and allow newly qualified radiographers (which the third year radiography students will be shortly) the chance to make a diagnosis that is supported via software.

6.5.1 LIMITATIONS

Participants

The first and second studies involved a total of 16 participants (five in the first, and 11 in the second) all trained at the UOE. Although trained to a high standard, and a known ability, the results are less generalisable; this is due to the small study size and participants not representing the true population that would utilise the CSPINE-CAD software in the real world. It must also be acknowledged that all the participants were volunteers and as such may have already been confident in the C-spine interpretation thus reducing the effects of the CSPINE-CAD software, as less confident groups may decline to participant, even though they would be the ones to benefit most. With a more accurate and larger representation sample group more distinct data could have been produced from these two tests, and thus been a more generalisable result.

Images chosen

The radiographs used in both tests were handpicked as the ones showing the most promise in having their injury highlighted by the CSPINE-CAD software. With all 183 radiographs being tested against the software beforehand, this showed bias in the image selection but was justified due to the pool of radiographs being extremely small. Out of 183 radiographs only 26 had injuries with three of those (8.67%) being used in the first test and 13 (50%) used in the second test. It must also be acknowledged that of those 26 radiographs 11 (42.31%) had injuries that would never be highlighted by the CSPINE-CAD software, due to its previously stated limitations regarding C1 and C2 fractures and misalignments, and one injury being a foreign body. That meant only 15 radiographs out of the 183 contained injuries that could possibly be highlighted by the CSPINE-CAD software, thus the bias was rationalised due to a lack of choice. This lack of images was also reason the second test contained radiographs that would not be picked up by CSPINE-CAD software, incidentally this created more variety in the images and reduced participants developing a learned behaviour in which upon seeing a lateral C-spine image would only concentrate on the vertebral bodies and misalignments. Additionally the radiographs containing injuries that were used still suffered from several other issues such as: parallax distortion, degenerative changes, and poor or incomplete lateral C-spines. These issues may have influenced both the

software's ability in segmenting the same C-spine radiograph consistently for all participants, and the participants' ability to discern or conclude an injury correctly. Although this reflects a more likely image in a real setting and also adds to the CSPINE-CAD ability to be more robust.

Environment

The first test was conducted in an office with dual monitors, and had the visual and tactile feel of a reporting office, making the atmosphere more realistic. The second test was done in a lecture computer room in an examination style. Again this limitation might reflect upon the sensitivity and specificity scores as the third year radiography students had most likely been taught in that lecture computer room, and as such might have entered a context-dependant state (a learned mind-set due to previous experience) so may have been less engaged in the study. Additionally the set up looked like an examination (43 computers all loaded with the same PDF, answer sheets and questionnaires at each station) which might have influenced their thinking. So the second test set up was not a fair representation of the true environment, but was justified due to needing a substantial area to do the larger scale testing all at once (due to the time and participant restraints already stated). Although it must be said some environmental factors were controlled as best as possible: all blinds were closed, temperature was optimum, and ambient intermittent noise kept as low as possible.

Language

One of the biggest limitations faced in interpreting and analysing the data was the ambiguity in the language used in the answer sheets. The extent of this ambiguity came in many variations: as previously stated this was one of the reasons behind the "benefit of doubt" data analysis section 3.4.1

For example Figure 114 shows the statement "*injury possible to C5*" this could be interpreted as a fracture, dislocation, or subluxation to C5. Due to this, this type of ambiguous diagnosis was not included in the data as it could not be concluded as either right or wrong.

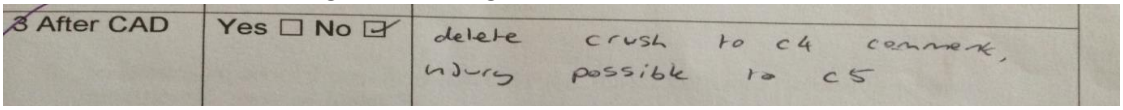


Figure 114. *Answer after CAD shows the ambiguity of language*

Some answers were vague in their language and unspecified so could not be included, for example Figure 115 reads "*alignment looks out*" but does not address the location of the malalignment

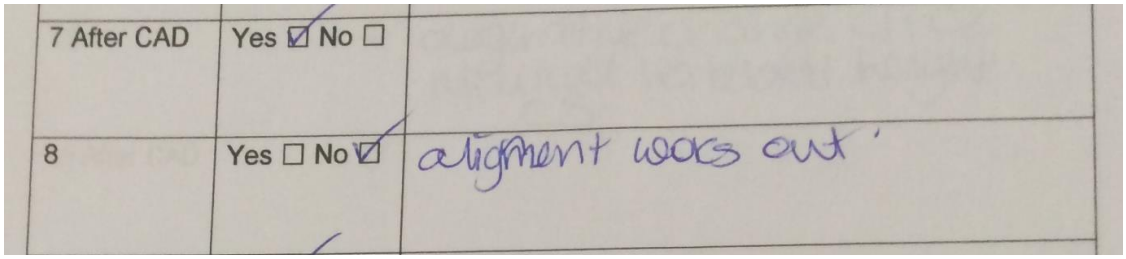


Figure 115*. "alignment looks out" Unspecified area, so data could not be included*

There were also issues and errors in answering the questions correctly, beyond the ambiguity of language, for example Figure 116 shows that some participants from the first test and second test had not fully understood the instructions as they left four of the "Normal? Yes No" questions unticked.

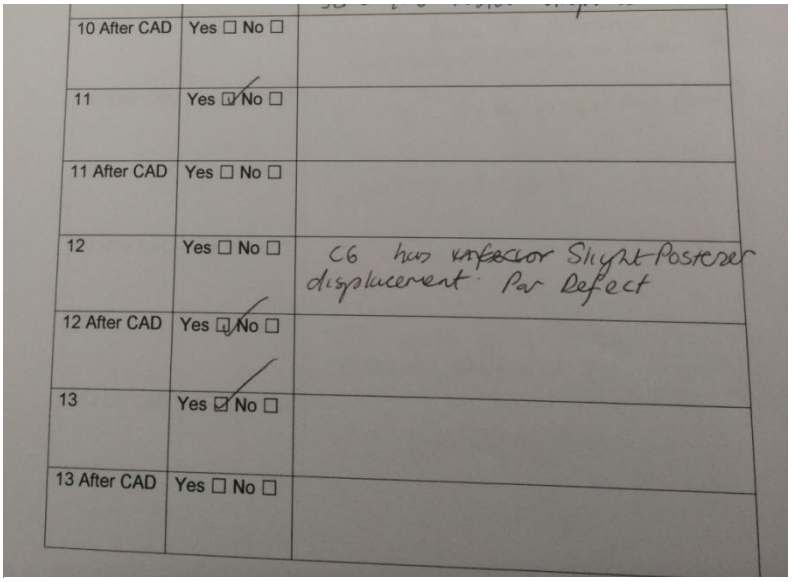


Figure 116*. A misunderstanding in using the answer sheet, as it clearly shows four questions unticked (image 10, 11, 12 and 13)*

Another issue was the misunderstanding of how to use the "delete" function this involved the correction to the original diagnosis but in the "after CAD" box, its use was stated during the training section and written on the front of the answer sheet. Yet was a common issue; as shown in Figure 117, 118 and 119. Figure 117 just states delete but is unspecified as to what to delete, and could be referring to the whole paragraph, if so their answer changes to "normal" but the "yes" box is unticked. In Figure 119 the participant has stated delete but not mentioned what, again due to ambiguity the delete statement was not included.

Figure 119 states delete but then references a sentence the participant had not previously written, so again this was not included in the analysis.

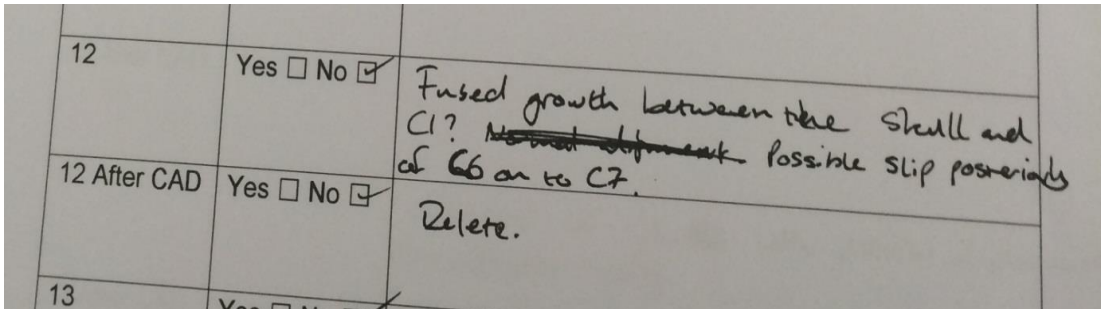


Figure 117. *One of the common misunderstandings of using delete*

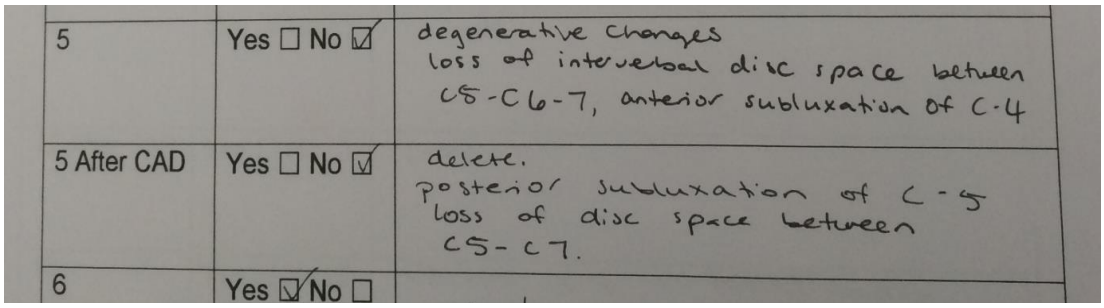


Figure 118. *Ambiguous answer as not specifying what to delete*

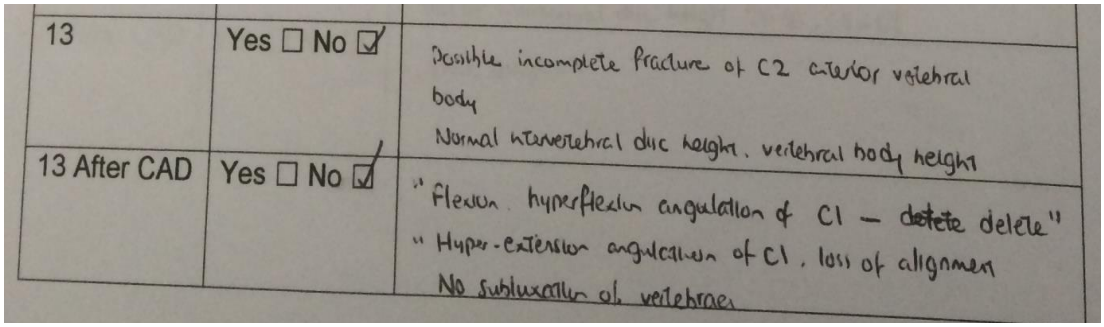


Figure 119. *Referencing a deletion of a sentence they had not written*

This ambiguity of language made the interpretation and analysis of the data a larger limitation than it should have been, although there was no physical modificaiton of the data, data was either accepted or rejected, it was still a large limitation. To counter this; both extremes of the data were represented (i.e. the ambigous “benefit of the doubt” data and the more strict “exact data” analysis). This made the data a fairer representation and dealt with some of the limitations imposed by the ambiguty of the language.

6.6 CONCLUSION

The data gathered from the two tests shows a similar trend with other CAD systems; such as the increase in sensitivity due to highlighting missed injuries,

and a decrease in specificity due to overcalling. The second test concluded that screen grabs of the software are not a reliable enough substitute for the actual CSPINE-CAD software unless the participant numbers are hugely increased, and as such should not be represented in future testing until these numbers are met, and even then discretion should be used.

The questionnaire data has shown promise, revealing a considerable increase in confidence when participants were using the CSPINE-CAD software, and all participants wanted the CSPINE-CAD as a second pair of eyes. The software was very easy to use by participants, and it only took on average 11.4 minutes to train an individual, with no issues being raised or communicated regarding the use of the software.

The data gathered suggests that a CSPINE-CAD system might be useful in increasing confidence in newly qualified radiographers, making them more courageous when attempting to write a diagnostic comment. This could have a knock on affect as an extra layer of protection and hopefully could then catch more missed C-spine injuries. Although given the software's lack of statistical significance caution should be used until this software is accurate and reliable enough in its indications, to make sure it does not have the opposite effect of reducing confidence.

Future work

Although only a feasibility study the sample size was still very low, this sample size needs to be increased in future testing to validate the results of the software. The answer sheet also needs to be revised in order to address the language issues, and to remove the need for a "benefit of the doubt" and "exact report" analysis. The third test should be conducted on radiographers and junior doctors especially F1s and F2s, following the method model of the first test, the results of which are shown in the next chapter.

CHAPTER 7. RESULTS – THIRD TEST DATA REGARDING CSPINE-CAD'S ABILITY TO IMPROVE LATERAL C-SPINE RADIOGRAPH DIAGNOSES

7.1 INTRODUCTION AND AIMS

This chapter presents the results relating to the third test of the CSPINE-CAD software on junior doctors and radiographers. The chapter aims to evaluate differences between a C-spine lateral radiograph diagnosis made without, and with CSPINE-CAD software.

7.2 OBJECTIVES

- To compare the data sensitivity and specificity scores of without and with CSPINE-CAD software
- To assess confidence levels from participants both when not using and using CSPINE-CAD software when making a diagnosis
- To assess data from the questionnaires to look at what features the participants want to see in CSPINE-CAD software
- To assess the questionnaire to see what participants want the CAD software applied to next
- To see the differences in opinions in the junior doctors against radiographers

7.3 BRIEF METHODS AND STATISTICS

The methods are described in detail in Chapter 3, section 3.3.5, analysis methods is described in Chapter 3, section 3.4.4. 26 participants diagnosed 30 lateral C-spine radiographs using a confidence scoring system (1= certain no injury, 2= 1-19.99%, 3= 20-39.99%, 4= 40-59.99%, 5= 60-79.99% and finally 6= 80-100% confident there is an injury), a feedback questionnaire was also completed by each participant.

7.4. RESULTS FOR THIRD TEST

The data from the third test were calculated creating an overall sensitivity and 1-specificity score and AUC for before and after CAD, this was applied across all confidence threshold levels and then separated via threshold levels and radiographs. The result of all confidence thresholds across all radiographs is shown in Table 7.1, Table 7.2 and Figure 120.

Table 7.1 *Sensitivity and 1-specificity scores of the third test per confidence level, and total area under a curve score before CAD (key = tp = true positive, fn= false negative, tn= true negative, fp= false positive)*

For each threshold	2 or above	3 or above	4 or above	5 or above	6
sensitivity = tp / (tp+fn)	0.7650	0.6909	0.5499	0.3789	0.2009
specificity = tn / (tn+fp)	0.7645	0.8599	0.9327	0.9700	0.9895
specificity -1	0.2355	0.1401	0.0673	0.0301	0.0105
95% confidence interval	**95% CI**	**95% CI**	**95% CI**	**95% CI**	**95% CI**
sensitivity confidence interval	0.7318-0.7959	0.6552-0.7249	0.5122-0.5871	0.3429-0.4160	0.1718-0.2324
specificity confidence interval	0.7562-0.7727	0.8530-0.8665	0.9276-0.9375	0.9665-0.9732	0.9874-0.9914

Table 7.2. *Sensitivity and specificity scores of the third test per confidence level, and total area under a curve score after CAD (key = tp = true positive, fn= false negative, tn= true negative, fp= false positive*

For each threshold	2 or above	3 or above	4 or above	5 or above	6
sensitivity = tp / (tp+fn)	0.7322	0.6396	0.5199	0.3875	0.2151
specificity = tn / (tn+fp)	0.7755	0.8739	0.9289	0.9723	0.9884
specificity -1	0.2245	0.1261	0.0711	0.0277	0.0116
95% confidence interval	**95% CI**	**95% CI**	**95% CI**	**95% CI**	**95% CI**
sensitivity confidence interval	0.6978-0.7646	0.6028-0.6752	0.4823-0.5575	0.3513-0.4260	0.1852-0.2474
specificity confidence interval	0.7673-0.7836	0.8673-0.8802	0.9339-0.9433	0.9689-0.9754	0.9862-0.9904

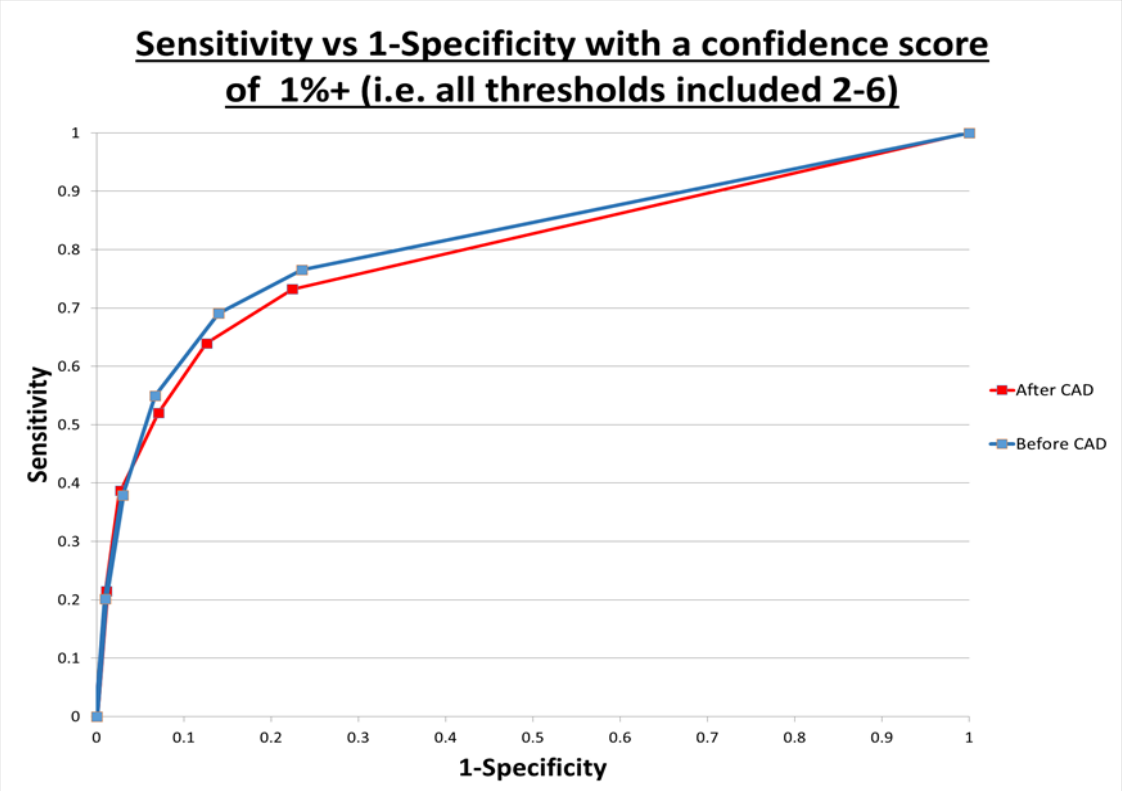


Figure 120. *Sensitivity vs 1-specificity of the third test for all confidence levels and radiographs.*

The results between before and after CAD (Table 7.1, 7.2 and Figure 120) showed CAD having a negative effect with an AUC loss of 1.65% after using CAD. This may have been due to the large uncertainties caused by the overlapping CI, or because there is a higher number of low confidence answers as shown by their 1-specificity differences, which may in turn be due to a known issue called “hedging”, which has been seen in up to 30.9% of radiologists reports [129], this is where an individual is more likely to overcall injuries or pathologies in order to hedge their bets. Due to the higher number of low confidence scores it was decided to create a sensitivity vs 1-specificity containing only answers of 60%+ (5 and 6) (Figure 121) as these would be over the 50% figure (i.e. 50/50).

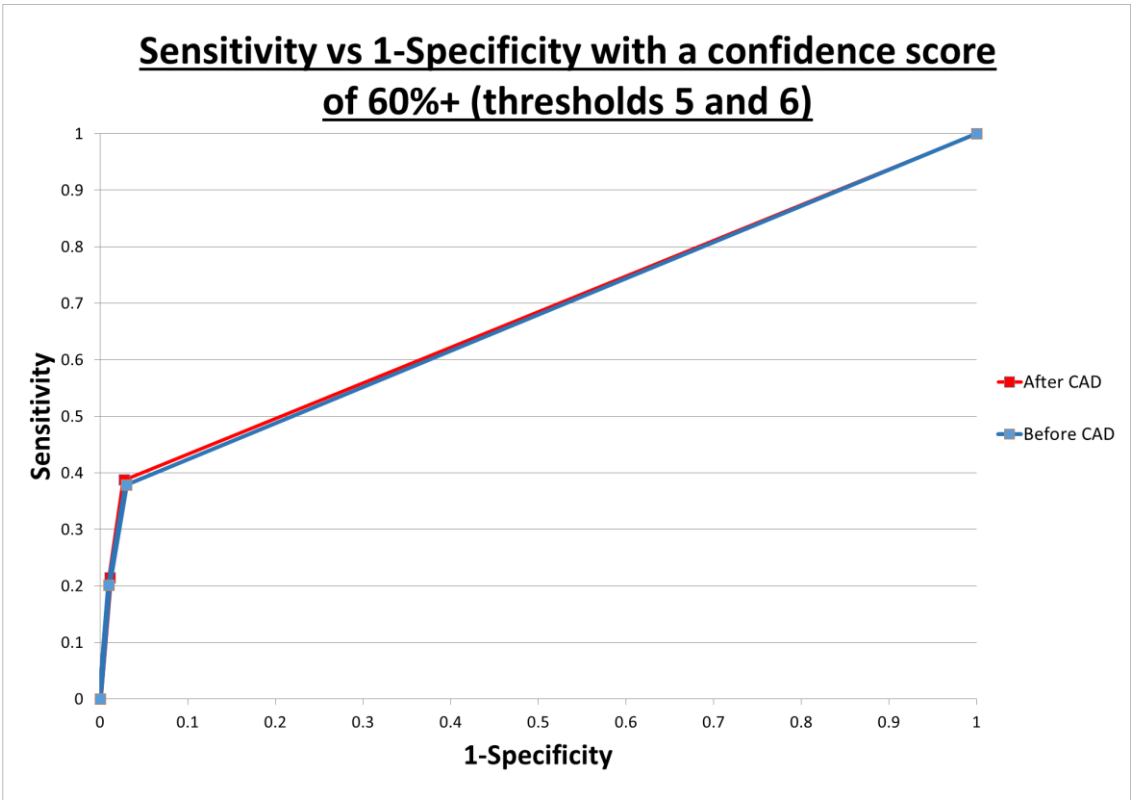


Figure 121. *Sensitivity vs 1-specificity of the third test for confidence thresholds five and six (60%+)*

Looking just at the 60%+ confidence scores (Figure 121) the CAD software seems to now help but only by 0.51% AUC in favour of after CAD use, again this was further separated into just the 80%+ confidence threshold (6) (Figure 122).

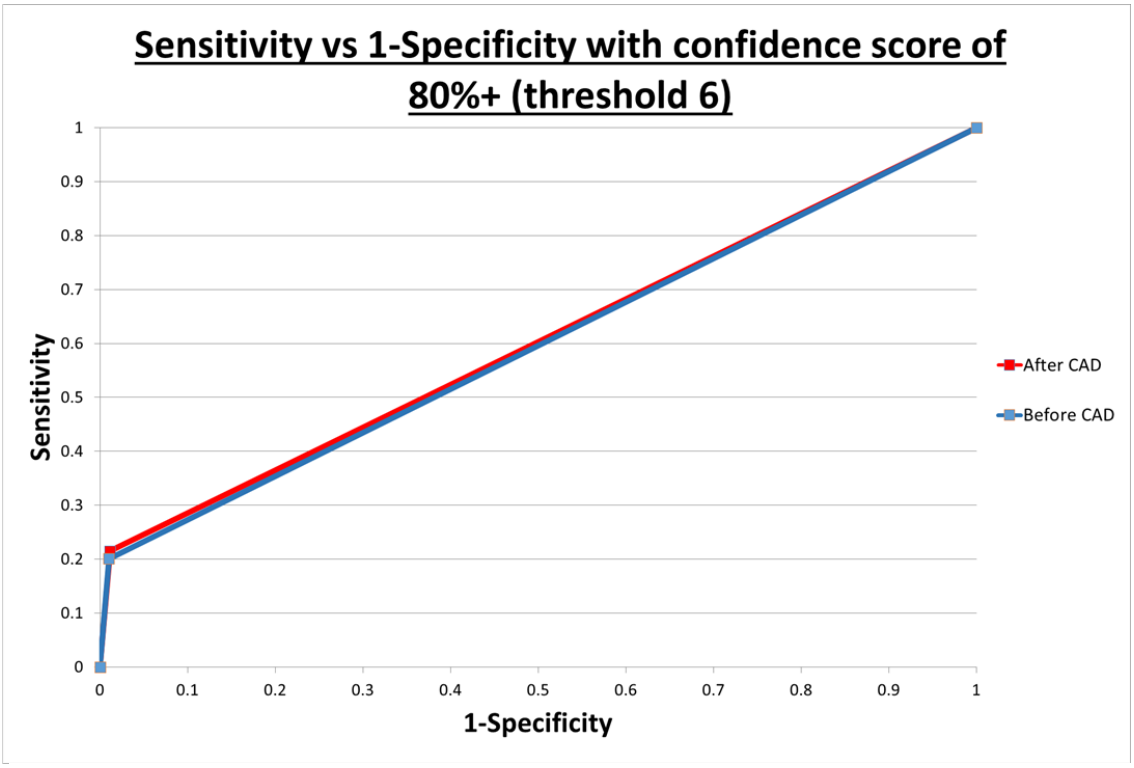


Figure 122. *Sensitivity vs 1-specificity of the third test for just 80%+ confidence (score of six)*

The difference in AUC 0.66% appears to increase in favour of CAD, but only by a small difference in the before and after CAD scores, and given the overlapping CI this shows no statistical significance.

7.5 RESULTS OF CSPINE-CAD REPEATABILITY TEST

Due to the results mentioned (section 7.4) additional testing was done as outlined in Section 3.3.7 and 3.3.5. This involved two reviewers testing the repeatability of the CSPINE-CADs ability to indicate the 24 injuries of the 30 radiographs used in the third test. As stated of the 30 radiographs 21 contained 24 injuries with the other nine radiographs either having no injury or had an injury that could not be detected by the software. All 30 radiographs had CSPINE-CAD applied 10 times per reviewer, with any CAD indication arrows recorded.

Although all 30 had CAD applied only the 21 radiographs with injuries were reviewed (as CAD could not indicate a normal image). Each radiograph had a score out of 10 given to it via the 10 repeats i.e. a radiograph where CAD indicated the correct injury in its 10 repeats would score 10/10 by a reviewer. This out of 10 score was then averaged between the two reviewers and is

shown in Table 7.3 (Appendices 24-26 show the raw data).

Table 7.3. *Averaged score out of 10 for CAD indicating known injury*

Image number	Average score out of 10
1	8
2	4.5
3	3.5
4	7
5	1.25
6	2.25
7	0
8	6
10	9
11	8
14	7.5
15	5
19	2.5
20	4
23	8.5
24	4.5
25	2
26	6
27	6.5
28	8
29	5

Seven radiographs scored a 7 or over out of 10 (three 8s, one 8.5, one 9, one 7.5, and one 7) one radiograph scored 0. The data were then separated into their scores out of 10 and sensitivity vs 1-specificity tables calculated (only data from 60%+ confidence was compared due to the previously stated "hedging" effect).

The most correct injuries identified after the use of CAD was question 10 in which five injuries were indicated before CAD and 14 injuries after CAD, this coincides with the radiograph having the highest repeatability for CAD indication (9 out of 10) The worst score 0 out of 10 had an injury that was not stated by any of the 26 participants before or after CAD (in the 60%+ confidence threshold).

The radiographs that had the highest after CAD loss were images; 2 (4.5 out of 10), 5 (1.25 out of 10) and 20 (4 out of 10) which were all reduced by four injuries after using CAD.

Due to these results showing a correlation between the higher the repeatability of the software (out of 10) and the after CAD confidence increasing, it was decided to separate the sensitivity and 1-specificty scores for each group, the ones scoring 7 or above (out of 10) and the ones scoring 6.5 or below (out of 10).

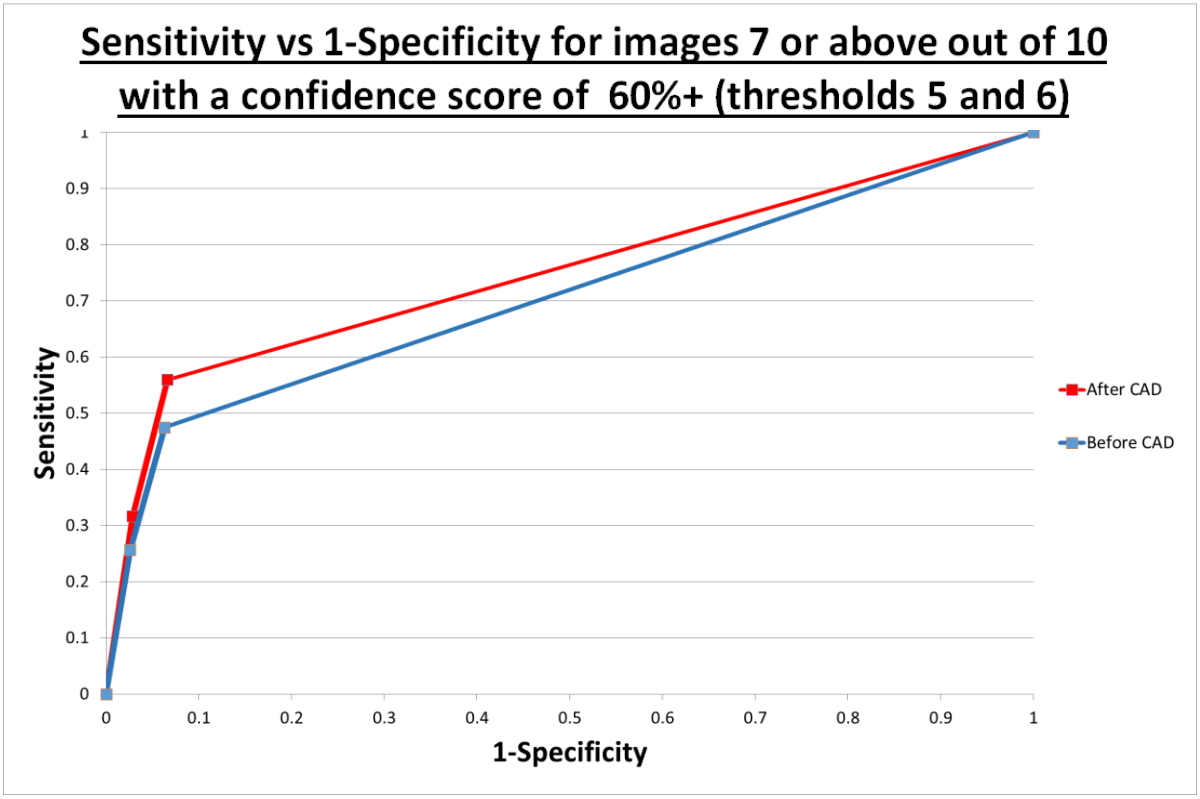


Figure 123. *Sensitivity vs 1-specificity of the third test for radiographs that scored ≥7/10 for CAD repeatability, using answers of only 60%+ in confidence*

Table 7.4 *Sensitivity and 1-specificity calculations and scores for before and after CAD*

Before CAD	5 and above	95% Confidence Intervals	6	95% Confidence Intervals
sensitivity = tp / (tp+fn)	0.4744	0.4089 - 0.5004	0.2564	0.2017 - 0.3134
specificity = tn / (tn+fp)	0.9370	0.9250 - 0.9476	0.9749	0.9668 - 0.9815
specificity -1	0.0630		0.0261	

After CAD	5 and above	95% Confidence Intervals	6	95% Confidence Intervals
sensitivity = tp / (tp+fn)	0.5598	0.4939 - 0.6244	0.3162	0.2572 - 0.3800
specificity = tn / (tn+fp)	0.9337	0.9216 - 0.9445	0.9716	0.9631 - 0.9786
specificity -1	0.0663		0.0284	

Table 7.5. *Area under a curve calculation for before and after CAD*

Before CAD

1-Specificity	Sensitivity	AUC
0	0	0.0033
0.0261	0.2564	0.0135
0.063	0.4744	0.6908
1	1	
	Total AUC	**0.7076**

After CAD

1-Specificity	Sensitivity	AUC
0	0	0.0045
0.0284	0.3162	0.0166
0.0663	0.5598	0.7282
1	1	
	Total AUC	**0.7493**

Tables 7.4, 7.5 and Figure 123 show the 7 or above (out of 10) data show a much higher after CAD score compared to before CAD. The AUC difference was 4.17% in favour of after CAD use, resulting in a total of 20 injuries that would have been missed without using CAD.

For the images that scored 6.5 or below these were also combined for their before and after CAD scores as shown in Tables 7.6, 7.7 and Figure 124.

Figure 124. *Sensitivity vs 1-specificity of the third test for radiographs that scored ≤6.5/10 for CAD repeatability, using answers of only 60%+ in confidence*

Table 7.6 *Sensitivity and 1-specificity calculations for confidence thresholds five and six*

Before CAD	5 and above	95% Confidence Intervals	6	95% Confidence Intervals
sensitivity = tp / (tp+fn)	0.3312	0.2891-0.3762	0.1731	0.1405-0.2111
specificity = tn / (tn+fp)	0.9665	0.9609-0.9714	0.9892	0.9857-0.9919
specificity -1	0.0335		0.0108	

After CAD	5 and above	95% Confidence Intervals	6	95% Confidence Intervals
sensitivity = tp / (tp+fn)	0.3034	0.2625-0.3476	0.1667	0.1347-0.2043
specificity = tn / (tn+fp)	0.9715	0.9662-0.9760	0.9883	0.9847-0.9911
specificity -1	0.0285		0.0117	

Table 7.7. *Area under a curve calculations for before and after CAD*

Before CAD		
1-Specificity	**Sensitivity**	**AUC**
0	0	0.0009
0.0108	0.1731	0.0057
0.0335	0.3312	0.6433
1	1	
	Total AUC	**0.6500**

After CAD		
1-Specificity	**Sensitivity**	**AUC**
0	0	0.0010
0.0117	0.1667	0.0039
0.0285	0.3034	0.6331
1	1	
	Total AUC	**0.6381**

Tables 7.6, 7.7 and Figure 124 shows the 6.5 or below (out of 10) data resulting in a much lower after CAD score compared to before CAD.

The score difference in AUC was 1.19% in favour of without CAD, resulting in a total of 13 injuries that would have been missed when using CAD.

Questionnaire results

The questionnaire results showed that over 73% of participants would find the CSPINE-CAD software helpful in practice (Figure 125), with 12% unsure, and 15% saying no.

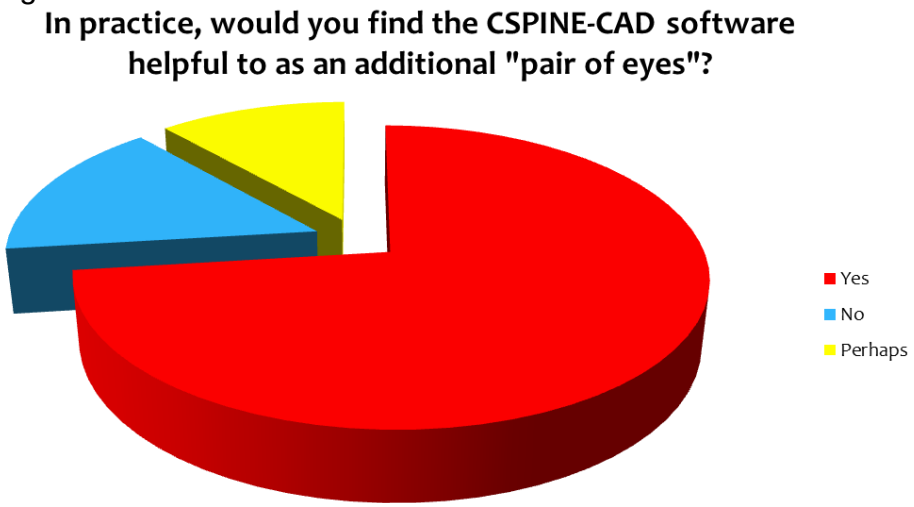


Figure 125. *Questionnaire data showing the percentage of participants who felt the software was helpful as an additional "pair of eye" compared to those who said 'no' or 'maybe'*

Table 7.8. *Questionnaire data for all participants*

Characteristic	Radiographers	Junior doctors
Average (in months) participants have worked (part time or full time)	90.86(range 0-252)	18.94 (range 0-48)
Percentage of participants with postgraduate qualifications in image interpretation or reporting	0%	0%
Average confidence score (out of 5) participants felt when interpreting C-spine radiographs	3.29 (range 2-4)	2.00 (range 1-4)

Additional questionnaire data indicated a relationship between the experience of the participants, and the confidence in interpreting C-spine radiographs (shown in Table 7.8). The average amount of time radiographer participants where in practice was 90.86 months, with an average confidence figure in interpreting C-spine radiographs being 3.29 (out of 5). Compared to the junior doctors who had an average of 18.94 months, and an average confidence figure of 2.00. This might also be the reason that although beneficial to both groups in increasing interpretation confidence when using CAD (as seen in the combined data in Figure 126), it had a larger influence on junior doctors.

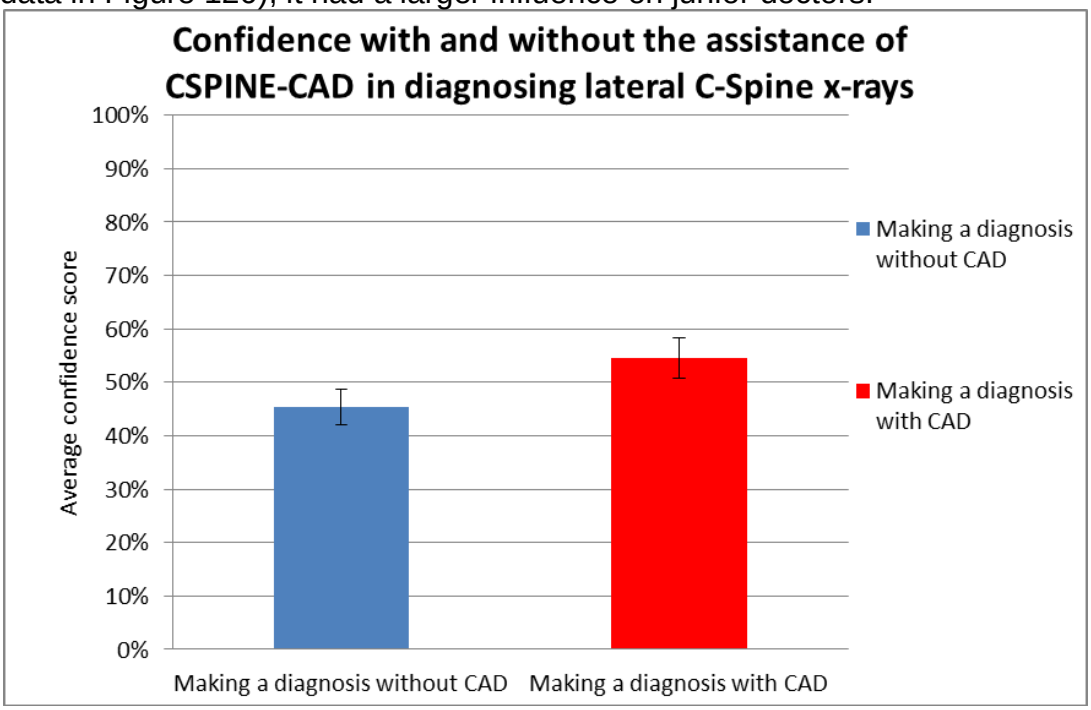


Figure 126. *Questionnaire data showing the scores given by participants making a diagnosis without CAD compared to with CAD (scores were on a scale of 1- 5 and then converted into a percentage, error bars show standard error.)*

Data from the questionnaire also showed (Figure 126) when asked '*how confident the participants felt when making a diagnosis?*' the average score was 45.38%. When asked *'how confident they felt making a diagnosis with the assistance of CAD?*' this average score increased to 54.62%, increasing overall confidence per participant by 9.24%. Additionally analysis of confidence scores between the two groups of participants was also calculated; the radiographers had an average confidence increase of 5.8% (0.29 out of 5) after using CAD, and the junior doctors had an average confidence increase of 10.4% (0.52 out of 5) after using CAD.

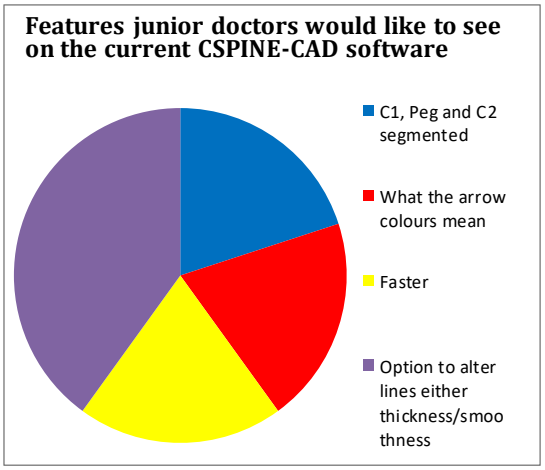


Figure 127. *Third test questionnaire data from junior doctors*

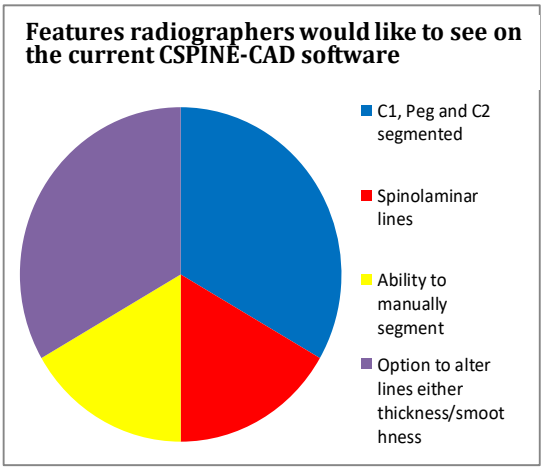


Figure 128. *Third test questionnaire data from radiographers*

Data was also gathered regarding the features that participants would like to see in the CSPINE-CAD software, this data was separated into the two groups (Figures 127 and 128). The junior doctors (Figure 127) mainly wanted to modify the alignment curves as one participant said

> *"….if it could be more accurate and (the) alignment lines (were) less prominent it may be more effective*"

Radiographers (Figure 128) had similar ideas and wanted to be able to reduce the thickness of the lines. Additionally a higher percentage of radiographers wanted to see C1, Peg or C2 segmentations to be added to the CSPINE-CAD software.

Combined numerically 33% of suggestions (4 out of the 12) wanted the alignment curves to be able to be modified.as an added feature to the software, additionally 25% wanted to see C1, Peg or C2 segmented (3 out of 12).

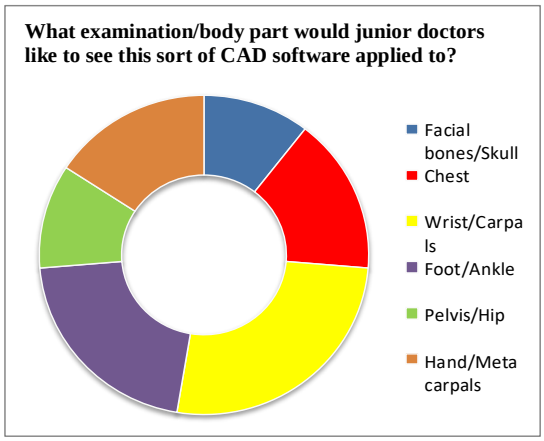


Figure 129. *Questionnaire data just from the junior doctors regarding what body parts/examinations they wanted the CAD software applied to next*

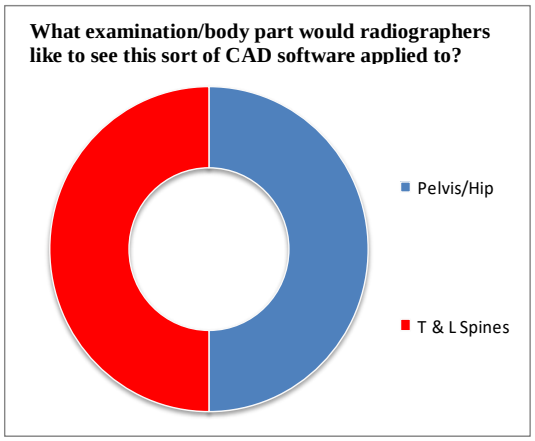


Figure 130. *Questionnaire data just from the radiographers regarding what body parts/examinations they wanted the CAD software applied to next*

Questions were also asked regarding what examinations/body part participants would like to see this sort of CAD software applied to, this again was separated via groups (Figure 129 and 130). The majority of junior doctors (26%, 5 out of 19 responses) wanted to see it applied to wrist/carpal radiographs, with 50% (2 out of 4 responses) of radiographers wanting to see it applied to thoracic and lumbar spines, with the same amount wanting it to be applied to the hip or pelvis radiographs, again the combined total of responses saw the majority wanting to see it one wrist/carpals radiographs (5 out of 23 responses), with second being pelvis/hip and ankle/foot (both scoring 4 out of 23 response).

Time Differences

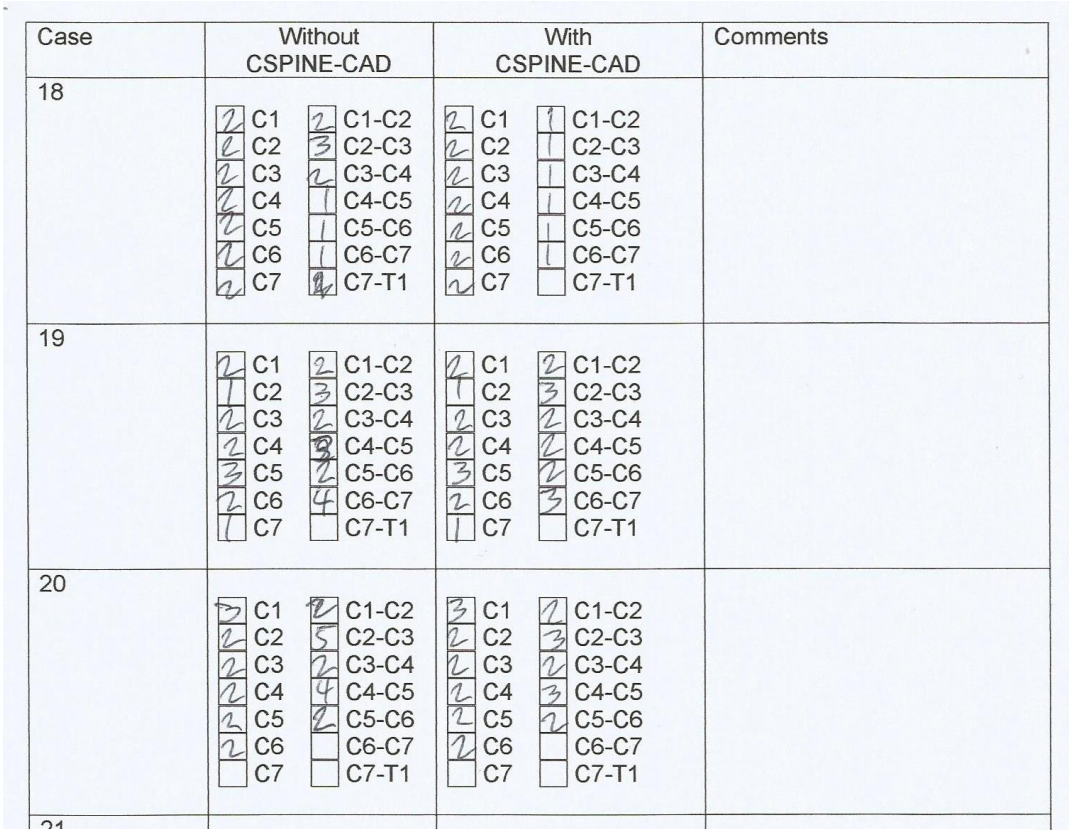
As with all of the tests the third test was timed; with the talk through taking on average 9.8 minutes (range of 6-17 minutes), the testing of the 30 radiographs taking 81.5 minutes (range of 60-118 minutes) and the questionnaire taking 3.2 minutes (range of 2-8 minutes). The total completion time took an average of 94.4 minutes (range 69-139 minutes).

7.6 DISCUSSION

Sensitivity and 1-specificity

Key finding show there is no statistically significant result due to large CI, but the results show promise with improved reliability of CAD.

Changes in the answer sheet prior to the start of the third test (as mentioned in section 3.3.5) resulted in limiting the language that could be used by the participants and removing the result away from the autheticity of a real report, although a comments box was included to allow some additional expression. Despite this, the change meant that the analysis was straightforward and a fairer representation of the participants' diagnosis as there was no ambiguity or "benfit of doubt"/"exact data" interpretations, this also meant handwriting deciphering was no longer an issue. This in turn made the senstiivty and 1-specificity scores the fairest representation so far, and combined with the new confidence thresholds added an extra dimension into the certainty of the diagnoses. Due to this new scoring system the sensitivity and 1-specificity could be analysed more fully, looking purely at all the confidence thresholds it is clear to see in Figure 120 that using CAD has a negative effect. Although this may have been due to the issue stated as "hedging" as in the over use of the lower confidence thresholds (an example of this is shown in Figure 131). Reanalysing the data to only include 60%+ confidence figures (thresholds 5 or 6), showed an increase in after CAD data (Figure 121 and 122), showing the CAD either creating or increasing confidence levels to a higher value, thus the results also showed an increase in higher confidence when making a diagnosis with the CSPINE-CAD software.



Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
18	C1 2, C2 2, C3 2, C4 2, C5 2, C6 2, C7 2; C1-C2 2, C2-C3 3, C3-C4 2, C4-C5 1, C5-C6 1, C6-C7 1, C7-T1 4	C1 2, C2 2, C3 2, C4 2, C5 2, C6 2, C7 2; C1-C2 1, C2-C3 1, C3-C4 1, C4-C5 1, C5-C6 1, C6-C7 1, C7-T1	
19	C1 2, C2 1, C3 2, C4 2, C5 3, C6 2, C7 1; C1-C2 2, C2-C3 3, C3-C4 2, C4-C5 3, C5-C6 2, C6-C7 4, C7-T1	C1 2, C2 1, C3 2, C4 2, C5 3, C6 2, C7 1; C1-C2 2, C2-C3 3, C3-C4 2, C4-C5 2, C5-C6 2, C6-C7 3, C7-T1	
20	C1 3, C2 2, C3 2, C4 2, C5 2, C6 2, C7; C1-C2 2, C2-C3 5, C3-C4 2, C4-C5 4, C5-C6 2, C6-C7, C7-T1	C1 3, C2 2, C3 2, C4 2, C5 2, C6 2, C7; C1-C2 2, C2-C3 3, C3-C4 2, C4-C5 3, C5-C6 2, C6-C7, C7-T1	
21			

Figure 131*. An example of "hedging" with excessive use of lower threshold figures*

During the calculations it was discovered that certain reviewed radiographs had a much higher after CAD score than others, whilst some radiographs had lower after CAD scores. It was decided to test all 30 radiographs for CAD repeatability in indicating the injuries, to see if there was a correlation between the repeatability of the CAD software and the after CAD scores produced by the 26 participants. Figures 123 and 124 show the effect the CAD has on the diagnosis, scores with 7 or more out of 10 for reliable/repeatable in indicating the injury had a greater after CAD score, with a figure of 6.5 or under out of 10 producing a poor after CAD score. The combination of the high and low after CAD scores might be cancelling each other out, and as such may have been the reason for the small difference in sensitivity vs 1-specificity and AUC, as shown in Figure 121.

<u>Questionnaire data</u>

The third test questionnaire showed positive results with over 73% of participants finding it useful, meaning there is a demand for C-spine CAD software within in a department. The participants who answered “perhaps” added qualifiers such as:

“*for subtle malalignments*”

"*not sure I would trust it as would rather another experienced interpreter"*

These answers although indecisive are still positive responses, given as the software's design is to be used as a 'spell checker' and neither be used constantly or replace an experienced colleague.

Questionnaire results showed only two participants lost confidence whilst making a diagnosis with the CSPINE-CAD software, both of whom said 'no' when asked regarding if they found the software helpful; incidentally these two participants were the two most experienced participants across both groups; one with 17 years' experience, and the other with 21 years' experience**.** This coincides with the original idea that this software will most likely be utilised by less experienced staff members.

The analysis of the questionnaire also showed that there is a 4.6% difference in confidence between the two groups (radiographers 5.8% increase and junior doctors 10.4% increase) when using the CAD software, this difference might be due to a higher number of junior doctors participating (19 compared to seven radiographers), or that the radiographer group contained the more experienced participants (including the two participants who lost confidence). Either way the CAD software showed an average increase of 9.24% across both groups, showing that even with the software's current drawbacks there is a desire for the CAD software when making a C-spine diagnosis.

Additionally there appears to be little difference in what the two groups wanted in terms of additions to the CSPINE-CAD software, with the main issue being the alignment curves being modified, and C1, peg or C2 segmentations included. In future versions of the CSPINE-CAD software it was already decided to remove the alignment curves and replace it with just the indication arrow (as discussed/shown in section 2.1.1 Figure 28 (C), the issue of the segmentation of C1, peg and C2 is still a problematic area as stated in section 2.2.3.

<u>Time</u>

The time needed for testing the CAD software was always an issue; it also might have been a factor in why three participants who had shown interest

originally did not test the software. In order to streamline the third test certain actions were employed. First a talk through checklist was used (Appendix 19), this went through how the software worked and gave a greater linear narrative to using the software (and higher repeatability between participants).This took on average 9.8 minutes per participant, compared to the first test which took an average of 11.4 minutes (which used the same set up and software but did not have a checklist), saving 1.6 minutes per participant. The new answer sheet as well as being more precise should have been quicker to fill in (i.e. writing radiographic comments as in the first and second test takes longer than putting numbers in a box). In total it took the third test participants 2.71 minutes to diagnose each radiograph (an average across 30 radiographs), with the first test taking 2.68 minutes per radiograph (an average across five radiographs), these are very similar figures and the slight difference may have been due to third test participants taking longer to make a decision, or that the 30 radiographs contained a lesser percentage of normal radiographs compared to the five. The questionnaire in the third test was also modified although more for additional data gathering than speed, the set-up retained its simplicity of the first test and averaged a slight improvement in time from an average of 3.6 minutes (first test) to 3.2 minutes (third test).

Implications

Due to the third test being more objective and addressing the issues of the previous two tests, the implication can be more strongly concluded. The third test has shown an increase in sensitivity (in the 60%+ and 80%+ data) and confidence when being used during testing. Although again the data gathered is not statistically significant so the implication is that there needs to be further improvement in the CAD software to increase its repeatability and reliability. The questionnaire data support the want for a CSPINE-CAD system and its integration in its “spell checker” function might help reduce the percentage of missed and misdiagnosed C-spine injuries, and allow junior doctors and radiographers the confidence and ability to make a more accurate diagnosis when supported via software.

7.6.1 LIMITATIONS

Participants

In total 32 participants agreed to do the study but due to time restraints and work/social commitments they could not all do the study; several attempts at rescheduling were aimed for but to no avail, this meant three dropped out before starting. During testing in order to save time four participants (who were self-limited for time) were tested at the same time, three participants were tested collectively in one room, and one participant was separated in another. The checklist was followed individually with all four participants. During my time with the lone participant a colleague of the other three had arrived and started to help one of the participants as such that individuals data were not included. Incidentally all three failed to complete the testing**,** although the lone participant did finish. Having excluded the data of one of the three participants the other two participant's incomplete data was reviewed. From reviewing their data it was apparent they had misunderstood the answer sheet due to large amounts of blank data from one participant (Figure 132) and several contradicting statements from the other participant between their confidence score and the comments (Figure 133).

As such the data from these two participants was also not included, although the lone participant's data were included due to correct use and completion.

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
13	C1 C1-C2 C2 C2-C3 C3 C3-C4 C4 C4-C5 C5 C5-C6 C6 C6-C7 C7 C7-T1	C1 C1-C2 C2 C2-C3 C3 C3-C4 C4 C4-C5 C5 C5-C6 C6 C6-C7 C7 C7-T1	coming artefact. CAD suspicious of C3 anterior body.
14	C1 C1-C2 C2 C2-C3 C3 C3-C4 C4 C4-C5 C5 C5-C6 C6 C6-C7 C7 C7-T1	C1 C1-C2 C2 C2-C3 C3 C3-C4 C4 C4-C5 C5 C5-C6 C6 C6-C7 C7 C7-T1	No change once CAD applied
15	C1 C1-C2 C2 C2-C3 C3 C3-C4 C4 C4-C5 C5 C5-C6 C6 C6-C7 C7 C7-T1	C1 C1-C2 C2 C2-C3 C3 C3-C4 C4 C4-C5 C5 C5-C6 C6 C6-C7 C7 C7-T1	Box at C7 not aligned at C7 Alignment lines match anatomy
16	C1 C1-C2 C2 C2-C3 C3 C3-C4 C4 C4-C5 C5 C5-C6 C6 C6-C7 C7 C7-T1	C1 C1-C2 C2 C2-C3 C3 C3-C4 C4 C4-C5 C5 C5-C6 C6 C6-C7 C7 C7-T1	CAD not aligned over C3, 5 & 6.
17	C1 C1-C2 C2 C2-C3 C3 C3-C4 C4 C4-C5 C5 C5-C6 C6 C6-C7 C7 C7-T1	C1 C1-C2 C2 C2-C3 C3 C3-C4 C4 C4-C5 C5 C5-C6 C6 C6-C7 C7 C7-T1	Artefact level with C1, 2. Vert body boxes not aligned with CAD or Alignment lines

Figure 132: *An example from one of the answer sheet pages showing no information in the "after CAD" box*

2	C1 C1-C2 C2 C2-C3 C3 C3-C4 C4 C4-C5 C5 C5-C6 C6 C6-C7 C7 C7-T1	C1 C1-C2 C2 C2-C3 C3 C3-C4 C4 C4-C5 C5 C5-C6 C6 C6-C7 C7 C7-T1	Degenerative change at C5/C6 particularly. slight anterior subluxation at C4/C5. - normal ageing process.
10	C1 C1-C2 C2 C2-C3 C3 C3-C4 C4 C4-C5 C5 C5-C6 C6 C6-C7 C7 C7-T1	C1 C1-C2 C2 C2-C3 C3 C3-C4 C4 C4-C5 C5 C5-C6 C6 C6-C7 C7 C7-T1	Very poor quality image - needs repeating to include soft tissue. C5 - C6 subluxation again - degenerative. Disagree with CAD.

Figure 133: *An example of the misunderstanding in using the answer sheet*

This error in misunderstanding and incompletion was most likely due to several issues the main ones being: the time constraints imposed by the participants themselves, and the researchers divided attention. Due to the time restraints participants may have not been fully engaged, this was possibly exacerbated by the three participants being in the same room. The researchers divided attention between the two rooms also meant the researcher was not present to intercede when the colleague entered the room. Due to these issues and misunderstandings not being experienced by any of the other 26 participants it can be suggested that any future testing should always be done with a maximum of two participants (unless a controlled environment can be utilised such as an examination hall or lecture theatre), with constant supervision maintained, otherwise a setup with several participants who are truly isolated from each other with the supervision then divided could be utilised.

In total 26 participants completed the testing, this sample group were the best representation of those who would use the CSPINE-CAD software. This testing involved a larger number of participants (compared to the first and second tests), and a more accurate sample representation. In order to increase generalisabilty more participants with a more balanced selection (i.e. radiographer numbers equalling junior doctor numbers) need to be tested with a larger set of radiographs, due to the issues of time restraints a larger amount of resources or possible modifications to how the CSPINE-CAD software could be tested would need to be introduced.

One issue that was not addressed was the pressure that radiographers and junior doctors work under in the real world when making a diagnosis or commenting. Being on the front line simple issues such as fatigue, stress, hunger, difficult patients, or even being on night shift can influence the ability to concentrate and diagnose a radiograph correctly [130, 131]. This third test was conducted at a time of the participant's convenience and under no obligation or stress, and as such this may have affected the results as not being a "true" representation. Although it can be presumed that fatigue or stress in a junior doctor or radiographer is seen as detrimental, as such a "true" representative test would have CAD highlighting injuries they might most likely have missed, and thus might produce a higher score when using CAD than without.

Environment

The testing took place at the UOE St Luke's campus, and at the RD&E, with the majority of testing done in the emergency department training room at the RD&E. This increased the situational validity of the results by using a realistic environment with the majority of testing done within a hospital. Although this is not a true representation of a bustling department environment one in which time is limited and distractions at their maximum, so cannot be directly compared to the real environment, although it is likely any time limitations or distractions would have a more favourable outcome for the after CAD result.

Images/radiographs

Just like the first and second tests the radiographs used in the third test were chosen as the radiographs with injuries that were most likely to be identified by the CSPINE-CAD software. Although the pool had increased from 183 radiographs to 270 images (at the time of the third test), only 105 radiographs contained injuries, with 23 of those being chosen (21.90% of radiographs used). It must also be acknowledged that of those 105 radiographs 28 (26.67%) had injuries that would never be identified by the CSPINE-CAD software due to its current limitations.

Comparison to literature

There appears to be very little in C-spine CAD radiograph imaging, with only two papers discovered during a literature search; one by Larhmam, Benjelloun and Said in 2012 [132], and the other by Lecron, Benjelloun and Said in 2013 [133]. These papers applied their CAD to 66 lateral C-spine radiographs in which it identified 97.5% of vertebral bodies, this study did not look at vertebral fracture or misalignment indication, nor did it test against real life professionals only the reports. Although it stated the need for C-spine CAD and its possible use, and they state in their future work to develop a CAD system for cervical trauma detection, there is currently no evidence this has been done. As such it is difficult to fully compare against, so additionally I have decided to compare this study to CAD in spinal CT imaging, and vertebral fracture detection in lateral chest radiograph imaging.

Most of the spinal CT CAD imaging is also still in its infancy with testing seemingly restricted to the accuracy of lesion detection via the software. In one study it showed a sensitivity score of 90% with a false positive rate (FPR) of 10.8 [134]**.** Another study [135] had a sensitivity of 83% with an FPR of 6.8 per patient, and an AUC of 0.95. Both studies stated that the majority of FPRs were caused by degenerative change in the spine; this may have been the reason for some of my own poor segmentation results during testing. The results so far of these studies show to be far greater than my own with higher sensitivity and AUC scores, but it must be stated that these studies did not compare their CAD to a real test situation in which these sensitivities would be more robustly tested.

In the case of vertebral fracture detection in lateral chest imaging Kasai et al [136] tested CAD on 60 lateral chest radiographs (21 patients with vertebral fractures) with 18 radiologists making a diagnosis first without, and then with CAD. The results showed an increase in vertebral fracture detection from an AUC difference of 0.906 to 0.951 ($p=0.002$), and a sensitivity change from 64.9% to 67.6% showing it improves diagnostic accuracy amongst radiologists. This testing is a better comparison due to similarities in utilising professional participants who were first asked to diagnose the image without, and then with CAD, the Genant scale was also used to determine the severity of the fractures with Kasai et al excluding images of poor quality (overlapping structures, poor contrast). Radiologists also undertook a training session beforehand similar to the example image checklist training I conducted prior to starting. In comparison their testing also involved looking at pulmonary nodules in addition to fracture which may have distracted the participants from the vertebral body fractures and made their results easier to perceive. Finally the time was recorded with the average taking 47 minutes for 60 cases (range 32-73 minutes) although there is a difference in looking at a lateral chest image compared to a C-spine image, the Kasai et al participants additionally had to review lung nodules as well, with them taking an average of 47 seconds per case compared to my 2.71 minutes per image in my test. This shows the naivety of my on study in not asserting a time restriction which may have influenced the result compared to a real life study.

7.7 CONCLUSION

The results show that the more reliable/repeatable the CSPINE-CAD software is the greater the after CAD effect is although there is no statistical significance within the test results. The questionnaire results show that there is a demand for the software, and that it increases the confidence in participants during testing across all groups. Additionally it seems that this type of CAD software has little use for senior experienced colleagues, which is in agreement with the idea of this software being utilised with less experienced staff members. In conclusion this means that as the C-spine CAD software develops and becomes more robust, accurate, and above all repeatable in indicating various injuries, it should yield more significant results.

Future work

Although only a feasibility project the sample size needs to be increased in future testing to validate the results of the CAD software, additional repeats of the CAD software consistency is also needed to be performed, to check repeatability in indicating injuries. Newer versions of the CAD software need to be developed to just include the visualisation of the indication arrows as originally designed, including highlighting the exact misalignment area, this would remove current ambiguity in defining the injury. The next stage would be trialling a newer version of the software with a larger database of radiographs and more participants in order to make the results have greater validity.

CHAPTER 8. SUMMARY OF RESULTS, DISCUSSION, CONCLUSION AND FUTURE WORK

The main aim of the study was to investigate the acceptability and efficacy of CSPINE-CAD software for CSI diagnosis through a series of tests on lateral C-spine radiographs. The participants recruited were chosen for their specialist knowledge, ability, and the impact that this type of software would have on their current or future careers. The original aim of the study during the testing was to assess the differences in sensitivity, specificity, and overall AUC scores in making a diagnosis on lateral C-spine radiographs, both with and without the use of the CSPINE-CAD software. The primary goal was to provide information relating to C-spine diagnoses via CSPINE-CAD software that may lead to a reduction in the percentage of missed or misdiagnosed C-spine injuries. In order to achieve these aims a number of techniques were employed and the efficacy of these was assessed in chapters 4 and 5 with results shown in chapters 6 and 7.

Results – Evaluation of the development of the CSPINE-CAD software

How the CSPINE-CAD software developed and evolved was investigated. The CSPINE-CAD software developed its ability to segment vertebral bodies and apply alignment curves via learning software; this required two radiographers to manually segment vertebral bodies and apply alignment curves which allowed the software to learn. Originally the intent was to have the CSPINE-CAD software learn to segment all the cervical vertebrae, and apply three alignment curves. Manual segmentation of C3-C7 was successful but due to the unique shape of C1 and C2, and superimposition of the peg, segmentation was difficult. Many alternatives were tried and tested, including non-anatomically correct segmentations, having the peg segmented as part of the whole of C2, and having the anterior arch separately segmented. But after trial and error in trying to manually segment C1 and C2 in an optimum and consistent way, it was concluded it was too cumbersome and time consuming. Additionally the three lines also provided difficulty, with the anterior and posterior lines being relatively easy for the software, but the creation of the spinolaminar line was deemed currently too difficult for the learning software.

This affected the software's ability to indicate any fractures to C1 or C2, and also any misalignments of C1-C2, C2-C3 or C7-T1. It was concluded that although the software would not currently include these features, the testing of the software would still be conducted due to the injuries it could indicate.

Results – Evaluation of the Genant SQ scale

The Genant SQ scale was a method used to determine the type and extent of a vertebral body fracture by measuring the anterior, middle and posterior aspects of the vertebral body and inter-comparing them. With this scale fully utilised within the software it was concluded to review and test its diagnosing accuracy. The original intent was to have the Genant SQ scale fully utilised within the software, including its written diagnosis next to the vertebral body on the image, maximising the information provided to the operator. The results demonstrated this was not possible due to a large overcalling of non-fractures as mild fractures, and a lack of correct classification of fractures, it was concluded to return to the original indication arrow plan. After removing the mild classification from testing the applied Genant SQ scale still picked up five out of the six known mild fractures, this was due to the scale classifying them incorrectly as moderate. As such the third version of the CSPINE-CAD software just had indication arrows and was used for the first and second tests, with the third test using the fourth version (which is exactly the same software just compatible with later versions of MATLAB).

Results – Evaluation of Interoperator and Intraoperator data

Due to results from the Genant testing that showed two radiographers getting different results using the same CSPINE-CAD software, the idea to compare the subjectivity of the manual segmentations was investigated. This was conducted by having five participants each manually segment a selection of the same ten lateral C-spine radiographs (interoperator), each participant's segmentations were then inter-compared. This test was modified and repeated as an intra-comparison (intraoperator) this involved the researcher manually segmenting the same ten radiographs ten times with a time separation to reduce bias, and then each segmentation was inter-compared. Scores produced indicated a high degree of agreement between participants, with Intraoperator scores being slightly more precise than interoperator scores. This consistency suggested that

using manually segmented radiographs is an appropriate source of data for the CSPINE-CAD software to learn from.

Results – First and Second Test

The first test involved one to one testing by five third year radiography students across five radiographs both without and with CAD, the second test involved 11 third year radiography students reviewing 20 images via a PDF screen grab of the radiographs both without and with the CAD software applied. The Main results from the two tests showed that third year radiography students using the CSPINE-CAD software had an increase in sensitivity, and a decrease in specificity when diagnosing lateral C-spine radiographs, compared to when they did not use it. Finding also showed confidence levels increased when using the software with all participants wanting the software as an additional 'pair of eyes'.

Results – Third test

The final groups recruited to the study were 19 junior doctors and seven radiographers reviewing 30 lateral C-spine radiographs. Results from the third test showed that for all confidence thresholds sensitivity goes down and specificity goes up when using CAD. The higher confidence thresholds were investigated separately showing a sensitivity increase and increase in specificity, but only for confidence thresholds above 60%+ (5 or above) with 80% (6) showing an increase in sensitivity and a decrease in specificity when using the CSPINE-CAD software, both results showed a positive effect of CAD on sensitivity. These figures were further investigated by testing the CSPINE-CADs repeatability in indicating the injuries within the 30 test radiographs. These were then separated for reliability with all radiographs scoring 7 or above out of 10, and all radiographs scoring 6.5 or below out of 10 being grouped together. These grouped data showed that the more reliable the CSPINE-CAD is at indicating the injury the higher the after CAD effect. Questionnaire finding showed confidence figures increased in both groups when using the CAD software, with an average increase of 9.24% per participant. With over 73% agreeing it was helpful as a second 'pair of eyes'.

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8.1 DISCUSSION AND LIMITATIONS OF ENTIRE STUDY

Recruitment

The study had many limitations; most notably the difficulties involved with recruitment and the potential for recruitment bias, as participants were recruited either at the UOE or the RD&E, in total across the three tests only 42 participants (first, second and third test combined total) tested the CSPINE-CAD software, so the participants might not be fully representative of the national population which potentially limits the generalisability of the study. The participants were further limited by delays and issues with acquiring the hardware and software for the testing, and the availability of rooms. This meant for the first test participants had to be available during a small testing window of approximately three months, with the second test participants had to be available on one particular day. With the third test participants had more freedom, but were still limited to room booking times coinciding with when they were free, or being available to travel to the UOE medical school at St Luke's. So in all three tests individuals who had originally shown interest could have possibility moved on by the time the testing was organised and began.

A further limitation was the size of the groups; the original aim of the third test was to test 30 participants with 15 being junior doctors and 15 being radiographers. Unfortunately due to issues of drop out and error in understanding as mentioned in section 7.6.1 only a total of 26 participants were tested, four short of the total desired, the participant groups were also unbalanced, with seven radiographers and 19 junior doctors. This meant the opinions and scores of the radiographers were not as fairly represented by the testing as the junior doctors.

Subjectivity and ambiguity

Other limitations include the subjectivity of the answer sheet used in the first and second tests, and how the data was interpreted, also the issues of the ambiguity of the language used, although these was strongly addressed in the revision for the third test.

Radiographs/images available

The small sample of radiographs used was also a limitation (reflected in the CI of the three tests), as was the radiographs all being from the RD&E, and as such were not a fair representation of the UK as a whole, different hospitals might have different protocols and produce better or worse radiographs. Also the types of injuries that could be highlighted by the CSPINE-CAD software might be more common in different age groups depending on the area, meaning the software might have an easier/harder time in indicating them. Although it must be stated generalisability within the radiographs was maintained with no genders, ethnicities or ages being excluded (except the under 18 year olds).

Cofounding variables

There were many potential and unavoidable cofounding variables due to the participants recruited, simple things such as time of day the testing was conducted; if it was just after their shift and thus they may have been tired, apathetic and uninterested in the testing (knowing full well there was no real consequence for an incorrect diagnosis) and thus the CSPINE-CAD software might look more impressive than it was, or vice versa a participant doing the testing prior to work might have been more attentive and spent longer on each radiograph than they would normally, this would show that the CSPINE-CAD was superfluous or ineffective**.** Additionally the experience of the participant showed to have an effect on the results, with the two most experienced participants stating they did not find the CAD useful, and actually lost confidence when using the CAD software. If more participants had had fewer or more years of experience then it might have influenced the usefulness of the CSPINE-CAD software, presuming the less experienced would be influenced more heavily by it, with the more experienced being negatively influenced by it.

Hawthorne effect and analysis paralysis

Another issue was the possibility of the Hawthorne effect [137] due to participants knowing they were doing a test so might have concentrated more and thus improved their performance, knowing logically that a selection of the radiographs must have injuries. This might have reduced the impact the CSPINE-CAD software had, and been the reason for the “hedging” issue described in section 7.3. One issue experienced which may have also limited

results is an issue called “analysis paralysis” [138] this is where the participant is given too much information in this case; alignment curves, arrows and segmented vertebral bodies, so constantly re-questions their decision/diagnosis, which may have also been the reason for the time differences. This may have led to a correct diagnosis being changed, so future versions of the software as stated will only include the indication arrows and neither the alignment curves or segmented vertebral bodies will be visualised, this should reduce the possible effects of this phenomena. Caution should therefore be used when interpreting the results, and these stated limitations (and modifications) may in part account for some of the differences between the tests.

8.2 CONCLUSION

The overall results from the study have no statistical significance, but indicate positives that CSPINE-CAD software can help identify C-spine injuries; this is shown in the first and second tests and in the higher confidence thresholds in the third test. With the addition of a combined total confidence increase from 52.86% to 65.24% after CAD, which is an increase of 10.57% per participant across all three tests (out of a total of 42 participants), and 83% of participants (35 out of 42) finding it helpful as a second ‘pair of eyes’. These results show that there is a need for a CAD system to be utilised in C-spine imaging**.** It must be stated that this version of the CSPINE-CAD software has its issues but based on the literature only one such system currently exists, which has gone no further than segmentation, as such this version should be continue to be developed.

This CSPINE-CAD software is a robust and highly objective program, which learned to segment from multiple sources, it is also integrated with a modified Genant SQ scale utilising indication arrows instead of word definitions that has allowed it a higher degree of accuracy in fracture indication. Combined with the implementation of alignment curve indication arrows it can highlight misalignments in excess of 3 mm.

In conclusion the data gathered suggests that this CSPINE-CAD software is beneficial in diagnosing lateral C-spine radiographs; both in the form of decreasing the percentage of missed or misdiagnosed fractures, and in increasing confidence in junior doctors and radiographers making them more assertive in writing diagnostic comments. This software is still in its infancy but the journey it has so far taken has shown its adaptation and functionality, with further growth this CSPINE-CAD software could reduce the C-spine injuries that are missed, and as it increases in its development, evolution and robustness, it might ultimately save lives.

8.3 FUTURE WORK

This study is still in its infancy and needs to be up-scaled; this can be done in several possible ways:

First by conducting similar studies to the third test, but increasing the number of participants, and the number and diversity of the radiographs, providing greater and more detailed information about the CSPINE-CAD software's limitations and benefits.

The testing could be trialled within the RD&E department by having the software installed on a couple of designated imaging computers, all radiographers, junior doctors would then be trained on both the CSPINE-CAD software and the answer sheet from the third test. Then any C-spine radiographs that come into the department could be reviewed on one of the designated computers with the participants following the same process as the third test method, with the addition of recording the date and time next to the diagnosis. All participants could use the same answer sheet which could then be collected at a nominated time. This data could then be compared to the corresponding reports. This test would be the closest to a true representation of the environment as you could possibly get.

Additionally the testing could be conducted with participants from or at other hospitals, and not just the RD&E, so the data are gathered from a wide range of NHS sources, this would show a higher generalisability of the data, and would

acknowledge any inconsistencies that might be present in the RD&E results.

Another possibility is merging the second and third tests; by creating a screen grab of the CSPINE-CAD software images and combining it with the new more stringent answer sheet. This is controversial due to the issues already stated in section 6.5 regarding the screen grab images not being a true representation of the CSPINE-CAD software, but it would allow two simple advantages which are: participant numbers, and time commitment. The screen grabbed software could be seen by anyone who could open a PDF or even a JPEG; they could then be easily uploaded or emailed, and require no special programs (unlike the CSPINE-CAD that needs MATLAB). Testing could then be done at the convenience of the participant, and could be done anonymously online, along with the questionnaire; it could even be timed based on login and logout sessions and done in small blocks. The invitation could possibly just be sent to radiographers via health and care professions council registered staff (30,044 registered) or to junior doctors via the general medical council, and a CPD certificate could be offered upon completion. This would address the issue of low participant numbers and time dedication needed.

As well as tweaking the testing parameters, the other main issue is with the software itself. As the software grows and evolves certain issues should be addressed which were raised by the participants via the questionnaires:

- The introduction of spinolaminar lines
- Segmentation of C1, peg and C2

The introduction of the spinolaminar lines has been addressed in a recent paper by the City University team (who created the CSPINE-CAD software) where they have started attempting to integrate the spinolaminar lines [139], although it is unknown when this version will be available.

The segmentation of C1 and C2 has not been addressed due to the issues discussed in section 4.2.3. This problem currently persists, but in future work it will hopefully be resolved. The CSPINE-CAD software also needs to develop its vertebral segmentations on degenerative disease, and poorly positioned patients, as these issues affect its repeatability in indicating injuries. Again this

has recently been investigated by the City University team who have looked into solving the degenerative change problem [140], with the hope being that future versions of the CSPINE-CAD software will incorporate this making it more robust and valid. Additionally the Indication arrows that currently highlight misalignment via the software need to be improved, currently rather than highlighting the exact junction (e.g. C5/C6) they indication the vertebral body. This can be misleading to the exact location of the injury, this would also mean the colour coding of the arrows would be redundant as you would only have to look at where the arrow was indicating (this was an issue with one participant in the third test as they had difficulty remembering what colour indicated what type of injury).

Other future developments might expand on the ideas of the participants during the testing, for instance the idea regarding CAD stating measurements might be an interesting development in indicating scoliosis, lordosis, or kyphosis this in turn might help speed up the patient pathway by making the diagnosis quicker. Another example is expanding the CSPINE-CAD software to be used on thoracic or lumbar spines images, foot or ankle measurements giving Bohler's angle, applying facial bones alignment curves, or shentons lines on pelvis radiographs. All of these ideas were suggestions put forward by the participants of examinations they would like to see the CAD software applied to next.

If CSPINE-CAD achieves the future work mentioned, further work would be invaluable in the CSPINE-CADs ability to be implemented into paediatric cervical spine radiograph imaging, and CT spinal imaging. Especially due to the recent revised changes by NICE [141].

APPENDICES

Appendix 1: College of Engineering, Mathematics and Physical Sciences Ethics approval

UNIVERSITY OF EXETER

ETHICS APPROVAL FORM

COLLEGE OF ENGINEERING, MATHEMATICS, AND PHYSICAL SCIENCES

Ethical Guidelines Approval Form

Title of Project: Computer-Aided Detection of Cervical Spine Injuries: A Feasibility Project (1410)	
Names of Researchers: Amy Overington, John Rigby, Vanessa Watts, Chloe Winzar	
Applicants E-mail: aeo209@exeter.ac.uk; jr389@exeter.ac.uk; vw234@exeter.ac.uk; cew222@exeter.ac.uk; k.m.knapp@exeter.ac.uk	**Estimated Start Date:** (DD/MM/YY) **27 / 10 /14**
Research Group: 1410, Medical Imaging	**Supervisor: Karen Knapp & Jenny Bartlett**

Lay Summary (max 400 words):

The cervical spine (the neck region) is a highly flexible part of the spine and is particularly vulnerable to trauma, such as injuries resulting from automobile accidents, falls, and shallow water dives. Dislocation or fracture of the cervical vertebrae has the potential for long-term and life-changing disabilities. Patients suspected of cervical spine injury (CSI) are often assessed using x-ray imaging. However, detection of CSI on the images presents a major challenge for emergency physicians, combining images that can be extremely difficult to interpret, particularly to the less experienced eye, with clinical scenarios that may result in death or serious disability with a failure to establish the correct diagnosis. Unfortunately, up to 20% of cases have a delayed or incorrect diagnosis - this has a significant personal and socioeconomic impact on family members, as well as a large financial burden on the NHS and social services. A paralysed person will incur between £1M and £3M in lifetime medical expenses as well as significant reductions in their quality of life and wellbeing. Therefore, early and accurate detection of a CSI is critical to plan appropriate care and prevent further injury. We propose novel computer-aided detection (CAD) software to aid in detection of dislocations and fractures to the cervical spine. To our knowledge, there is no existing CAD software designed for cervical spine injuries imaged with x-ray. Our research will be the first to produce alignment curves so that the physician can more accurately determine if a vertebra is displaced, as well as prompts designed to direct the physician's attention to a region of the image suspected of injury. The physician would use the CAD as a "spell-checker" for radiological images of the cervical spine. In addition to research and development of the software, the project includes a clinical validation, to determine the effect the CAD has on the ability of human readers to detect CSIs. The aim of this study is to trial the software using experienced (3rd year) and inexperienced student (2nd year) student radiographers to assess the impact on their diagnostic ability when interpreting C-spine images. Previous research has demonstrated third year radiography students to have similar diagnostic accuracy to radiology registrars, making them an ideal surrogate for junior doctors in the emergency department. Qualitative reviews of the software will also be sought through focus groups and questionnaires.

Please mark (x) as appropriate	*Yes*	*No*	*n/a*
Does your study involve work with animals?		x	
Does this study involve human tissue?		x	

UNIVERSITY OF EXETER

ETHICS APPROVAL FORM

Track A: No significant ethical implications *Please mark (x)as appropriate*

Yes	*No*	*n/a*
	x	

I consider that this project has no significant ethical implications to be brought before the Departmental Ethics Committee.

Briefly, what are the details of the experiment including the number and type of participants, methods and tests to be used (i.e. the procedure).

A developmental version of CSPINE CAD software will be trialled on up to 120 students (60 second years and 60 third years). All students will be offered the opportunity to participate in the study and participation taken as inferred consent. However, it will be made clear that this is not a requirement of their programme and participation is voluntary. The students will review set of up to 50 c-spine images with and without the use of the CAD software on 2 separate occasions. The range of complexity of the cases will be matched across the two sets of images and students will be split into two groups, one who use the CAD software first viewing and the other group who use it on the second viewing (a cross-over A-B design). Diagnostic accuracy will be calculated for both sets of images and with and without the software using ROC curves for the second and third year students. Students will be asked to complete questionnaires regarding their opinions and experience of the CAD software and whether they are willing to participate in small focus groups to evaluate their opinions further. Each image viewing will take approximately an hour and the questionnaire no more than 20 minutes. The focus groups will be for the duration of 1 hour, with a maximum of 6 students in each one. Thematic analysis will be applied to evaluate the student experiences and opinions. Students will be fed back their results for the image viewings along with the model reports for each c-spine case so they can utilise this for their own professional development.

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ETHICS APPROVAL FORM

Track B: Possibility of ethical implications *Please mark (x)as appropriate*

Yes	*No*	*n/a*

I consider that this project may have ethical implications that should be brought before the Departmental Ethics Committee, and/or it will be carried out with children or other vulnerable populations.

Purpose of project and its academic rationale.	
Brief description of methods and measurements.	
A clear but concise statement of the ethical considerations raised by the project and how you intend to deal with them.	

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ETHICS APPROVAL FORM

Participants
Human research

- Recruitment methods
- Number
- Age
- Gender
- Exclusion/inclusion criteria

Animal research

- Location of study site
- Method of obtaining/ marking/identifying subjects
- Handling procedures for field experiments

Consent and participant information arrangements. (Not relevant for animal research) Please attach intended information and consent forms.

Consent and participant debriefing. (Not relevant for animal research) Please attach intended debriefing information.

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ETHICS APPROVAL FORM

Consent *Please mark (x) as appropriate*	*Yes*	*No*	*n/a*
Will you describe the main experimental procedures to the participants in advance, so that they are informed in advance what to expect?			
Will you tell the participants that their participation is voluntary?			
Will you obtain a written consent for participation?			
Will you tell the participants that they may withdraw from the research at any time and for any reason?			
Will you tell participants that their data will be treated with full confidentiality, and that, if the results are published, it will not be identifiable as theirs?			
Will you debrief participants at the end of their participation (i.e. give them a brief explanation of the study)?			

If you have ticked No to any of the questions in the section above and you consider that your project has no significant ethical implications, please give an explanation here	

Vulnerable Groups *Please mark(x) as appropriate*	*Yes*	*No*	*n/a*
School children (under 18 years of age)			
People with learning or communication difficulties			
Those at risk of psychological distress or otherwise vulnerable			
People in custody			
People engaged in illegal activities (e.g. drug taking)			

Do participants fall into the following categories?

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ETHICS APPROVAL FORM

Projects involving human samples

Please mark (x) as appropriate

The project will use DNA from:		
	Stock (anonymous)	
	Newly recruited participants	

Please mark (x) as appropriate	*Yes*	*No*	*n/a*
Subjects will be informed of the aims and implications of the study procedure/information attached).			
Subjects will be notified of the results on request or automatically			
Participants will be advised on the legal and medical implications following from knowledge of their own results			
Tissue samples from the study will be destroyed upon completion			
If not, for how many years will tissue samples from the study kept?		**Years**	

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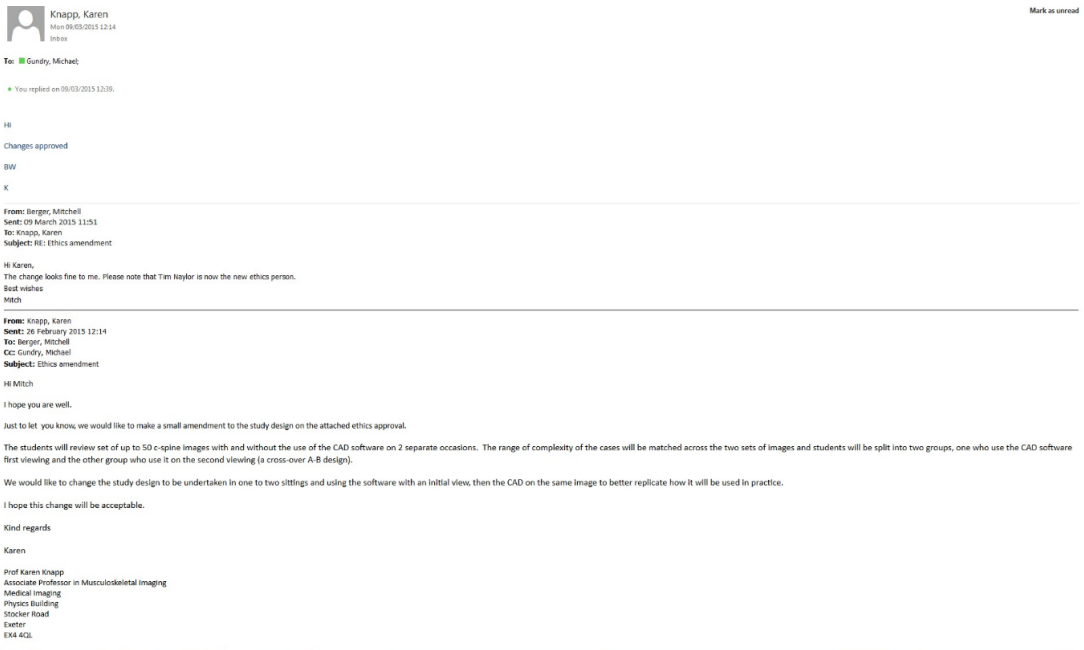
ETHICS APPROVAL FORM

Risk Assessments

The study has been assessed for risk and the following risk assessments are relevant (please attach any new Risk Assessment and COSHH forms on this page or enter the title of any existing relevant forms below).

Signed..M Berg..... Date..28/8/14.....

Appendix 2: Modifications to ethics of the first and second test



Knapp, Karen
Mon 09/03/2015 12:14
Inbox

Mark as unread

To: Gundry, Michael;

You replied on 09/03/2015 12:30.

Hi

Changes approved

BW

K

From: Berger, Mitchell
Sent: 09 March 2015 11:51
To: Knapp, Karen
Subject: RE: Ethics amendment

Hi Karen,
The change looks fine to me. Please note that Tim Naylor is now the new ethics person.
Best wishes
Mitch

From: Knapp, Karen
Sent: 26 February 2015 12:14
To: Berger, Mitchell
Cc: Gundry, Michael
Subject: Ethics amendment

Hi Mitch

I hope you are well.

Just to let you know, we would like to make a small amendment to the study design on the attached ethics approval.

The students will review set of up to 50 c-spine images with and without the use of the CAD software on 2 separate occasions. The range of complexity of the cases will be matched across the two sets of images and students will be split into two groups, one who use the CAD software first viewing and the other group who use it on the second viewing (a cross-over A-B design).

We would like to change the study design to be undertaken in one to two sittings and using the software with an initial view, then the CAD on the same image to better replicate how it will be used in practice.

I hope this change will be acceptable.

Kind regards

Karen

Prof Karen Knapp
Associate Professor in Musculoskeletal Imaging
Medical Imaging
Physics Building
Stocker Road
Exeter
EX4 4QL

Appendix 3: University of Exeter medical school research ethics approval

UNIVERSITY OF EXETER MEDICAL SCHOOL RESEARCH ETHICS COMMITTEE

APPLICATION FORM

FOR

RESEARCH ETHICS APPROVAL

Name of Applicant:	Michael Gundry
Project Title:	Investigating the acceptability and efficacy of computer-aided detection software for cervical spine fracture diagnosis
Date:	23/02/2015
Version Number: *(1 for first time applications)*	2
Application Number: (For Ethics Committee use only)	15/02/064

SECTION A: GENERAL

1 Title of the Study:	Can CSPINE-CAD software for the cervical spine assist junior doctors and radiographers in assessing lateral c-spine radiographs and aid accurate diagnoses?		
Project Start Date:	01/05/2015	Project End Date:	01/10/2015

2 Full name of applicant: Michael John Gundry					
Position Held:	Masters student (and qualified radiographer)				
Institution:	Exeter University	Course Title (if student):	Masters by research in medical imaging		
Location:	Brixham				
Email:	mg361@exeter.ac.uk	Telephone:	01803 857341	Fax:	
Please provide details of any and all other researcher(s) who will work on the research project: (if more than three researchers please extend table as appropriate)					
Name(s):	Professor Karen Knapp				
Position Held:	Associate Professor in musculoskeletal imaging/Radiographer				
Location:	Exeter University				

Contact details (e-mail/ telephone/fax):	K.M.Knapp@exeter.ac.uk
Name(s):	Dr Judith Meakin
Position Held:	Lecturer/Medical physicist
Location:	Exeter University
Contact details (e-mail/ telephone/fax):	J.R.Meakin@exeter.ac.uk
Name(s):	Dr Andy Appelboam
Position Held:	ED Consultant
Location:	Royal Devon and Exeter Hospital
Contact details (e-mail/ telephone/fax):	
Name(s):	Dr Adam Reuben
Position Held:	ED consultant
Location:	Royal Devon and Exeter Hospital
Contact details (e-mail/ telephone/fax):	
Name(s):	Associate Professor Obi Ukoumunne
Position Held:	Associate Professor in medical statistics
Location:	Exeter University
Contact details (e-mail/ telephone/fax):	O.C.Ukoumunne@exeter.ac.uk
Name(s):	Dr Greg Slabaugh
Position Held:	Associate Professor/Computer scientist
Location:	City University
Contact details (e-mail/ telephone/fax):	Gregory.Slabaugh.1@city.ac.uk

3 Is this proposal part of a PhD?	Yes		No	x

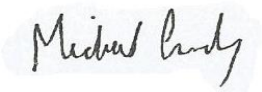
If yes, please complete the remainder of this section.			
Year of Study:			
Name of Primary Supervisor/Director of Studies:		Position held:	
Location:			
Contact details (email/telephone/fax):			
Name of Second Supervisor:		Position held:	
Location:			
Contact details (email/telephone/fax):			

4 Declaration to be signed by the Applicant or the supervisor in the case of a student:

- I confirm that the research will be undertaken in accordance with the University Ethical Framework, Good Research Practice Policy, and Code of Research Ethics.
- I will undertake to report formally to the relevant University Research Ethics Committee for continuing review approval.
- I shall ensure that any changes in approved research protocols are reported promptly for approval by the relevant University Ethics committee.
- I shall ensure that the research study complies with the appropriate regulations and relevant University of Exeter policies on the use of human material (if applicable) and health and safety.
- I shall ensure that any external permissions necessary for the research to be undertaken are obtained prior to the research taking place.
- I am satisfied that the research study is compliant with the Data Protection Act 1998, and that necessary arrangements have been, or will be, made with regard to the storage and processing of participants' personal information and generally, to ensure confidentiality of such data supplied and generated in the course of the research.

  (Note: Where relevant, further advice is available from the University of Exeter Medical School {UEMS} Data Protection Officer).
- I will ensure that all adverse or unforeseen problems arising from the research project are reported in a timely fashion to the Chair of the relevant University Research Ethics Committee.

- I will undertake to provide notification when the study is complete and if it fails to start or is abandoned.
- I have met and advised the student on the ethical aspects of the study design and am satisfied that it complies with the current professional (*where relevant),* School and University guidelines.
- I have read this application and believe it to be scientifically and ethically sound



Signature of Applicant: ……..
Date:21/01/15…….

Signature of Supervisor:……  .....Date…12/01/2015……

Departmental Approval

- I give my consent for the application to be forwarded to the University of Exeter Medical School Research Ethics Committee with my recommendation that it be approved.
- I confirm that this submission has been appropriately peer reviewed.

Signature of Head of Research Institute/Centre or Vice Dean (Education) (or approved nominee)

Signature:  **Date: 26/01/2015**

Printed Name: Prof Stuart Logan

5 Name and affiliation of Peer Reviewer(s)			
Name:	Independent Scientific Review	Position held:	RDS Consultant
Institution:	Royal Devon and Exeter NHS Foundation Trust		
Contact details (email/telephone/fax):	01392 406144 **rohanchauhan@nhs.net**		

SECTION B: FUNDING

6 If the research is externally funded, what is the source of the funding?

6.1 What is the value of the grant? £10,201				
6.2 Are there any conditions attached to the funding which could have an impact on this application?				
YES	x	NO		
If yes, please specify. Subject to ethics and R&D approval.				

SECTION C: THE RESEARCH

7 In lay terms, please provide an outline of the proposed research, including:

- background
- objectives / hypothesis
- research methodology
- contribution of research
- justification of benefit
- be specific about focus groups
- state whether this is forming part of a PhD

(*max 1000 words)*.

Background

The cervical spine (the neck region) is a highly flexible part of the spine which is particularly vulnerable to trauma. Dislocation or breaks of the neck have the potential for long-term and life-changing disabilities. Patients suspected of neck injury are often assessed using x-rays. However up to 20% of cases have a delayed or incorrect diagnosis, which can result in paralysis, or even death. We propose novel computer-aided detection software, "CSPINE-CAD", to aid diagnosis of injuries to the cervical spine through assisting inexperienced and experienced doctors and other healthcare workers. More accurate diagnosis will improve healthcare outcomes for patients improve life for their friends and relatives and reduce the financial burden to the NHS in caring for those with preventable paralysis. This study will test the CSPINE-CAD software and in junior doctors and radiographers using it.

This ethics application is sought to undertake testing of CSPINE-CAD software in junior doctors and qualified radiographers; those who will frequently be first in line to evaluate the images. Accurate identification of a fracture on the lateral C-spine image by a radiographer enables adjustment of radiographic technique or could provide an indication for a direct transfer to computed tomography (CT) to better characterise the fracture. In time, this could lead to new ways of working where radiographers request the CT based on their interpretation of a lateral C-spine image, thus reducing the number of times the patient is returned to the emergency department (ED) between imaging; saving time, improving workflow and reducing costs. Furthermore, increased confidence and accuracy interpreting C-spine radiographs by junior doctors can reduce the time the patient is waiting for a consultant to review the image prior to further imaging or even discharge. Changes in patient pathway may reduce the burden on the ED and increase patient throughput time, improving diagnostic accuracy, ensuring a

better experience for the patient and releasing capacity within the ED. Developing software which could act as a "spell checker" for c-spine imaging could be the first step in underpinning changes. Furthermore, the use of CSPINE-CAD, is the software works well, could be used to help reduce the number of missed cervical spine fractures in busy ED's.

Aims and objectives

Aims:

- The aim of this study is to evaluate the acceptability and efficacy of CSPINE-CAD software for the diagnosis of fractures and dislocations in this key anatomical area.

Objectives:

- To evaluate the accuracy of qualified radiographers in diagnosing C-spine bony injuries with and without the use of CSPINE-CAD software;
- To evaluate the accuracy of junior doctors in diagnosing C-spine bony injuries with and without the use of CSPINE-CAD software;
- To evaluate the acceptability of the CSPINE-CAD software by qualified radiographers and junior doctors.

Research methodology

This is a feasibility study to determine the appropriate dataset size, complexity, recruitment pathways, image viewing arrangements and acceptability of the software. An intervention will be used to provide datasets which the participants can review both with and without the use of the CSPINE-CAD software. The participants will be recruited through, flyers, e-mails and notification at staff meetings and training sessions. They will be asked to spend approximately 1-1hr 45 minutes to complete the total study (in a pilot it took an average of 41.8 minutes for 10 3rd year radiography students to review 20 lateral c-spine images, sign the consent form, and fill in the questionnaire), and will be provided with a continuing professional development certificate in return. 15 Junior doctors (F1 and F2's) and 15 radiographers will be recruited to evaluate the software.

A set of 30 cases will be developed. The cases will include a range of normal, subtle fractures and more obvious fractures. The radiologist reports of the radiograph series and the CT scans where patients have had supplementary imaging will be used to define the "gold standard" report.

The researcher will visit each of the participants for a one to one data collection meeting where they will be provided with the images and the software on a study laptop to ensure the same viewing conditions for all participants.

Participants will be provided with 30 cases each to review independently and document their diagnoses with the researcher present. The participants will also undergo training to use the CSPINE-CAD software prior to starting (in a pilot study it took on average 12 minutes to train 3rd year radiography students on the software). After reviewing the first case a diagnosis will be reached and then the

CAD software will be applied, and any corrections or additions to the diagnosis will then be placed in a separate box below the original diagnosis. This reflects the true use of how the software will be implemented in its 'spell checker' function making the results more valid.

. It is anticipated that the image viewings will take in the region of one hour to complete all the cases provided.

Participants will also be asked to complete a survey regarding their experience of using the CSPINE CAD-software, which should take no longer than 15 minutes. Basic information on the participants including time since qualification and any postgraduate imaging qualifications will also be recorded.

Upon completion of the study, all participants will be provided with feedback of their performance along with their CPD certificate.

Include any questionnaires, psychological tests, etc. at the end of your application.

8 Location of study

8.1 Where will the study take place? Royal Devon and Exeter Hospital

8.2 If the study is to be carried out overseas, what steps have been taken to secure research and ethical permission in the country of study? (Please attach evidence of approval if available.)

9 Multi-centre and off-campus studies

If this is a multi-centre or off-campus study, please answer the appropriate questions below; otherwise, go to Question 11.

9.1 Does this project involve a consortium (other research partner organisations)?

YES	x	NO		

If yes, please complete the details below in Question 9.2.

9.2 Who has overall responsibility for the study?

Collaboration between Exeter University, City University and the Royal and Devon Exeter Hospital. Collaborations agreements are in place and have been agreed via the respective legal teams

Please provide details of the contractual agreement between UEMS and the other organisation(s).

9.3 Is this an off-campus study?

YES	x	NO		

If yes, please provide signed, written permission from an appropriate level of management within the relevant organisation(s). See Appendix 5

10 Has approval been sought from other Ethics Committees and LRECs?

YES		NO	x	

Please enclose copies of approval letters, where applicable.

11 Who will have overall control of the data generated?

Exeter University – Michael Gundry and Karen Knapp

12 How do you propose to disseminate the results of your research?

The results will be presented at the UKRC, the national imaging conference for radiography and radiology and local and national emergency medicine conferences. If the results are sufficiently strong, then a paper will be written for publication in the skeletal radiology, radiography or an emergency medicine journal.

13 METHODS AND PROCEDURES

Describe the nature of the task required of participants and the various precautionary measures to be taken to avoid harm or discomfort if appropriate. If the study is likely to cause discomfort or distress to subjects, estimate the degree and likelihood of discomfort or distress.
(Include a copy of any questionnaire / survey form to be used at the end of your application)

As stated 15 Junior doctors (F1 and F2's) and 15 radiographers will be invited to evaluate the CAD C-spine software. They will be asked to spend approximately 1-1.5 hours to evaluate 30 images within a dataset and fill in a questionnaire, it should take no more than 1.5 hours for 30 cases – these radiographers and doctors will be doing this in everyday practice, so they should be quick at interpreting the radiographs. This is a generous time as in practice we would expect one case per 2 minutes. Also as stated it took 3rd year radiography students on average 41.8 minutes to complete a set of 20 c-spine lateral images and this time includes filling in the consent form and the questionnaire There should be no harm involved with the only possible discomfort being ergonomically produced during prolonged seating. The area chosen to conduct the study will be quiet, room temperature and with controlled lighting. All participants will be trained on the software which is very user friendly, and only involves clicking on the vertebral body centres, and then clicking the "perform segmentation" button, it will then apply the CAD software. The participant then clicks the "next" button to load the next image. Based on data from the pilot it will take approximately 12 minutes to train an individual, who will be taught by myself (Michael Gundry), I will remain in the room but not in a position to view the screen. Each participant will review the same 30 images but each in a different order (these will be rearranged independently from me so I will not know what order the images will be) All participants will be informed of the study

and will have the right to withdraw and stop at any point should they wish to.

Following completion of the study, feedback will be provided to those who wish to have it on their performance compared to model reports along with a continuing professional development (CPD) certificate.

13.1 Does the study include any of the following interventions / invasive procedures?

	YES	NO		YES	NO
Participant-observation / non participant-observation	☒	☐	Self-completion questionnaires	☒	☐
Interviews	☐	☒	Video / audio recording	☐	☒
Focus Groups	☐	☒	Administration of substance / drug (e.g. caffeine / doubly labeled water etc)	☐	☒
Physical examination	☐	☒	Manipulation of diet	☐	☒
Arterial puncture*	☐	☒	Venepuncture*	☐	☒
Urine sample*	☐	☒	Fingertip blood sample*	☐	☒
Body Imaging (e.g. MRI, DEXA, X-rays)	☐	☒	Saliva sample*	☐	☒
* if yes, will samples be retained for subsequent testing for factors other than described in this proposal?				☐	☐
If yes, will samples be anonymised?				☐	☐

If you are using human tissue in your project, you must complete section E.

14 Products and devices

14.1 Does the research involve the testing of a product or device?

YES	x	NO		
If yes, please describe it.				
CSPINE-CAD software version 1.0, which has been developed to assist in c-spine image interpretation.				
14.2 If this research involves a drug, is it being used in accordance with its licensed uses?				
YES		NO		
If no, please explain why:				
N/A				

SECTION D: THE PARTICIPANTS

For the purposes of this section, "participants" include human subjects, their data, their organs and/or tissues. For participants to be recruited to the research, please state:

15 Number of participants:	30

16 If data are to be collected on different sites, please state the number of participants at each site:

Site 1:		Number of participants:	
Site 2:		Number of participants:	

(insert additional sites if necessary)

17 How have you arrived at this number? Please state proposed inclusion/exclusion criteria. If appropriate has the protocol been reviewed by a Statistician?

15 junior doctors and 15 qualified radiographers have been selected as these numbers are feasible for recruitment and provide an overall number (30 participants) sufficient to provide means and standard deviations upon which to base power calculations for future studies and funding applications.

18 Age group or range *(e.g., under 60s)*:			Any age as long as they meet the qualified requirements i.e. junior doctors and qualified radiographers			
18.1 Sex:	Male	x		Female	x	

19. Is this a single sex study?					
	YES		**NO**		**x**
If yes, please justify the reason(s) for gender selection					

While some studies explicitly focus on gender specific experiences, care should be taken to ensure that women or men are not unnecessarily excluded from participating in research.

20 Do participants belong to any of the following vulnerable groups?					
Children:	**YES**		**NO**	x	
Participants unable to give informed consent in their own right *(e.g., people with learning difficulty)*:					
	YES		**NO**	x	
Other vulnerable groups (please specify)					
	YES		**NO**	x	

Care will need to be taken to formulate inclusion/exclusion criteria that clearly justify why certain individuals are to be excluded, to avoid giving the impression of unnecessary discrimination. On the other hand, the need to conduct research in "special" or "vulnerable" groups should be justified and it needs generally to be shown that the data required could not be obtained from any other class of participant.

If the answer to any of the above is yes, please complete Questions 21 to 25; otherwise proceed to Question 26.

21 Please explain why it is necessary to conduct the research in such vulnerable participants and whether required data could be obtained by any other means.
22 Please state what special or additional arrangements have been made to deal with issues of consent and the procedures to safeguard the interests of such participants.

23 Please describe the procedures used to ensure children (i.e., persons under 18 years) are able to provide consent/assent to participation.
24 If appropriate, please state whether and how parental consent, or the consent of the legal guardian and/or order/declaration of the court, will be sought in relation to the participation of children in the research.
25 If the participant is unable to consent in their own right, will you seek the prior approval of an informed independent adult and any other person or body to the inclusion of the participant in the research?

	YES		**NO**		

State precisely what arrangements will be put in place.

Recruitment and Selection
The Research Ethics Committee will need to be satisfied with the effectiveness and propriety of recruitment and selection procedures given the participant involved, e.g., that the participant will not feel in any way obliged to take part, that advertisements do not appear to offer inducements. The Committee will be particularly interested in cases where a participant's relationship with the investigator could raise issues about the voluntary status or motive of the participant's involvement in the research (e.g., students).
26 How will the participants in the study be selected, approached and recruited (please indicate the inclusion and exclusion criteria)?
The participants will be recruited through, flyers, e-mails and notifications at staff meetings and training sessions. The flyers will be put up in staff rooms with a contact email address. During any of the main meetings within the hospital (say a weekly one) the research proposal will be introduced, this is to make individuals aware of it, this will include the benefits and possible future implications and the awarding of a CPD certificate. It will be clearly stated as voluntary, and anyone (within the inclusion criteria) interested can volunteer. Inclusion: F1s and F2s (junior doctors) and qualified radiographers

Exclusion: Senior doctors, radiography students See Appendix 7 for flyer and Appendix 8 for email					
If you are proposing to advertise, please include a copy of the advert to be used at the end of your application.					
27 Where are you recruiting the participants?					
Royal Devon and Exeter Hospital					
28 Relationship of participant to investigator:		Fellow medical professionals			
29 Will the participants take part on a fully voluntary basis?					
	YES	x	**NO**		
30 Will students (e.g. PCMD, UEMS, other Schools or Colleges) be involved as participants in the research project?					
	YES		**NO**	x	
If yes, please provide full details.					
31 Will payments or other inducements be made to participants?					
	YES		**NO**	x	
If yes, give amounts, type and purpose.					
Information to Participants and Consent					
32 Will participants be informed of the purpose of the research?					
	YES	x	**NO**		
If no, please explain why.					
33 Will the participants be given a written information sheet?					
	YES	x	**NO**		
If yes, please use the sample at Appendix 1					
If no, please explain why and delete Appendix 1.					
34 Will written consent be obtained?					
	YES	x	**NO**		
If yes, please use the sample at Appendix 2					
If no, please explain why and delete Appendix 2.					

35 Where potential participants will/may suffer from any difficulties of communication, state the methods to be employed both to present information to the participants and achieve consent. *If written, please include a copy at the end of your application.*
36 Ensure that the Information Sheet includes details of the participants' right to withdraw from the study at any time without penalty.
Where relevant (should incidental significant findings emerge during the course of a study)

36.1 Will any information be given to the participants' GP (if deemed necessary)?					
	YES		**NO**	x	
36.2 Have the participants consented to having their GP informed?					
	YES		**NO**	x	

37 Please state what measures will be taken to protect the confidentiality of the participant's data (i.e., arising out of the research and contained in personal data).
The information will be recorded directly onto encrypted and password protected laptop. The data will be de-identified and moved on to the University of Exeter's servers behind a password user account and also stored within the Royal Devon and Exeter Hospital. Personal data such as name and e-mail address will be held separately and will be used to return performance and CPD certificates at the end of the study.
38 How will the data be stored during the life of the project ?
On encrypted and password protected computers and laptops at the University of Exeter and within the Royal Devon and Exeter Hospital. Any data transferred will be on a password protected USB and will not include any personal information (i.e. names and email addresses)
39 University of Exeter Guidelines state that primary data generated in the course of research must be kept securely in paper or electronic format, as

appropriate and held normally for a period of five years (or as required by the funding body) after the completion of a research project. http://www.exeter.ac.uk/research/toolkit/throughout/ethics/goodpractice/ **Please provide details of how data will be stored, how long the data will be retained following completion of the study and how the data will be disposed of once this period has ended**
The data will be stored on a password protected laptop with data moved to Exeter Universities servers behind an password protected user accounts, additionally during analysis this non personal data will be placed onto a password protected USB stick and moved onto my own personal password protected laptop to analyse and write up the results. Ultimately this non personal data will be written up with a paper copy forming part of my thesis, again this data used will not contain any personal information. The personal information will be destroyed within 6 months of completion of the study.
40 Who will be ultimately responsible for data storage and disposal for this project?
Myself (Michael Gundry), Professor Karen Knapp (for the laptop check and Exeter servers), Dr Andy Appelboam, Dr Adam Reuben to check the RD&E servers.
41 How will participants be informed of the results of the study if they so wish?
Email address will be taken (and stored separately) and used to disseminate results of the research and CPD certificates.

42 Risk to research participants				
42.1 do you think there are any ethical problems or special considerations/hazards with the proposed Study? If so, please describe				
No				
43 Does your proposed study require a Health and Safety risk assessment and if so, has this been carried out?				
YES		NO	x	
44 Are there any potential conflicts of interest arising from the project, deriving from relationships with collaborators/sponsors/participants/interest groups?				

	YES		NO	x	
Please disclose all relevant personal and commercial interests.					
This is an off-shoot of an EPSRC funded study which supported the development of the software. One of the requirements was to have an external company involved and this is Optasia Medical Ltd. There is a collaboration agreement drafted using the legal team and approved by the four partners (University of Exeter, City University, RD&E and Optasia Medical) which underpins all of this work. Therefore Optasia Medical will not be directly involved with the study, but the results will extend the scope of the previous EPSRC project.					

SECTION E: USE OF HUMAN TISSUE (as defined in the Human Tissue Act 2004)
http://webarchive.nationalarchives.gov.uk/20130107105354/http://www.dh.gov.uk/prod_consum_dh/groups/dh_digitalassets/@dh/@en/documents/digitalasset/dh_4103686.pdf

*** Please contact Jackie Whatmore (DI, St. Lukes's and Streatham Campuses) J.L.Whatmore@exeter.ac.uk , Gillian Baker (DI, Research Innovation and Learning Development Centre) g.c.baker@exeter.ac.uk or Nick Church n.j.church@exeter.ac.uk for further information.**

If you wish to store any human samples you must inform the relevant Designated Individual (DI) and you will need to complete an Application to Store Human Samples Form.

45 Will human tissue or other biological material will be used?

* *If no, please proceed to final checklist and delete this section from your application form.*

	YES		NO	x	

CHECKLIST

Please ensure that you have completed all sections of this application and included any relevant information **within the application form file.**

- Questionnaires, Psychological Tests
- Relevant correspondence relating to involvement of collaborating department/s, other institutions
- Peer Review report and your response to the reviewer's comments.
- Appendix I if appropriate
- Appendix II if appropriate
- Appendix III if appropriate

- Any advertisement for the proposed research
- If using drugs, all relevant correspondence with the pharmaceutical/industrial company; full declaration of financial or direct interest, copies of certificates: CTC/CTX/DDX etc and relevant correspondence relating to agreed arrangements for dispensing with the pharmacy
- Copy of lead applicant's CV

IT IS ESSENTIAL THAT ALL DOCUMENTATION IS INCLUDED WITHIN THE APPLICATION DOCUMENT AND SUBMITTED AS ONE ELECTRONIC FILE.

Please ensure you have saved the Application Form appropriately and included a date and version number (No 1 for first time applications) on the front page. Electronic signatures are required from ALL persons signing the application form and peer review.

When complete, please save your application as either a word document or pdf document and forward to uemsethics@exeter.ac.uk

Attachments/Appendices within ethics application

Royal Devon and Exeter NHS Foundation Trust | NHS | University of Exeter Medical School

Can CSPINE-CAD software for the cervical spine assist junior doctors and radiographers in assessing lateral c-spine radiographs and aid accurate diagnoses?

UEMS REC REFERENCE NUMBER: *Apr15/B/064*

INFORMATION SHEET FOR *PARTICIPANTS*
VERSION NUMBER 2.1 : DATE 22/04/2015

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you decide to participate we thank you. If you decide not to take part we thank you for considering our request. This research is funded by the Royal Devon and Exeter NHS Foundation Trust as via their small grant funding scheme.

What is the aim of the project?
Aims:

- The aim of this study is to evaluate the acceptability and efficacy of CSPINE-CAD software for the diagnosis of fractures and dislocations in this key anatomical area.

Objectives:

- To evaluate the accuracy of qualified radiographers in diagnosing C-spine bony injuries with and without the use of CSPINE-CAD software;
- To evaluate the accuracy of junior doctors in diagnosing C-spine bony injuries with and without the use of CSPINE-CAD software;
- To evaluate the acceptability of the CSPINE-CAD software by qualified radiographers and junior doctors.

Description of participants required

We require 15 junior doctors and 15 qualified radiographers

What will participants be asked to do?

Should you agree to take part in this project, you will be asked to review a set of 30 C-Spine images and using our answer sheet write down anything you see, for each image CAD will be applied and any modifications to your diagnosis will be noted underneath. At the end you will be asked to fill in a questionnaire asking you about your experiences.

Time commitment

The time to complete this study will take between an hour and an hour and 45 minutes; this will include approximately 10 minutes being trained to use the software, an hour for the image analysis, and 10 minutes to complete the questionnaire.

Can participants change their mind and withdraw from the Project?

You may withdraw from participation in the project at any time without any disadvantage to yourself of any kind.

What data or information will be collected and what use will be made of it?

The data collected from the answer sheet and questionnaire will be used to analyse the accuracy of the CAD software, this will involve comparing the results received against the "gold standard" and inter comparison between all involved especially on confidence and opinion questions

Results of this project may be published but any data included will not be individually identifiable.

Participants in this project will be provided with a copy of the final report.

The data collected will be securely stored in such a way that only Professor Karen Knapp and Michael Gundry a master's student will be able to gain access to it. I understand that data collected during the study may be looked at by individuals from the Research Team only, from regulatory authorities or from the NHS Trust, where it is

relevant to my taking part in this research. I give permission for these individuals to have access to my records. I understand that the information will be kept confidential

Why me?
We are looking at specifically radiographers and junior doctors as this software will primarily affect you as front line professionals, and may provide useful in a clinical setting.

What if participants have any questions?

If you have any questions about our project, either now or in the future, please feel free to contact either:-
Michael Gundry (Masters by Research student) or Professor Karen Knapp

Exeter university
mg361@exeter.ac.uk

Exeter University
K.M.Knapp@exeter.ac.uk

Complaints

If you have any complaints about the way in which this study has been carried out please contact the Chair of the University of Exeter Medical School Research Ethics Committee:-

Peta Foxall, PhD
Chair, UEMS Research Ethics Committee
Email : P.J.D.Foxall@exeter.ac.uk

This project has been reviewed and approved by the University of Exeter Medical School Research Ethics Committee

Royal Devon and Exeter NHS Foundation Trust

Can CSPINE-CAD software for the cervical spine assist junior doctors and radiographers in assessing lateral c-spine radiographs and aid accurate diagnoses?

UEMS REC REFERENCE NUMBER: *Apr15/B/064*

CONSENT FORM FOR PARTICIPANTS VERSION NUMBER: 2.1 DATE 22/04/2015

I have read the Information Sheet Version Number 2.1 Dated 22/04/2015 concerning this project and understand what it is about. All my questions have been answered to my satisfaction. I understand that I am free to request further information at any stage. I know that:

		Initials
1.	my participation in the project is entirely voluntary;	
2.	I am free to withdraw from the project at any time without any disadvantage;	
3.	the data email addresses, questionnaires and answer sheets will be retained in secure storage;	
4.	Data will be retained for up to 5 years in an anonymous format and I consent for its use in related studies and systematic reviews	
5.	The results of the project may be published but my anonymity will be preserved.	
6.	I understand that data collected during the study may be looked at by individuals from the Research Team only; from regulatory authorities or from the NHS Trust, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my records. I understand that the information will be kept confidential.	

I agree to take part in this project.

..... ……. .....
(Printed name of participant) (Signature of participant) (Date)

..... ……. .....
(Printed name of researcher) (Signature of researcher) (Date)

This project has been reviewed and approved by the University of Exeter Medical School Research Ethics Committee

Royal Devon and Exeter NHS Foundation Trust

University of Exeter Medical School

CSPINE-CAD Answer sheet

ID Number _____ Date _____

For each case reviewed, please rate the boxes relating to the corresponding vertebra to indicate a fracture if one is present and the boxes corresponding to the inter-vertebral disc space to indicate misalignment (which may be associated with fracture/dislocations) between two or more vertebrae. This needs to be done for the first read, without the use of CSPINE-CAD and for the second read with the use of CSPINE-CAD. Please note your level of confidence for the presence of a fracture or misalignment when **1 is equal to no fracture or misalignment, 3 is equivocal and 6 is where you are certain there is a fracture or misalignment**.

Please add any comments on the image as you wish, for example if the image is sub-optimal or if degenerative change is confounding your diagnosis.

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
EXAMPLE	[1] C1 [1] C2 [1] C3 [1] C4 [1] C5 [1] C6 [1] C7 [1] C1-C2 [1] C2-C3 [3] C3-C4 [1] C4-C5 [1] C5-C6 [1] C6-C7 [1] C7-T1	[1] C1 [1] C2 [1] C3 [1] C4 [1] C5 [1] C6 [1] C7 [1] C1-C2 [1] C2-C3 [5] C3-C4 [1] C4-C5 [1] C5-C6 [1] C6-C7 [1] C7-T1	Minor degenerative changes noted C3 to C6.
1	[ ] C1 [ ] C2 [ ] C3 [ ] C4 [ ] C5 [ ] C6 [ ] C7 [ ] C1-C2 [ ] C2-C3 [ ] C3-C4 [ ] C4-C5 [ ] C5-C6 [ ] C6-C7 [ ] C7-T1	[ ] C1 [ ] C2 [ ] C3 [ ] C4 [ ] C5 [ ] C6 [ ] C7 [ ] C1-C2 [ ] C2-C3 [ ] C3-C4 [ ] C4-C5 [ ] C5-C6 [ ] C6-C7 [ ] C7-T1	
2	[ ] C1 [ ] C2 [ ] C3 [ ] C4 [ ] C5 [ ] C6 [ ] C7 [ ] C1-C2 [ ] C2-C3 [ ] C3-C4 [ ] C4-C5 [ ] C5-C6 [ ] C6-C7 [ ] C7-T1	[ ] C1 [ ] C2 [ ] C3 [ ] C4 [ ] C5 [ ] C6 [ ] C7 [ ] C1-C2 [ ] C2-C3 [ ] C3-C4 [ ] C4-C5 [ ] C5-C6 [ ] C6-C7 [ ] C7-T1	

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
3	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
4	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
5	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
6	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
7	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
8	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
9	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
10	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
11	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
12	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
13	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
14	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
15	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
16	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
17	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
18	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
19	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
20	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
21	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
22	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
23	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
24	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
25	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
26	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
27	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
28	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
29	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
30	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
SPARE CASE NO:	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
SPARE CASE NO:	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	

Royal Devon and Exeter NHS Foundation Trust

NHS UNIVERSITY OF EXETER MEDICAL SCHOOL

CSPINE-CAD project Questionnaire

ID Number _____

Date _____

Email address (in order to send you the results of the study and your CPD certificate)

_____

1. What is your professional background?:
   Radiographer ☐Medical Doctor ☐

2. How many years have you worked full time (37.5hrs or more) or part time (please state hours worked)?

_____

3. Do you have any postgraduate qualifications in image interpretation or reporting? If yes, please state what and when you obtained the qualifications.

_____

4. On a scale of 1 to 5, (where 5 is very confident and 1 is not confident at all), how confident do you feel when interpreting cervical-spine radiographs?

   Not confident Very confident
   1☐ 2☐ 3☐ 4☐ 5☐

5. On a scale of 1 to 5 (where 5 if very confident and 1 is not confident at all), how confident did you feel when making a diagnosis on the test datasets?

   Not confident Very confident
   1☐ 2☐ 3☐ 4☐ 5☐

6. On a scale of 1 to 5 (where 5 if very confident and 1 is not confident at all), how confident did you feel when making a diagnosis on the test datasets with the assistance of the CSPINE-CAD software?

Not confident Very confident
1☐ 2☐ 3☐ 4☐ 5☐

7. In practice, would you find the CSPINE-CAD software helpful to as an additional “pair of eyes”?

_____

8. Are there any other features you would like to see in the CSPINE-CAD software?

_____
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_____
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__

9. If you found this useful, what other types of examination/body part would you
like to see this sort of CAD software applied to?

_____

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Royal Devon and Exeter NHS
NHS Foundation Trust

Royal Devon and Exeter
Hospital (Wonford)
Barrack Road
Exeter
EX2 5DW

Dr Andy Appelboam
ED Consultant
RD&E
Barrack Road
Exeter EX2 5DW

RESEARCH AND DEVELOPMENT DIRECTORATE
Direct Dial: 01392 406144
Direct Fax: 01392 403012
Email: rohanchauhan@nhs.net

Date: 08/01/15

Dear Andy,

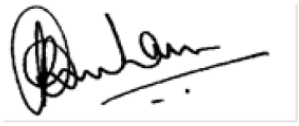
Study Reference:AA/8/01/15

Title: The CSPINE study: investigating the acceptability and efficacy of computer-aided detection software for cervical spine fracture diagnosis.

Your proposal has been returned from Independent Scientific Review. According to this assessment we are pleased to say that the proposal does meet minimum standards. Please use this document as part of your submission to ethics.

If you have any feedback on the Scientific Review process please do contact me.

Best wishes,



Rohan Chauhan

NHS Clinical Research Advisor/RDS Consultant

Michael Gundrys CV

Michael Gundry
23 Churston Way
Brixham
TQ5 8DE
mjgundry@tiscali.co.uk
Mobile: 07973442892

Personal Profile

I'm highly motivated, reliable and organised individual who displays a conscientious, thorough, and positive attitude at all times. I'm caring, compassionate, with excellent interpersonal and communication skills.

Education

University of Exeter	Currently studying (2015) MSc Masters by medical research in medical imaging
University of Exeter	BSc Hons medical imaging diagnostic radiography, 2:1
South Devon College	A-Levels – Human Biology B and Psychology C
South Devon College	National certificate in forensic science Distinction, Key skills level 2, Key skills level 3 in communication (portfolio component)
Brixham Community College	GCSEs - 9 in C and above (including in Maths, Science and English)

Clinical experience

September 2011- June 2014
Whilst studying at Exeter University I spent a total amount of 52 weeks in clinical placement sites at Torbay Hospital, Derriford Hospital, and Bournemouth Hospital. Which included theatre and a CT head assessment. In this time I passed all of my clinical competencies and gained good overall experience of NHS imaging departments. Throughout my placements I provided patient centred care and work to a high standard, I am also trained up to Intermediate Life Support, and will also be trained up on cannulating.

Employment History

April 2009 –April 2011 Morrisons - Administration Department
Duties included communication with all departments, with a customer centred service, prioritising workloads, and working as a team member and on ones own initiative.

2007-2008 (see education)

Dec 2005- Dec 2006 Inland Revenue - Administration Assistant
Employed for a fixed term contract of twelve months, which involved accurate inputting and updating of tax records. Working both as a team member and individual, with communication within the team paramount due to the need for accuracy and investigation.

Sep 2003- Mar 2004 Inland Revenue - Administration Assistant
Employed on a fixed term seven-month contract. Responsible for the capture and accurate inputting of tax records. Worked to tight deadlines and checked own work to provide a high standard of quality.

Jan 2003 – Mar 2003 Inland Revenue - Administration Assistant
Employed on a fixed term three-month contract. Responsible for weeding and organising folders/files. Worked to tight deadlines.

Hobbies and Interests

I support Tottenham Hotspur FC and enjoy going to the cinema with my friends, playing computer games and reading. I am currently re-reading the inappropriately named trilogy of five books by Douglas Adams, and the QI book of the dead by John Lloyd and John Mitchinson. I have a keen interest in art, physics, psychology and philosophy, and also enjoy listening to podcasts such as Infinite monkey cage and TED talks.

References

Dr Karen Knapp
Lecturer
University of Exeter
K.M.Knapp@exeter.ac.uk

Angela Gray
Clinical Tutor
University of Exeter
A.T.Gray@exeter.ac.uk

Royal Devon and Exeter NHS Foundation Trust

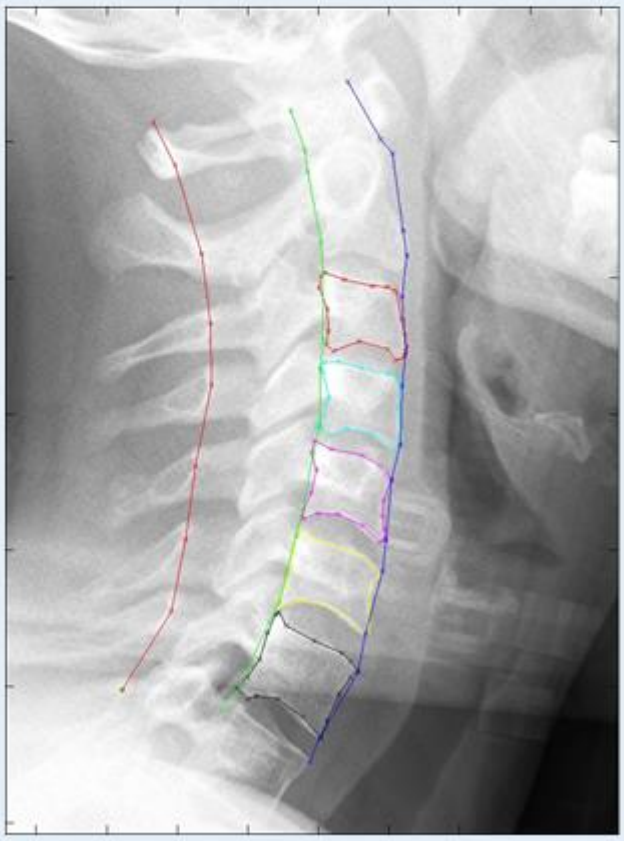
NHS

UNIVERSITY OF EXETER | MEDICAL SCHOOL

CPD Opportunity

Interested in testing cutting edge computer aided detection (CAD) software?

Are you a radiographer or an F1 or F2? Then C-spine imaging needs you. You will analyse and diagnose 30 lateral C-spine images with and without the CAD software, and then fill in a short questionnaire about your experience in total this will take approximately 1hr and 15 minutes. You will then receive a CPD certificate.



If you are interested please contact:

Michael Gundry

Mg361@exeter.ac.uk

SEND DISCARD INSERT APPS

To: exeter hospital staff

Cc:

Subject: CPD activity testing cutting edge software

CPD flyer_KMK.docx
2 MB

Calibri 12

Dear All,

This email is being circulated for the opportunity of being involved in testing some state of the art computer assisted detection (CAD) software on C-spine x-rays (developed between The Royal Devon & Exeter Hospital, Exeter University and City University London) We are **looking for radiographers and F1s and F2s** to help us test this software. It's entirely voluntary and will take approximately 1hr and 15 minutes, it consists of looking at 30 C-Spine images with and without CAD and filling in a small questionnaire. At the end of the testing you'll receive a CPD certificate and be notified (should you wish) of any results of the testing. If you wish volunteer please email me on mg361@exeter.ac.uk For more information please see the flyer attached, and also the web address http://staff.city.ac.uk/~sbbh653/cspine/researchTeam.html.

Regards

Mike Gundry

MEDICAL IMAGING
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ENGINEERING,
MATHEMATICS AND
PHYSICAL SCIENCES

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Stocker Road
Exeter
UK EX4 4QL

t +44 (0) 1392 724133
f +44 (0) 1392 724111
e K.M.Knapp@exeter.ac.uk

Dear Ms Georgia Jones,

My name is Michael Gundry, I'm a medical imaging masters' student from the University of Exeter, and I'm writing this letter out of courtesy to inform you about some research Professor Karen Knapp and I are conducting. The research is using Computer-aided detection (CAD) software applied to lateral C-spine x-ray images, this software will pick up misalignments of the C-spine and vertebral body changes, the hope being that this software will decrease missed C-spine injuries (figures have shown C-spine injuries are missed in 20% of cases). This C-spine CAD software will be tested on qualified radiographers, and F1 and F2 doctors at the Royal Devon and Exeter Hospital. This will involve participants evaluating 30 lateral C-spine images without CAD and then with the software applied, it will also include a questionnaire. In total 15 radiographers and 15 doctors will be tested and the results compared. If you require any further information on the research please contact me on mg361@exeter.ac.uk or my supervisor Professor Karen Knapp on K.M.Knapp@exeter.ac.uk

Yours sincerely

Michael Gundry

University of Exeter Medical School Research Ethics Committee

Guidelines for reviewers

The purpose of reviewing	• To assist the Research Ethics Committee in making decisions about the acceptability of the proposal. • To assist or advise applicants on areas in which their study may be improved through amendment. • The provision of constructive feedback to applicants.
Quality	• You are asked to advise on the originality, reliability, and importance of the study. • Originality: does the work add to what is already in the published literature? If so, what does it add? • Reliability: this covers matters such as clear research question, appropriate and adequate methodology.
Confidentiality	• All applications are confidential. Please do not discuss your report with anyone else.
Conflict of interest	• You should declare any conflict of interest that might bias your opinion. A conflict of interest exists when professional judgement concerning a primary interest (the validity of research) may be influenced by secondary interests (personal matters such as financial gain, personal relationships or professional rivalry).
The Score Sheet: the report	• This report will be read by both applicants and the Committee. • You may like to use the following structure for your comments: 1. Overall evaluation and general comments 2. Detailed evaluation of specific features 3. What changes (major and minor) might be made to improve the study. • Please be objective and constructive in writing your report – it may be helpful to write as if you were giving feedback face to face with the applicant..

University of Exeter Medical School Research Ethics Committee

Reviewer Form

Name of Reviewer:	
Employing Organisation:	

Qualifications and area of expertise:	
Details of any potential conflict of interest:	
Name of Researcher:	
Project Title:	

	Yes	**No**	**N/A**
Is there a clear research question?	☐	☐	☐
Has the development and design of data collection methods (quantitative and qualitative) been adequately outlined?	☐	☐	☐
Is the statistical/data analysis methodology appropriate?	☐	☐	☐
Have ethical issues been addressed appropriately?	☐	☐	☐
Have the limitations of the study been addressed?	☐	☐	☐

Please grade each feature (where appropriate) from excellent to very poor:

Evaluation Scale: (5) Excellent (4) Very Good (3) Good (2) Fair (1) Poor

Originality	Choose an item.
Reliability	Choose an item.
Importance	Choose an item.

Do you have any ethical issues you would like to bring to the attention of the Committee? Please make your comments for the University of Exeter Medical School Research Ethics Committee in the box below.

Signed:
(Electronic signature required)
Date:

Appendix 4: Case for support documentation (with attachments)

The CSPINE study: investigating the acceptability and efficacy of computer-aided detection software for cervical spine fracture diagnosis.

Dr Andy Appelboam[1], Dr Adam Reuben[1], Prof Karen Knapp*[1,2], Dr Jude Meakin[2], Michael Gundry[2], Prof Obi Ukoumunne[2], Dr Michael Phillips[3], Dr Greg Slabaugh[3]

1: Royal Devon and Exeter Foundation Trust (* honorary contract holder)
2: University of Exeter
3: City University

Lay Summary

The cervical spine (the neck region) is a highly flexible part of the spine which is particularly vulnerable to trauma. Dislocation or breaks of the neck have the potential for long-term and life-changing disabilities. Patients suspected of neck injury are often assessed using x-rays. However up to 20% of cases have a delayed or incorrect diagnosis, which can result in paralysis, or even death. We propose novel computer-aided detection software, "CSPINE-CAD", to aid diagnosis of injuries to the cervical spine through assisting inexperienced and experienced doctors and other healthcare workers. More accurate diagnosis will improve healthcare outcomes for patients improve life for their friends and relatives and reduce the financial burden to the NHS in caring for those with preventable paralysis. This study will test the CSPINE-CAD software and in junior doctors and radiographers using.

Research Question

Can CSPINE-CAD software for the cervical spine assist junior doctors and radiographers in assessing lateral c-spine radiographs and aid accurate diagnoses?

Rationale and background

Cervical spine injuries (CSIs) occur in approximately 4.3% of all trauma patients (Holmes et al., 2005). These injuries typically result from high energy impact, involving automobile accidents (44%), falls (22%), dives into shallow water (15%) and other causes (Platzer et al., 2006). CSI can also occur with more minor injuries in elderly patients and in those with pre-existing bone pathologies. Cervical spine injuries are a major source of morbidity and mortality across all age groups. Evaluation of the cervical spine x-ray often represents a major radiological challenge for emergency physicians, combining images that can be extremely difficult to interpret, particularly to the less experienced eye, with clinical scenarios that may result in death or serious disability with a failure to establish the correct diagnosis. Early and accurate detection of a CSI is critical to plan appropriate care and prevent further injury. The management of neck injury in the absence of a fracture usually involves exercise and encouragement to mobilise; however, in the presence of a neck injury, management of a fracture

involves a prolonged period of immobilisation and frequently surgery. Despite recent advances in patient evaluation protocols and improved availability of radiologic examination, up to 20% of CSI patients suffer extension of their injuries due to delayed (not detected in the first 24 hours) or missed diagnosis (Platzer et al., 2006). Delayed or incorrect diagnosis can have tragic consequences for the patient, including permanent neurological deficit, quadriplegia, or death. Such outcomes will clearly also have a considerable personal and socioeconomic impact on family members, as well as increase the financial burden on the NHS and social services.

An effective protocol for evaluating the cervical spine for bony injury in trauma is crucial. However, there has been much debate about best practices in the clinical literature, and procedures vary at different hospitals. Typically NEXUS criteria (Hoffman et al., 2000) or Canadian C-spine rules (Como et al., 2009) are applied to guide the imaging requirements of low-risk patients. For example, the NEXUS criteria stipulate that if the patient is alert, sober, has no neurological deficit, and does not present painful injury or tenderness, then radiological imaging is not required. However, many patients still require imaging in the assessment of suspected cervical spine injury, particularly high risk patients or those with a dangerous mechanism of injury. Patients who require imaging typically undergo a cervical spine x-ray series. The standard UK practice is for three radiographs to be taken from lateral, odontoid (PEG), and anteroposterior (AP) views (Graber et al., 1999), as shown in Figure 1. The lateral image provides a side view of all seven cervical vertebrae and the cervico-thoracic junction and is considered to be the most useful view for detecting vertebral body fractures and dislocations from the misalignment of the vertebral column. It can also be carefully scrutinised for fractures of the spinous processes as well as the spacing between the vertebral bodies. The odontoid projection, taken through the patient's mouth, provides a view of the first two (of the seven) cervical vertebrae and is examined for fracture or asymmetry. Finally, the consistency of the height of the cervical spines as well as their alignment is examined on the AP view.

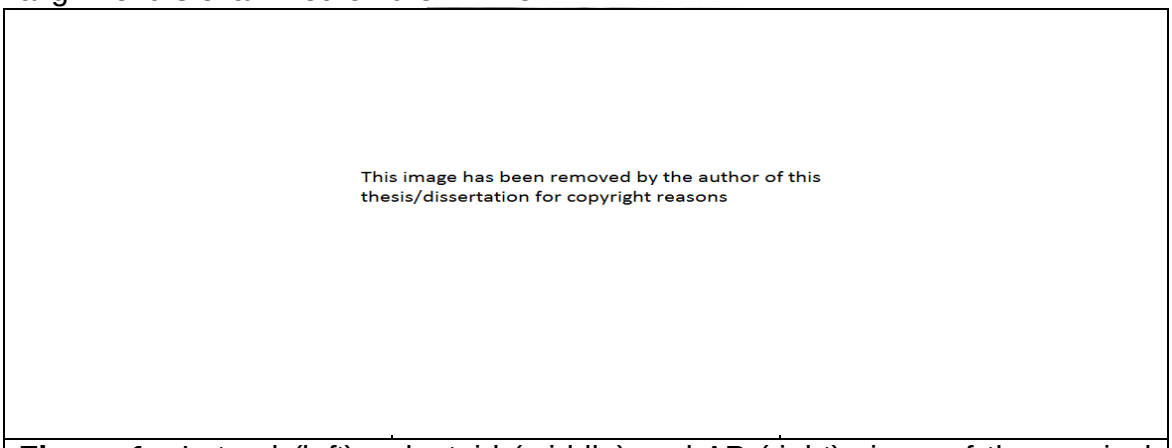

Figure 1. Lateral (left), odontoid (middle) and AP (right) views of the cervical spine.

Radiologic imaging may vary depending on hospital protocols and patient condition. Some studies have described cases when only a lateral view is taken (Davis et al., 1993); however this is considered incomplete. Additional views such as oblique or swimmer's view (taken with one arm extended over the head), are often required to visualise the cervico-thoracic junction when the lateral view of the cervical spine is deemed inadequate; however many UK

clinicians and junior emergency department staff lack the experience in interpreting such views (Holmes et al., 2005). Computed Tomography (CT) or magnetic resonance (MR) imaging may be requested when the standard x-ray images are inadequate or there is clinical suspicion due to persistent symptoms or neurologic deficits. Although some centres image trauma patients with CT instead of x-ray images, this is reserved for major trauma since the radiation dose for such an examination is significant. While some have argued for CT to replace x-ray imaging for assessing CSI (Bailitz et al., 2009), this remains controversial in the literature (Kokabi, 2011; Holmes et al., 2005) and is not considered routine practice.

Despite standardisation and advances in imaging, missed or delayed diagnosis of cervical spine injuries is still a common problem in emergency departments, and has an incidence rate of up to 20% (Platzer et al., 2006). In one study (Platzer et al., 2006), the most common cause (accounting for 44%) of missed cervical spine injuries was misinterpretation of the images. Another study (Davis et al., 1993) resulting in a similar number (47%) of missed or delayed diagnosis due to misinterpretation. Junior staff responsible for initial radiologic examination failed to diagnose the injuries until experienced staff later performed a second evaluation of the radiographs. In Platzer et al., 2006, complications attributed to delayed or missed diagnosis ranged from motor and/or sensory neurologic deficits to complete quadriplegia. In other studies, 67% of patients with missed cervical fractures suffered neurological deterioration and nearly 30% of delayed CSI diagnosis developed permanent neurological deficit (Morris et al., 2004).

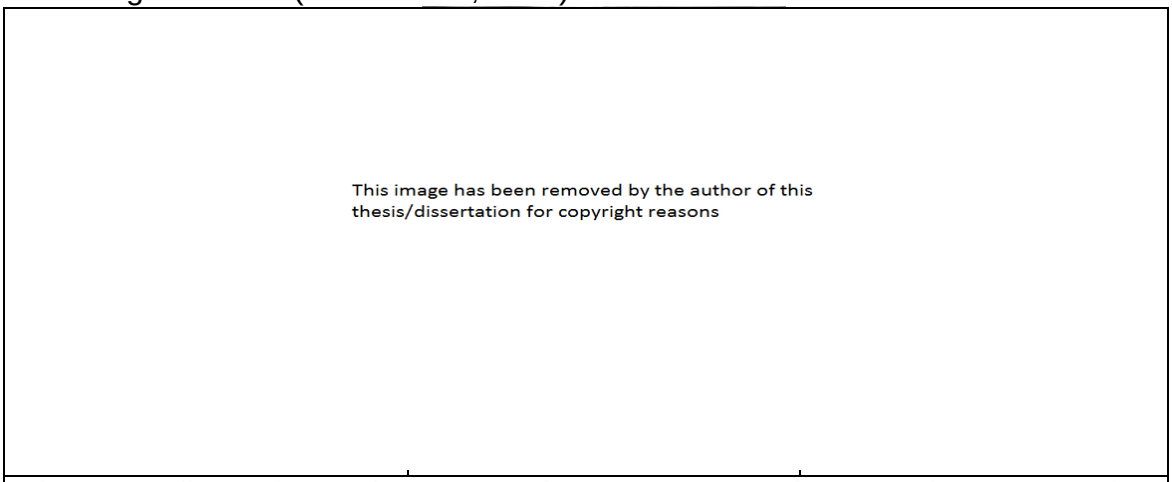

Figure 2. Illustration of the proposed software. A semi-automatic segmentation of the C2 – C7 vertebral bodies will be performed, shown on the left as orange contours. We will then compute alignment curves along the anterior (green) and posterior (blue) vertebral body cortex, as well as the spinolaminar junction (purple). Pattern recognition algorithms will then be executed, using the original image, segmentations, and alignment curves to detect potential anomalies. CAD prompts, rendered as arrows, will be presented to the physician to highlight any potential alignment (yellow) issues or fractures (red).

We propose a feasibility project to evaluate the acceptability and usefulness of novel CSPINE-CAD software when used by junior doctors and radiographers. The novel CSPINE-CAD software has been designed to assist physicians in interpreting lateral radiographic images of the cervical spine; the concept is illustrated in Figure 2. Based on minimal input by the physician, the software will semi-automatically perform segmentation of the C2 – C7 vertebral bodies.

The segmentation will provide spatial context for subsequent processing. Next, three alignment curves will be computed along the anterior and posterior vertebral body cortex, as well as the spinolaminar junction. In clinical practice, the physician is often asked to visually check the C-spine alignment by making a mental picture of these curves; however, we will compute and display them directly on the image.

Using machine learning algorithms, individual vertebrae will be analysed for dislocation and fracture and suspicious regions of the image will be highlighted for further review by the physician. As is common with CAD methods, the software will be utilised in a second-reader mode, meaning the image will first be reviewed by the physician without CAD. Then, the CAD will be activated providing prompts, and the physician can then change their findings if desired. Essentially, our proposed method will act as a "spell-checker" for C-spine fractures and dislocations visualised in lateral C-spine images

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If the project proves successful, later we plan to extend the methodology to the odontoid and AP views.

While there is a substantial body of literature for image analysis of spinal radiographs, much existing work focusses on the thoracic and lumbar regions of the spine (corresponding to mid and lower back, respectively), where the vertebral bodies appear more regular in the image. Previous work tailored to the cervical spine (Stanley et al., 2001; Long et al., 1999) has investigated segmentation of vertebral bodies using curvature (Stanley et al., 2001), image thresholding (Long et al., 1999), corner detection (Benjelloun et al., 2009). However, to our knowledge, no research has been performed to produce alignment curves for computer-aided detection of dislocations; or CAD localising cervical spine fractures.

Work to date:

The development of the software has been funded by an EPSRC grant and the project team has been working together for the past 18 months in developing the original funding application and subsequently on developing the software. The EPSRC grant completes in February 2015 and includes a preliminary evaluation using third year student radiographers who have been demonstrated in a previous study to be at a similar level of accuracy to inexperienced doctors (Wood et al., 2012)

Extending the testing into qualified radiographers and junior doctors

This funding application is focusing on extending the project to undertake further testing of the CSPINE-CAD software in junior doctors and qualified radiographers; those who will frequently be first in line to evaluate the images. Accurate identification of a fracture on the lateral C-spine image by a radiographer enables adjustment of radiographic technique or could provide an indication for a direct transfer to computed tomography (CT) to better characterise the fracture. In time, this could lead to new ways of working where radiographers request the CT based on their interpretation of a lateral C-spine

image, thus reducing the number of times the patient is returned to the emergency department (ED) between imaging; saving time, improving workflow and reducing costs. Furthermore, increased confidence and accuracy interpreting C-spine radiographs by junior doctors can reduce the time the patient is waiting for a consultant to review the image prior to further imaging or even discharge. Such small steps as these can reduce the burden on the ED and increase patient throughput time, improving diagnostic accuracy, ensuring a better experience for the patient and releasing capacity within the ED.

Aims and objectives

Aims:

- The aim of this study is to evaluate the acceptability and efficacy of CSPINE-CAD software for the diagnosis of fractures and dislocations in this key anatomical area.

Objectives:

- To evaluate the accuracy of qualified radiographers in diagnosing C-spine bony injuries with and without the use of CSPINE-CAD software;

- To evaluate the accuracy of junior doctors in diagnosing C-spine bony injuries with and without the use of CSPINE-CAD software;

- To evaluate the acceptability of the CSPINE-CAD software by qualified radiographers and junior doctors.

Research Design

This is a feasibility study to determine the appropriate dataset size, complexity, recruitment pathways, image viewing arrangements and acceptability of the software. An intervention will be used to provide datasets which the participants can review both with and without the use of the CSPINE-CAD software. The participants will be recruited through advertisements, flyers, e-mails and notification at staff meetings and training sessions. They will be asked to spend approximately 1-1.5 hours to complete the study and will be provided with a continuing professional development certificate in return. 15 Junior doctors (F1 and F2's) and 15 radiographers will be recruited to evaluate the software.

Two image datasets of 10 cases will be developed. The cases will include a range of normal, subtle fractures and more obvious fractures. The radiologist reports of the radiograph series and the CT scans where patients have had supplementary imaging will be used to define the "gold standard" report.

The researcher will visit each of the participants for a one to one data collection meeting where they will be provided with the images and the software on a study laptop to ensure the same viewing conditions for all participants.

Participants will be provided with the two datasets of 10 cases each to review independently and document their diagnoses with the researcher present. The participants will then undergo training to use the CSPINE-CAD software and will be randomly allocated to re-review one of the datasets with the additional use of the CSPINE-CAD software. The use of two datasets is aimed at considering the fact that image reviewers may perform better on the second data series and that this might make the CAD-based review perform better. Therefore, the use

of an additional dataset enables us to explore this potential confounder and also increases the number of images to reduce participants sharing information on their findings with other participants prior to their image viewing session. It is anticipated that the image viewings will take in the region of one hour to complete all the datasets provided.

Participants will also be asked to complete a survey regarding their experience of using the CSPINE CAD-software, which should take no longer than 15 minutes. Basic information on the participants including time since qualification and any postgraduate imaging qualifications will also be recorded.

Upon completion of the study, all participants will be provided with feedback of their performance along with their CPD certificate.

Data Management

The data will be de-identified and stored on encrypted and password protected computers and laptops at the University of Exeter and within the Royal Devon and Exeter Hospital. Personal data such as name and e-mail address will be held separately and will be used to return performance and CPD certificates at the end of the study. The personal information will be destroyed within 6 months of completion of the study.

Software

Data will be stored on Excel and analysed using STATA. The CSPINE CAD-software will be run using MATLAB and K-PACS will be used as the DICOM viewer where required.

Statistical Analysis

While this is a feasibility study to provide data to underpin future funding applications, with the recognition that this has not been properly powered to yield statistically significant results, some basic analysis will be completed. Sensitivity, specificity and area under the curve (AUC) calculated from receiver-operator characteristic (ROC) curves will be calculated to assess diagnostic accuracy for the images both with and without the use of CSPINE-CAD.

The numbers of images in the datasets are based on a previous study undertaken by Wood et al (Wood et al, 2012). This appears to be a number which is sufficient to provide a range of cases and is manageable for participants. Fifteen junior doctors and 15 qualified radiographers have been selected as these numbers are feasible for recruitment and provide an overall number (30 participants) sufficient to provide data upon which to base power calculations for future funding.

Project management

The programme team consists of a multidisciplinary team with complementary

skills and expertise as follows:
Dr Andy Appelboam and Dr Adam Reuben: ED consultants who provide clinical expertise and advice from the ED side.
Prof Karen Knapp and Michael Gundry: Radiographers who provide clinical expertise and experience from the medical imaging side
Prof Obi Ukoumunne is a statistician specialising in diagnostics and bring to the team his statistical expertise. He will lead on the statistical analysis.
Dr Jude Meakin: a medical physicist who has expertise in image segmentation and testing software
Dr Greg Slabaugh and Dr Michael Phillips: Computer scientists who have developed the CSPINE CAD programme.

The project team will meet monthly for the duration of the study. The ED consultants and the radiographers will select and agree the image datasets to be used. The computer scientists will provide technical support and ensure the CSPINE CAD software is functioning appropriately. They will also be able to undertake analysis of the efficacy of their software at determining the vertebral bodies and alignment curves in the study datasets. Karen Knapp, Jude Meakin and Greg Slabaugh will undertake the study development, analysis and dissemination. The team will monitor recruitment and delivery of the study in the timescales required.

All members of the team will have undertaken and have up to date ICH-GCP training.

Dissemination

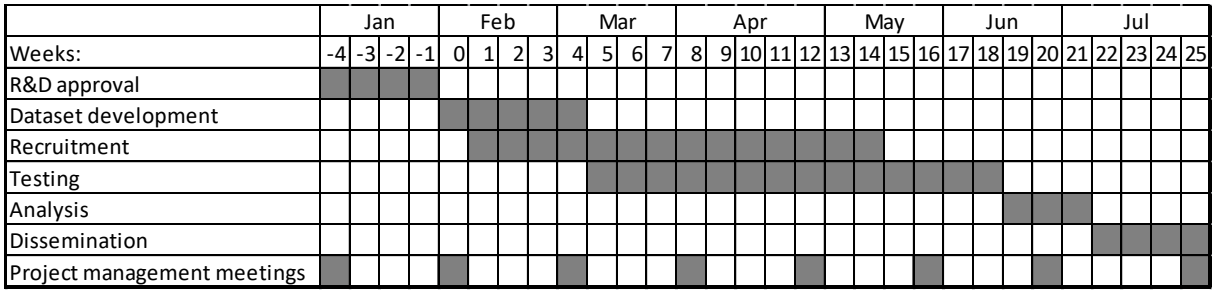
The results will be presented at the UKRC, the national imaging conference for radiography and radiology and local and national emergency medicine conferences. If the results are sufficiently strong, then a paper will be written for publication in the skeletal radiology or an emergency medicine journal.

Patient involvement

A female patient in her forties was approached to review this funding application and provide feedback from her experiences of having fractured her C-spine five years previously, which resulted in open reduction and internal fixation of the fracture. She now remains functional and well, but was well aware of the severity of her fracture and the potential loss of function she faced.
She met with Karen Knapp and had the project described to her. She was then provided with the opportunity to read the funding application, which she was keen to do. Upon completion of considering the funding application, JS stated the following: "*Having read through the proposed study investigating the acceptability and efficacy of computer-aided detection, I have suffered a C-spine fracture and would love to see CAD software in place to assist junior doctors etc. to diagnose a cervical injury. Although my fracture was diagnosed effectively, I dread to imagine the implications if a fracture was missed or an incorrect diagnosis made*."

Timescale

The proposed timescale for the project is outlined below:



Ethical considerations

This study will use anonymous datasets and staff from within the NHS. It therefore does not require NRES ethical approval. It will however, require R&D approval from the RD&E. Since there is already R&D approval for the previous study to develop and test the software in student radiographers, further approval to test the software in the clinical staff populations as outlined in this proposal is not thought to be contentious. Ethical approval will be sought from the University of Exeter Medical School's research ethics committee to undertake the testing within the staff.

Budget summary and costings

Staff time	**Hours**	**Total (£)**
Michael Gundry	100	1,940
Karen Knapp	37.5	1,641
Jude Meakin	37.5	1,180
Greg Slabaugh	37.5	1,665
Andy Appelboam	10	543
Adam Reuben	10	562
Other costs		
Travel / parking for testing		500
Photocopying and consumables		250
High resolution laptop		1,000
Conference registration		285
Travel / accommodation and subsistence at conference		635
Total		**10,201**

National Importance and future work

Spinal cord injuries present a significant socioeconomic burden. In the UK, a person is paralysed every 8 hours (HM Government, 2011). An injured person will incur between £1M and £3M in lifetime medical expenses (NSCISC, 2012), depending primarily on the age at which an injury occurs. In the UK it is estimated that the annual cost of caring for people paralysed by spinal cord injury is more than £500M (Spinal Cord Injury Statistics, 2012); however this estimate is conservative as it only based on patients that accessed a spinal cord injury centre. The NHS health economics mean that preventing disability

is likely to be cost effective as long-term rehabilitation costs are often state-funded. It is estimated that 21% of people discharged from spinal cord injury centres go into nursing homes, hospitals or other institutionalised settings rather than their own homes (Spinal Cord Injury Statistics, 2012). For many spinal cord injury patients, education, career, marriage, and independence are disrupted and sometimes never restored. The human cost is such that around 20% of patients leave spinal cord injury centres clinically depressed (HM Government, 2011).

The proposed research will address this important societal challenge in the UK by advancing technology and clinical care for trauma patients.

Testing of the novel CSPINE-CAD software in the clinical setting is the next step to underpinning further development of the software and moving it from the laboratory setting to clinical practice. The project team will use the results from the current EPSRC study and from this proposed study to underpin future grant applications for further large funding applications such as NIHR i4i.

References

Bailitz et al., “CT Should Replace Three-View Radiographs as the Initial Screening Test in Patients at High, Moderate, and Low Risk for Blunt Cervical Spine Injury,” J. of Trauma, 66(6), 2009.

Baker et al., “Computer-aided Detection of Colorectal Polyps: Can It Improve Sensitivity of Less-Experienced Readers? Preliminary Findings,” Radiology 245, 2007.

Benjelloun et al., “Spine Localization in X-ray Images Using Interest Point Detection,” Journal of Digital Imaging, 22(3), 2009.

Borius et al., “Cervical spine injuries resulting from diving accidents in swimming pools: outcome of 34 patients,” J. European Spine, 19(4), 2010.

Como et al., “Practice management guidelines for identification of cervical spine injuries following trauma: update from the eastern association for the surgery of trauma practice management guidelines committee,” J. of Trauma, 67(3), 2009.

Davis et al., “The Etiology of Missed Cervical Spine Injuries,” Journal of Trauma, 34(3), 1993.

Graber et al., “Cervical Spine Radiographs in the Trauma Patient,” American Family Physician, 59(2), 1999.

HM Government, Third Annual Report of the Bioscience & Health Technology Database, 2011.

Hoffman et al., “Validity of a Set of Clinical Criteria to Rule Out Injury to the Cervical Spine in Patients with Blunt Trauma,” National Emergency X-Radiography Utilization Study Group, New England Journal of Medicine, 343, 2000.

Holmes et al., “Computed Tomography Versus Plain Radiography to Screen for Cervical Spine Injury: A Meta-Analysis,” J. of Trauma, 58(8), 2005.

Karunanithi, K. “Growing trends in Computer aided detection markets,” Frost and Sullivan Market Insight, 2011, http://www.frost.com/sublib/display-market-insight-top.do?id=234718092 (accessed 7 Oct 2012)

Kokabi et al., “Application of Imaging Guidelines in Patients with Suspected Cervical Spine Trauma: Retrospective Analysis and Literature Review,” Emergency Radiology, 18(1), 2011.

Long et al., “Segmentation and feature extraction of cervical spine x-ray images,” Proc. SPIE Medical Imaging, 3661, 1999.

Morris et al., “Clearing the Cervical Spine in Polytrauma,” Anaesthesia 59, 2004.

NSCISC - National Spinal Cord Injury Statistical Center, 2012. Spinal Cord Injury Facts and Figures at a Glance, 2012. [pdf] Birmingham: University of Alabama at Birmingham. Available at: <https://www.nscisc.uab.edu/PublicDocuments/fact_figures_docs/Facts%202012%20Feb%20Final.pdf> [Accessed 30 September 2012.].

Platzer et al., “Delayed or Missed Diagnosis of Cervical Spine Injuries,” Journal of Trauma, 61(1), 2006.

Slabaugh et al., “A Robust and Fast System for CTC Computer-Aided Detection of Colorectal Lesions,” J. Algorithms, 3(1):21-43, special journal issue on Machine Learning for Medical Imaging, 2010.

Slabaugh et al., “Variational Guidewire Tracking Using Phase Congruency,” Proc. International Conference on Medical Image Computing and Computer Assisted Intervention (MICCAI), 2007.

Spinal Cord Injury Statistics, 2012. Apparelyzed. [online] Available at: <http://www.apparelyzed.com/statistics.html> [Accessed 30 September 2012.].

Spinal Research Facts and Figures, 2012. International Spinal Research Trust. [online] Available at: <http://www.spinal-research.org/research-matters/spinal-cord-injury/facts-and-figures/> [Accessed 5 October 2012.]

Stanley et al., “A radius of curvature-based approach to cervical spine vertebra image analysis,” Biomed. Sci. Instrum. 37, 2001.

Wood et al., “Visual expertise in detecting and diagnosing skeletal fractures,” Skeletal Radio. 2012 Sep 1. [Epub ahead of print]

Karunanithi, K. “Growing trends in Computer aided detection markets,” Frost and Sullivan Market Insight, 2011, http://www.frost.com/sublib/display-market-insight-top.do?id=234718092 (accessed 7 Oct 2012)

Baker et al., “Computer-aided Detection of Colorectal Polyps: Can It Improve Sensitivity of Less-Experienced Readers? Preliminary Findings,” Radiology 245, 2007.

Attachments/Appendices 1

Data collection pro-forma

Dataset 1

Image	Normal?	Diagnosis
1	Yes / No	
2	Yes / No	

3	Yes / No	
4	Yes / No	
5	Yes / No	
6	Yes / No	
7	Yes / No	
8	Yes / No	
9	Yes / No	
10	Yes / No	

Dataset 2

Image	Normal?	Diagnosis
1	Yes / No	
2	Yes / No	
3	Yes / No	
4	Yes / No	
5	Yes / No	
6	Yes / No	
7	Yes / No	
8	Yes / No	
9	Yes / No	
10	Yes / No	

CSPINE-CAD Dataset 1 / 2 (delete as appropriate by the researcher)

Image	Normal?	Diagnosis
1	Yes / No	
2	Yes / No	
3	Yes / No	

4	Yes / No	
5	Yes / No	
6	Yes / No	
7	Yes / No	
8	Yes / No	
9	Yes / No	
10	Yes / No	

Attachment/Appendix 2

Example survey questions

1. What is your professional background? Delete as appropriate: Radiographer / Medical Doctor
2. How long have you practiced post qualification (expressed as years per full-time equivalent i.e. 37.5 hours per week)?
3. Do you have any postgraduate qualifications in image interpretations or reporting? If yes, please state what and when you obtained the qualifications.
4. On a scale of 1 to 5, where 5 if very confident and 1 is not confident at all, how confident do you feel when interpreting cervical-spine radiographs?
5. On a scale of 1 to 5, where 5 if very confident and 1 is not confident at all, how confident did you feel when making a diagnosis on the test datasets?
6. On a scale of 1 to 5, where 5 if very confident and 1 is not confident at all, how confident did you feel when making a diagnosis on the test datasets with the assistance of the CSPINE-CAD software?
7. In practice, would you find the CPSINE-CAD software helpful to as an additional “pair of eyes”?
8. Are there any other features you would like to see in the CPINE-CAD software?

Please note, these are merely example questions and should the funding application be successful, full questions will be developed, piloted and refined prior to the data collection period.

Appendix 5: List of 183 radiograph reports recorded from the Royal Devon and Exeter hospital

Pat ID/ Img ID	Patient Info			Image Info					Diagnostic Information			Old Image Info			
	Date	Age	Sex	Face	Pos	Or	Di	Mon	Tags	Diagnosis	Further Description	Other Comments	Lateral	AP	Peg	Others
CS 0001	30/04/14	65	M	L	T	H	N	2	L, CT	None		Stent in carotid artery, probably exclude	**IMG00004**	IMG00001	IMG00000 IMG00002	Swim: IMG00003
CS 0002	30/04/14	46	M	R	E	V	N	2	E, R	Degen	Particularly between C4-C7. Osteophyte Formation.	**?T1-T6 not diagnostic?**	**IMG00006**	IMG00005	N/A	Swim: IMG00007
CS 0003	29/04/14	50	F	R	E	V	Y	2	E, R	None		Would expect more curvature	**IMG00009**	IMG00008	N/A	N/A
CS 0004	28/04/14	25	F	L	E	V	J	1		None		*IMG00010 says AP but actually lateral	**IMG00010**	IMG00011	N/A	N/A
CS 0005	27/04/14	51	M	L	E	V	Y	2	L	Fracture	Anterior Disp at peg, C1 pushed forward		**IMG00013**	IMG00012	IMG00014	N/A
CS 0006	25/04/14	19	F	L	T	H	Y	2	CT, L	None		Collar/spinal board, not perfectly lateral	**IMG00016**	IMG00015	N/A	N/A
CS 0007	25/04/14	48	M	L	E	V	J	2	L	None			**IMG00019**	IMG00018	N/A	N/A
CS 0008	24/04/14	91	M	L	E	V	N	2	CT, L	None		Difficult to Segment	**IMG00020**	IMG00022	IMG00021	Swim: IMG00023
CS 0009	24/04/14	87	F	L	E	V	Y	1		Degen	Calcified Cartilage	*IMG00024 says Lateral but looks AP	**IMG00025**	IMG00024	N/A	N/A
CS 0010	24/04/14	90	M	L	T	H	N	2	CT, L	Fusion	Fusion of plate and cage	Spinal Board Present	**IMG00027**	IMG00026	IMG00029	Lat 2: IMG00028
CS 0011	23/04/14	32	M	L	T	H	N	2	CT, L	None	Normal Variations		**IMG00032**	IMG00030	IMG00033	Lat: IMG00031
CS 0012	21/04/14	20	F	L	E	V	N	2	ER, L	Min Degen		IMG00034 says AP but looks peg	**IMG00035**	IMG00036	IMG00034	Lat: IMG00037
CS 0013	20/04/14	84	M	R	E	V	J	2	CT, R	None			**IMG00039**	IMG00038	IMG00042	Lat: IMG00041
CS 0014	20/04/14	23	M	L	T	H	N	2	L, CT	None		Tricky to segmented	**IMG00044**	IMG00043	IMG00045	Swim: IMG00046
CS 0015	20/04/14	37	M	L	E	V	Y	2	ER, L	None	C3 - line artefact? Tender? No fractures		**IMG00049**	IMG00048	IMG00047	N/A
CS 0016	17/04/14	73	F	L	T	H	Y	2	CT, L	Min Degen	C3/C4 - lipping?	No IMG00053	**IMG00050**	IMG00052	IMG00051	N/A
CS 0017	16/04/14	86	M	R	E	V	N	2	ER, R	Degen		Grotty image	**IMG00054**	IMG00058	IMG00055	Peg: IMG00056 Swim: IMG00057
CS 0018	15/04/14	88	M	L	E	V	N	2	ER, L	Degen	C4/C5 and C5/C6, Big gap		**IMG00059**	IMG00060	N/A	N/A
CS 0019	14/04/14	77	M	L	E	V	J	2	L, RD, ER	Fracture	4-part burst # C1 and base of C2		**IMG00061**	IMG00064	IMG00063	Lat: IMG00062
CS 0020	14/04/14	29	M	L	E	V	N	2	EX, L	None			**IMG00065**	N/A	N/A	Lat: IMG00066 Lat: IMG00067
CS 0021	13/04/14	68	F	R	E	V	Y	1		Degen	Changes at C1/2 C5/6 with facet joint changes	Osteopenia	**IMG00068**	IMG00069	N/A	N/A
CS 0022	12/04/14	76	M	R	E	V	Y	1		Degen	Disc space changes at C3/4 and C5/6	Calcium deposit in ligament (right of C4)	**IMG00070**	IMG00071	N/A	AP 2: IMG00072
CS 0023	12/04/14	65	F	R	E	V	Y	1		Degen	Diffuse, particularly C5/C6		**IMG00073**	IMG00074	N/A	N/A
CS 0024	12/04/14	44	M	R	E	V	J	2	WB, R, L	Post Surgery	Metal Plates present	Karen says not worth looking at	**IMG00075**	IMG00076	N/A	N/A
CS 0025	11/04/14	82	F	L	E	V	Y	1		Degen	Particularly between C3-C6, C4/C5 almost fused		**IMG00078**	IMG00077	N/A	N/A
CS 0026	10/04/14	64	F	L	E	V	Y	1		Degen	Beaking at end of C4 and C5. Early degen changes.	Hard to see facet joints due to degen (C3-C5)	**IMG00080**	IMG00079	N/A	N/A
CS 0027	10/04/14	61	M	L	E	V	N	2	L, CT	Fracture, Degen	C6 body and spinous process # (subtle), possible degen changes outside C5/C6 or calcification	Lines on this are the spinal board	**IMG00082**	IMG00081	IMG00084	Lat: IMG00083 Lat: IMG00085
CS 0028	10/04/14	85	F	R	E	V	N	1		Degen	Changes C7/T1 not visualised		**IMG00086**	IMG00087	N/A	N/A
CS 0029	10/04/14	76	F	L	E	V	J	1		Min Degen	C4 Little, C5/C6 Lipping, C6/C7 posterior area	whitened C5 and some C6 due to scoliosis?	**IMG00088**	IMG00089	N/A	N/A
CS 0030	10/04/14	87	F	L	T	H	J	2	L, CT	Degen	Diffuse, osteopedic	N/A	**IMG00093**	IMG00090	IMG00091	Peg: IMG00092

CS 0031	09/04/14	70	M	R	E	V	Y	2	WB, R	Post Surgery		Karen says not worth looking at	**IMG00095**	IMG00094	N/A	Swim: IMG00096
CS 0032	09/04/14	88	M	L	E	V	Y	2	L	Degen	At base of C-spine, C6/C7 and some in C5		**IMG00099**	IMG00097	N/A	Lat: IMG00098
CS 0033	09/04/14	54	M	R	E	V	Y	1		Degen	C3-C7 disc space narrowing, beaking in C3,C6, C7 (osteophyte formation), C5 fused		**IMG00100**	IMG00101	N/A	N/A
CS 0034	09/04/14	42	F	L	E	V	J	1		Degen	C5-C6	White lines in vertebra just patients anatomy	**IMG00102**	IMG00103	IMG00104	N/A
CS 0035	08/04/14	46	F	L	E	V	Y	2	L	None			CS0035	N/A	N/A	N/A
CS 0036	08/04/14	91	F	L	E	V	Y	2	L, SIT	Fracture, Min Deg	Anterior Disp C1 on C2, # of Peg and C2 body		CS0036	N/A	N/A	N/A
CS 0037	08/04/14	53	M	R	E	V	J	1		Degen	C5-C6		CS0037	N/A	N/A	N/A
CS 0038	07/04/14	55	F	L	E	V	J	1		Fusion	No fractures	Post Surgery, contains metalwork	CS0038	N/A	N/A	N/A
CS 0039	07/04/14	66	F	L	E	V	Y	1		None	But possible osteophyte formation (C6) and degen change (C5, unusual shape)		CS0039	N/A	N/A	N/A
CS 0040	07/04/14	34	M	L	E	V	N	2	L, CT	None		Lost normal lordotic curve	CS0040	N/A	N/A	N/A
CS 0041	07/04/14	75	M	R	E	V	N	1		Degen	C4-C6		CS0041	N/A	N/A	N/A
CS 0042	07/04/14	94	M	L	E	V	N	1		Degen	Particularly C4-C5, facet joints not well preserved	osteopedic? V white end plates, loss of TS	CS0042	N/A	N/A	N/A
CS 0043	06/04/14	91	F	L	E	V	Y	2	WB, L	Fracture	C2 body, peg base & facet joint, C1 also looks different because it is rotated	Fracture possiby diagnosed from CT so not as clear on the x-ray ie tough to detect	CS0043	N/A	N/A	N/A
CS 0044	05/04/14	22	M	L	T	H	J	2	L, CT	None		img not 100% lateral so C2-C5 closer than norm	CS0044	N/A	N/A	N/A
CS 0045	05/04/14	39	M	R	E	V	Y	2	R	None			CS0045	N/A	N/A	N/A
CS 0046	04/04/14	66	M	L	E	V	J	2	ER, L	None			CS0046	N/A	N/A	N/A
CS 0047	04/04/14	45	M	R	E	V	Y	2		Degen	Joint space narrowing C5/6 & C6/7 (lipping on C5)	Possibly osteophyte formation on C5	CS0047	N/A	N/A	N/A
CS 0048	04/04/14	40	F	L	E	V	J	2	ER, L	None			CS0048	N/A	N/A	N/A
CS 0049	04/04/14	78	F	L	T	H	Y	2	CT, L	Retro, Degen	Retro of C5 backwards on C6		CS0049	N/A	N/A	N/A
CS 0050	04/04/14	61	F	L	E	V	Y	1		Degen	C5-C6 (some osteophyte formation), scolosis in C3		CS0050	N/A	N/A	N/A
CS 0051	03/04/14	45	F	R	E	V	Y	1		None			CS0051	N/A	N/A	N/A
CS 0052	03/04/14	43	F	R	E	V	N	1		Min Degen			CS0052	N/A	N/A	N/A
CS 0053	03/04/14	49	M	L	E	V	N	1		Degen	Scolosis of C5, front lipping on C5		CS0053	N/A	N/A	N/A
CS 0054	03/04/14	30	F	L	E	V	J	1		Min Degen	C6/C7 mild lipping		CS0054	N/A	N/A	N/A
CS 0055	03/04/14	63	F	R	E	V	Y	1		Degen	Joint space narrowing C4-C7	Near C6, nutrient vessel where bloody supply enters vertebra	CS0055	N/A	N/A	N/A
CS 0056	03/04/14	70	F	L	E	V	Y	1		Degen	C4-C7, some osteophyte formation	Karen thinks a biconcavity compression fracture at C3, and calcifications	CS0056	N/A	N/A	N/A
CS 0057	03/04/14	83	F	L	E	V	Y	1		Degen	Severe from C4-C6, C5-C6 either osteophyte formation or calcification of a ligament		CS0057	N/A	N/A	N/A
CS 0058	02/04/14	53	F	L	E	V	Y	2		None	No foreign body seen		CS0058	N/A	N/A	N/A
CS 0059	02/04/14	55	F	L	E	V	J	1		Retro, Degen	Min Retro C5 on C6	Very Good Image, tag says R but its L	CS0059	N/A	N/A	N/A
CS 0060	02/04/14	30	M	L	E	V	Y	1		None		Squares in top of C4/C5, normal for patient	CS0060	N/A	N/A	N/A

CS 0061	02/04/14	60	M	L	E	V	J	1		Degen	C5-C7, some osteophyte formation		CS0061	N/A	N/A	N/A
CS 0062	02/04/14	96	F	L	E	V	Y	1		Retro, Degen	Retro, slippage between C3 on C4 & C4 on C5		CS0062	N/A	N/A	N/A
CS 0063	02/04/14	73	M	R	E	V	N	1		Fusion, Degen	C2/C3 & C4/C5 fusion, lipping on C2-C5	**Additional Additional Scan Best to Use**	CS0063	N/A	N/A	N/A
CS 0064	02/04/14	50	M	L	E	V	Y	1		Degen	Corticated bony opacity consistent with long-standing annulus fibrosis calcification (C6 right, disc calcified)		CS0064	N/A	N/A	N/A
CS 0065	01/04/14	48	F	R	T	H	N	1		None			CS0065	N/A	N/A	N/A
CS 0066	01/04/14	80	F	R	E	V	N	1		Degen	C3/C4 (big lipping) & C5/C6. Extreme osteoporosis	End plates beautifully preserved	CS0066	N/A	N/A	N/A
CS 0067	01/04/14	53	M	R	T	H	N	2	R, CT	None			CS0067	N/A	N/A	N/A
CS 0068	01/04/14	61	M	R	E	V	N	2	CT, R	None			CS0068	N/A	N/A	N/A
CS 0069	31/03/14	76	M	L	E	V	N	2	ER, L	Degen	C3-C7 loss of disc space	calcification on back of spine	CS0069	N/A	N/A	N/A
CS 0070	31/03/14	54	M	R	E	V	Y	1		Fusion, Degen	C2/C3 fused		CS0070	N/A	N/A	N/A
CS 0071	31/03/14	78	F	R	E	V	Y	1		Degen	C7/T1 reduced disc space, sclerotic area above C6 (fuzzy area), osteopenia		CS0071	N/A	N/A	N/A
CS 0072	30/04/14	51	M	R	E	V	Y	2	WB, R	Post Surgery			CS0072	N/A	N/A	N/A
CS 0073	31/03/14	86	M	L	E	V	N	1		Degen	diffuse, narrowing disc space	calcifications on back of spine	CS0073	N/A	N/A	N/A
CS 0074	31/03/14	44	M	R	E	V	N	1		Degen	C5-C6 lipping	odd shaped vertebrae, Shermans Disease?	CS0074	N/A	N/A	N/A
CS 0075	31/03/14	70	F	R	E	V	Y	1		Degen	Degen C5-C6, Loss of Disc Space/Lipping C6-C7, osteoporosis		CS0075	N/A	N/A	N/A
CS 0076	31/03/14	77	M	L	E	V	Y	1		Degen	C3-C7 Loss of Disc Space		CS0076	N/A	N/A	N/A
CS 0077	30/03/14	79	F	R	E	V	Y	2	ER, R	Fracture	C2 peg # (Type II), shifted backwards, jagged edge		CS0077	N/A	N/A	N/A
CS 0078	30/03/14	22	F	L	E	V	J	1		None	None		CS0078	N/A	N/A	N/A
CS 0079	29/03/14	44	F	L	T	H	J	2	L, CT	Fracture	Anteriolisthesis of C2-C3. # posterior of C2 body. Unstable. Hangman's Fracture. Should be clear		CS0079	N/A	N/A	N/A
CS 0080	29/03/14	96	M	L	T	V	N		CT, L	NBI	Undiagnostic C2-C4 only visible	Patient on Spinal Board				
CS 0081	29/03/14	25	F	L	T	V	Y		SUP, L	NBI		Good image				
CS 0082	29/03/14	53	M	L	**?**	H	N		L	NBI	C1-C2 potentially fused, congenital?	Patient on Spinal Board				
CS 0083	29/03/14	87	M	L	E	V	J		ER, L	NBI, Degen	Retrolisthesis C4-C5, Osteophyte C5, Degen C5-C6	Osteopenic				
CS 0084	29/03/14	68	M	L	T	H	J		CT, L	NBI, Degen	C4-C5-C6 degenerative change, low disc space	Osteopenic				
CS 0085	28/03/14	67	M	R	E	V	J		**ER, R**	NBI, Degen	C4-C5 degen, loss of disc space C5-C6					
CS 0086	28/03/14	68	F	L	E	V	Y		L	Degen	C5-C6 slight misalignment due to degen change, C6 osteophyte/calcification of ligament					
CS 0087	28/03/14	31	M	L	E	V	Y		L	NBI						
CS 0088	28/03/14	18	F	R	E	V	Y		WB, R	NBI	Misalignment/bend at C4-C5. Flexion?					
CS 0089	28/03/14	67	M	R	E	V	Y		**R**	Degen						
CS 0090	28/03/14	44	F	L	E	V	Y		**L**	NBI						

CS 0091	27/03/14	84	F	L	E	V	Y		L, ER	Degen	Mild anterior spondylolisthesis C2 on C3. Loss of disc space throughout, especially C3-C4	Earring (probably) present on image. Paralax distortion at C7. Osteopenic.							
CS 0092	27/03/14	24	M	R	E	V	N		R, MARK	NBI	Airgun pellet in soft tissues posterior neck. No #								
CS 0093	27/03/14	85	F	L	E	V	N		**L**	Degen	Between C5-C6, C5 osteophyte formation								
CS 0094	27/03/14	58	F	L	E	V	Y		L	Degen	Mild, loss of disc space throughout C3-C7	Misalignment at Ant, but not so much Post							
CS 0095	27/03/14	69	M	L	E	V	Y		**L, SB**	Degen	Changes in C3-C7								
CS 0096	27/03/14	78	F	L	E	V	N		**L**	Degen	Changes in C3-C7								
CS 0097	27/03/14	17	M	L	T	H	N		L, CT	NBI									
CS 0098	26/03/14	41	F	L	E	V	J		L	NBI, Degen	C6-C7 degen change, loss of cervical lordosis	Spine straight, should be curved							
CS 0099	26/03/14	41	F	R	E	V	J		L	NBI		Within normal limits							
CS 0100	26/03/14	68	M	L	E	V	N		**L**	Degen	C3 onwards								
CS 0101	26/03/14	77	M	L	E	V	J		**L, ER**	Degen	C5-C7 osteophyte formation, narrow joint space								
CS 0102	26/03/14	70	F	L	E	V	Y		**L**	Degen	C1-C2 fused, throughout but particularly C3-C4								
CS 0103	26/03/14	76	M	L	E	V	Y		L	Post Surgery	Degenerative change present								
CS 0104	25/03/14	52	M	L	E	V	Y			NBI		Lack of definition on C2							
CS 0105	25/03/14	42	M	R	E	V	Y		R	NBI		Poor visualisation of C1							
CS 0106	25/03/14	55	F	L	E	V	J		L, WB	Post Surgery									
CS 0107	25/03/14	95	F	L	E	V	N		**L**	Osteoporotic	Plentiful spondylotic changes, underlying infection, extreme degenerative change, osteopenic	C3-4 disc spaces poorly visualised							
CS 0108	25/03/14	66	F	R	E	V	Y		**R**	Adv Degen	Narrowing of disc spaces. Ant osteophyte formation. C5-C6 gap advanced, rest moderate								
CS 0109	24/03/14	75	M	L	E	V	Y		WB, L	Degen	Prominent Ant osteophyte formation/bone cyst C5-C6, also bottom C4 and top C6								
CS 0110	24/03/14	70	M	L	E	V	Y		**L**	Degen	Loss of cervical lordosis. No acute #'s. C7/T1 malalignment - prob projectional, unlikley acute / significant. Spondolethesis/osteophyte C7/T1								
CS 0111	24/03/14	60	F	R	E	V	Y		**R**	Degen	mild degen at C5-C7								
CS 0112	24/03/14	61	M	L	E	V	Y		**L**	Degen	Spondylotic changes C4/5 and C6/7								
CS 0113	24/03/14	78	M	L	E	V	J		**L, ER**	Degen	Disc space narrowing and ant osteophyte formation (bottom of C6), osteopenic	No vertebral collapse? myeloma patient							
CS 0114	24/03/14	25	M	L	E	V	Y		L	NBI									
CS 0115	24/03/14	45	M	L	E	V	J		**L, SB**	Degen	Minimal Degen Change C4-C5 and Calcifications								
CS 0116	24/03/14	71	F	L	E	V	J		**L**	Degen	Adv, C4-C5. 2mm posterior translation of C4 on C5								
CS 0117	23/03/14	52	M	R	E	V	J		**R**	NBI									
CS 0118	23/03/14	62	M	L	T	H	N		CT, L	NBI									
CS 0119	21/03/14	39	F	L	E	V	J		L, ER	???	Loss of normal cervical lordosis. Grade 1 spondylolisthesis of C7 on T1. Minor disc space loss C5-C6 with anterior osteophyte formation	Stable appearances.							
CS 0120	21/03/14	72	F	L	E	V	Y		**L, SB**	NBI	Normal Alignment	Intresting Case for Genant Scale							

CS	0121	21/03/14	82	M	L	E	V	?		L	???	Surgical fixation C6/7. No new fractures	Unchanged from previous examination
CS	0122	21/03/14	83	M	R	E	V	N		**R, WB**	Degen	Morderate C6-C7, Normal Alignment	
CS	0123	21/03/14	83	F	L	T	V	Y		CT, L	???	Slight misalignment C5-C6,w/joint space narrowing	Acute injury cannot be ruled out.
CS	0124	20/03/14	58	F	R	E	V	Y		**R**	Degen	C4-C7. Disc space narrowing and osteophyte formation. Facet joint changes at C7/T1?	
CS	0125	20/03/14	55	M	L	T	H	N		L, CT	NBI	Calcification at C5	
CS	0126	20/03/14	84	F	L	E	V	Y		**L**	NBI, Degen	Loss of normal cervical lordosis, disc space C5-C6, Ant osteophyte formation C3-C6. Osteopenic.	
CS	0127	20/03/14	78	F	L	E	V	Y		**L**	Degen	Lower spine. Mild disc and facet joint disease.	
CS	0128	19/03/14	48	F	L	E	V	J		CT, L	NBI, Degen	Mild Degen at C6-C7	
CS	0129	19/03/14	62	F	L	E	V	Y		**L**	NBI	Osteopenic.	
CS	0130	X	X	X									
CS	0131	19/03/14	73	F	L	E	V	Y		**L**	NBI, Degen	Changes C5-C6	
CS	0132	19/03/14	40	M	L	E	V	Y		**L, ER**	NBI	No prevertebral soft tissue swelling	
CS	0133	18/03/14	32	M	R	E	V	Y		R	NBI		
CS	0134	18/03/14	70	F	R	E	V	Y		**R ER**	NBI, Degen	Mild	
CS	0135	18/03/14	52	F	R	E	V	Y		**R**	NBI, Degen	Changes mid-lower c-spine	
CS	0136	17/03/14	53	M	L	E	V	N		**L**	NBI		
CS	0137	17/03/14	69	M	R	E	V	N		**R**	???	Callus noted around peg in keeping with healing #	Alignment satisfactory
CS	0138	17/03/14	51	M	R	E	V	Y		**R, ER**	TBC	TBC	
CS	0139	16/03/14	59	M	R	E	V	Y		R, WB	Degen	Moderate, Marked osteophyte formation	
CS	0140	16/03/14	36	M	R	E	V	J		R, ER	NBI		
CS	0141	14/03/14	41	F	R	E	V	Y		**R**	NBI		
CS	0142	14/03/14	85	F	L	E	V	J		**L**	Degen	Changes mid-c-spine	
CS	0143	14/03/14	52	F	L	E	V	N		L, ER	NBI		
CS	0144	14/03/14	62	F	L	E	V	Y		**L, WB**	Degen	Mild, C3-C7, alignment maintained	
CS	0145	14/03/14	43	F	L	E	V	Y		**L, ER**	NBI		
CS	0146	13/03/14	50	M	R	E	V	N		**R, ER**	NBI	Very mild degen changes	
CS	0147	13/03/14	66	F	L	E	V	N		**L, ER**	Degen	Minor, loss of normal lordosis	
CS	0148	13/03/14	72	F	R	E	V	J		**R, EXT**	Degen	Widespread, Minor slip C3 on C4 and C4 on C5	
CS	0149	13/03/14	40	M	R	E	V	J		R	NBI	Congenital fusion C2-C3	
CS	0150	13/03/14	28	F	R	E	V	Y		**R**	NBI		
CS	0151	13/03/14	84	M	L	E	V	N		**L**	Degen	Spondylotic changes	
CS	0152	13/03/14	71	F	L	E	V	Y		**L**	Degen		

CS	153	20/11/2014	49	M							NBI	
CS	154		44	F							Degen	Flattening of lordosis. Minor deg changes c5/6
CS	155		82	M							Degen	No vert body collapse. Deg changes
CS	156		72	M							Degen	Mild deg
CS	157		71	M							Degen	Segmentation anomaly C6/7 C5-6 spodylotic changes
CS	158		67	F							Degen	Moderate degenerative changes C5/6 and C6/7
CS	159		75	F							Degen	Deg changes throughout
CS	160		28	M							NBI	
CS	161		60	F							Degen	C6-7 deg changes
CS	162		64	M							Degen	C3/4 deg changes
CS	163		54	M							NBI	
CS	164		62	F							Grade 1 spondy	Grade 1 spondylolistheses of C2 on C3.
CS	165		82	F							Degen	Deg esp C5/6. No # No sig loss of vert body ht
CS	166		76	M							Degen	Deg changes C4-7. Prev cervical rib resection
CS	167		75	M							NBI	
CS	168		78	F							Degen	Multiple level moderate disc and facet joint change
CS	169		58	F							Degen	Minor degenerative changes
CS	170		19	M							NBI	
CS	171		68	F							Degen	Moderate OA C6-7. Loss of cervivcal lordosis
CS	172		47	M							Retrolisthesis	Grade 1 retrolisthesis C6/7 NBI
CS	173		69	F							Degen	Mild deg changes C4-6, predominantly facet joints
CS	174		80	F							Degen	Grade 1 spondylolistheses of C2 on C3, retrolistheses from nC3 to C5
CS	175		79	M							Degen	Multilevel spondylotic changes. Antegrade slip C4 on C5. Not possible to exclude #
CS	176		68	F							Degen	Minor degenerative changes C4-6
CS	177		41	M							NBI	Mild deg changes
CS	178		64	F							Degen	Deg change C5/6/7. Retrolisthesis with minor slip of C5 on 6
CS	179		26	M							NBI	
CS	180		36	M							ORIF	and C6/7 fusion. # of rt upper screw.
CS	181		52	M							NBI	Deg change C6/7
CS	182		41	M							NBI	
CS	183		71	M							Degen	Moderate OA C5/6/7. Spondylolithesis C4 on 5

Definitions of Disease
Osteopenia - low bone density
Pos - is the patient positioned on the table (T) or standing (E, erect)?
Or - is the image orientation horizontal (H) or vertical (V)?
Di - is the image diagnostic (i.e. shows C7 and T1)? (Y = Yes, N = No, J = Just, N = Nearly)
Mon - 1 = Negative, 2 = Normal Greyscale
Tags on Overlay: (L = Left, R = Right, CT = Cross Table, ER = Erect, RD = Red Dot, EX = Extension, WB = Weight Bearing, SIT = Sitting

parallax distribution will be difficult left/right
parallax distribution RE segmentations - take brighter, lower edge rather than upper
osteophytes - segment or not? Probably yes
osteoporosis - very low density
If all vertebra are curved then it is likely that this is just the persons anatomy but if just one vertebra is curved could mean degenrative change or a fracture

Appendix 6: Internal email for recruitment of third year radiography students

CSPINE CAD research

Reply Reply all Forward ...

Mark as unread

KK Knapp, Karen
Thu 19/02/2015 14:55

Hide recipients

To: [redacted]

Cc: Gundry, Michael;

Dear all

As some of you are aware, Michael Gundry and I are working on a project developing CAD software to assist in the diagnosis of c-spine fractures. We are looking for volunteers for two parts of this project.

Part 1: Tuesday 10th March in Harrison 207 (computer room) 9am to 11am we are running a session for third year students to trial the CSPINE-CAD software for image interpretation. You will be provided with your results and these will be followed up with the images and radiologist reports on ELE so you can review these and use them as a learning activity.

If you would like to participate in this, please e-mail Michael Gundry on mg361@exeter.ac.uk

Part 2: One to one sessions with Michael using the CSPINE CAD software in Matlab and providing us with feedback on how user-friendly you find it. These will be by individual appointment and held on the second floor. Again, please book an appointment with Michael.

If you wish, you are permitted to take part in both parts of the study and we can provide you with CPD certificates to reflect your participation.

Thank you all for your assistance in this work. I know some of you have already indicated your interest to me, could you confirm your participation with Michael either by e-mail or you can find him frequently sat in the corner on the second floor and I'm sure he will be happy to talk to you if you drop by.

Kind regards

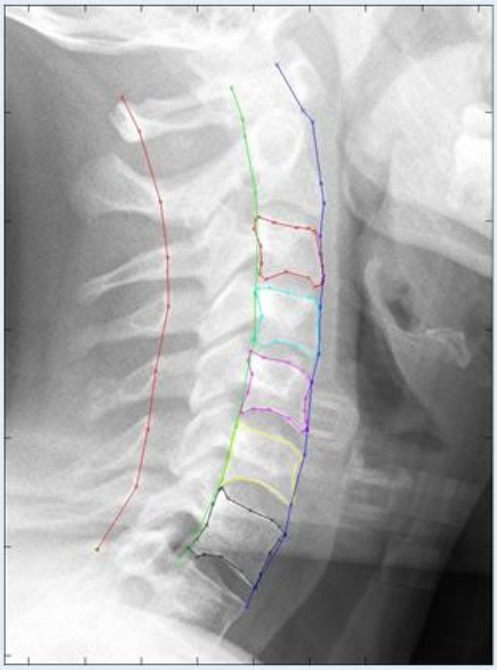
Karen and Michael

Appendix 7: leaflet for all prospective participants in the third test

CPD Opportunity

Interested in testing cutting edge computer aided detection (CAD) software?

Are you a radiographer or an F1 or F2? Then C-spine imaging needs you. You will analyse and diagnose 30 lateral C-spine images with and without the CAD software, and then fill in a short questionnaire about your experience in total this will take approximately 1hr and 15 minutes. You will then receive a CPD certificate.

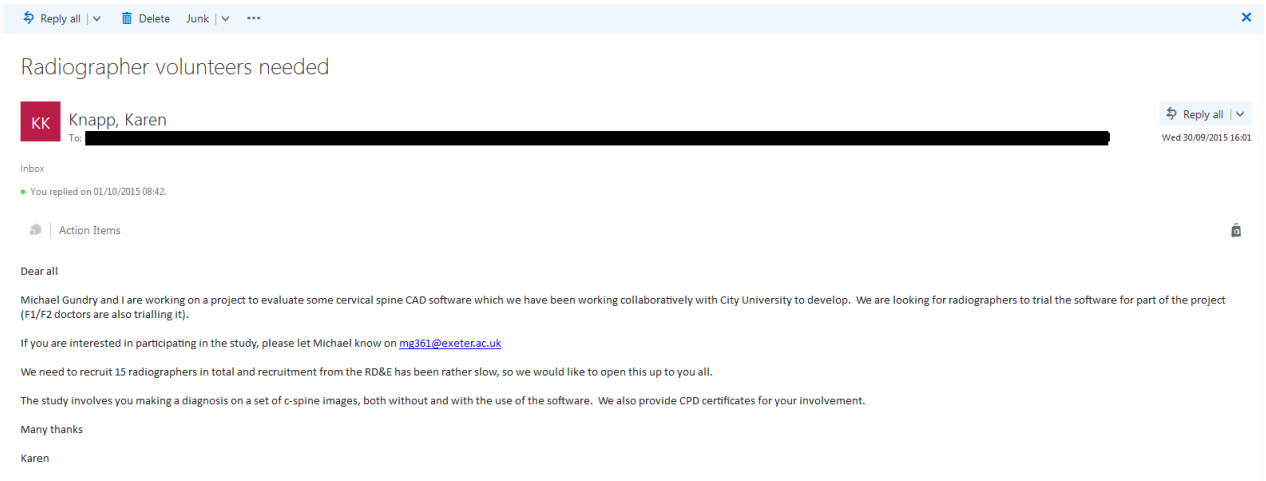


If you are interested please contact:

Michael Gundry

Mg361@exeter.ac.uk

Appendix 8: Internal email sent to all radiographers within the medical imaging department of the University of Exeter



Reply all | Delete Junk | ...

Radiographer volunteers needed

KK Knapp, Karen

To: [redacted]

Reply all | Wed 30/09/2015 16:01

Inbox

You replied on 01/10/2015 08:42.

Action Items

Dear all

Michael Gundry and I are working on a project to evaluate some cervical spine CAD software which we have been working collaboratively with City University to develop. We are looking for radiographers to trial the software for part of the project (F1/F2 doctors are also trialling it).

If you are interested in participating in the study, please let Michael know on mg361@exeter.ac.uk

We need to recruit 15 radiographers in total and recruitment from the RD&E has been rather slow, so we would like to open this up to you all.

The study involves you making a diagnosis on a set of c-spine images, both without and with the use of the software. We also provide CPD certificates for your involvement.

Many thanks

Karen

Appendix 9: Participant information sheet for third test

Royal Devon and Exeter NHS Foundation Trust

NHS

UNIVERSITY OF EXETER | MEDICAL SCHOOL

Can CSPINE-CAD software for the cervical spine assist junior doctors and radiographers in assessing lateral c-spine radiographs and aid accurate diagnoses?

UEMS REC REFERENCE NUMBER: *Apr15/B/064*

INFORMATION SHEET FOR *PARTICIPANTS*
VERSION NUMBER 2.1 : DATE 22/04/2015

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you decide to participate we thank you. If you decide not to take part we thank you for considering our request. This research is funded by the Royal Devon and Exeter NHS Foundation Trust as via their small grant funding scheme.

What is the aim of the project?

Aims:

- The aim of this study is to evaluate the acceptability and efficacy of CSPINE-CAD software for the diagnosis of fractures and dislocations in this key anatomical area.

Objectives:

- To evaluate the accuracy of qualified radiographers in diagnosing C-spine bony injuries with and without the use of CSPINE-CAD software;

- To evaluate the accuracy of junior doctors in diagnosing C-spine bony injuries with and without the use of CSPINE-CAD software;

- To evaluate the acceptability of the CSPINE-CAD software by qualified radiographers and junior doctors.

Description of participants required

We require 15 junior doctors and 15 qualified radiographers

What will participants be asked to do?

Should you agree to take part in this project, you will be asked to review a set of 30 C-Spine images and using our answer sheet write down anything you see, for each image CAD will be applied and any modifications to your diagnosis will be noted underneath. At the end you will be asked to fill in a questionnaire asking you about your experiences.

Time commitment
The time to complete this study will take between an hour and an hour and 45 minutes; this will include approximately 10 minutes being trained to use the software, an hour for the image analysis, and 10 minutes to complete the questionnaire.

Can participants change their mind and withdraw from the Project?

You may withdraw from participation in the project at any time without any disadvantage to yourself of any kind.

What data or information will be collected and what use will be made of it?

The data collected from the answer sheet and questionnaire will be used to analyse the accuracy of the CAD software, this will involve comparing the results received against the "gold standard" and inter comparison between all involved especially on confidence and opinion questions

Results of this project may be published but any data included will not be individually identifiable.

Participants in this project will be provided with a copy of the final report.

The data collected will be securely stored in such a way that only Professor Karen Knapp and Michael Gundry a master's student will be able to gain access to it. I understand that data collected during the study may be looked at by individuals from the Research Team only, from regulatory authorities or from the NHS Trust, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my records. I understand that the information will be kept confidential

Why me?
We are looking at specifically radiographers and junior doctors as this software will primarily affect you as front line professionals, and may provide useful in a clinical

setting.

What if participants have any questions?

If you have any questions about our project, either now or in the future, please feel free to contact either:-

Michael Gundry (Masters by Research student) or Professor Karen Knapp
Exeter university Exeter University
mg361@exeter.ac.uk K.M.Knapp@exeter.ac.uk

Complaints

If you have any complaints about the way in which this study has been carried out please contact the Chair of the University of Exeter Medical School Research Ethics Committee:-

Peta Foxall, PhD
Chair, UEMS Research Ethics Committee
Email : P.J.D.Foxall@exeter.ac.uk

This project has been reviewed and approved by the University of Exeter Medical School Research Ethics Committee

Appendix 10: Participant information sheet for 3rd year radiography students for first test

Can CSPINE-CAD software for the cervical spine assist third year radiography students in assessing lateral c-spine radiographs and aid accurate diagnoses?

CEMPS REFERENCE NUMBER: 1410

INFORMATION SHEET FOR *PARTICIPANTS*
VERSION NUMBER 1 : DATE 09/01/2015

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you decide to participate we thank you. If you decide not to take part we thank you for considering our request.

What is the aim of the project?
Aims:

- The aim of this study is to evaluate the acceptability and efficacy of CSPINE-CAD software for the diagnosis of fractures and dislocations in this key anatomical area.

Objectives:

- To evaluate the accuracy of third year radiography students in diagnosing C-spine bony injuries with and without the use of CSPINE-CAD software;

- To evaluate the acceptability of the CSPINE-CAD software by third year radiography students.

Description of participants required

We require third year radiography students

What will participants be asked to do?

Should you agree to take part in this project, you will trained in using the CAD software and then be asked to review a set of 5 C-Spine images and using our answer sheet write down anything you see, For each image CAD will be applied and any modifications to your diagnosis will be noted underneath. At the end you will be asked to fill in a questionnaire asking you about your experiences.

Time commitment
The time to complete this study will take about 30 minutes (roughly 20 minutes

for the image analysis and 10 minutes to fill in the questionnaire)

Can participants change their mind and withdraw from the Project?

You may withdraw from participation in the project at any time without any disadvantage to yourself of any kind.

What data or information will be collected and what use will be made of it?

The data collected from the answer sheet and questionnaire will be used to analyse the accuracy of the CAD software, this will involve comparing the results received against the "gold standard" and inter comparison between all involved especially on confidence and opinion questions

Results of this project may be published but any data included will not be individually identifiable.

CPD certificates will be handed out on the day

Why me?
We are looking at specifically third year radiography students as this software will primarily affect you as you become radiographers and will in future help you in diagnosing C-Spine fractures more accurately and quickly and thus the movement of patients to CT allowing a better service.

What if participants have any questions?

If you have any questions about our project, either now or in the future, please feel free to contact either:-

Michael Gundry (Masters by research student) or Professor Karen Knapp
Exeter university Exeter University
mg361@exeter.ac.uk K.M.Knapp@exeter.ac.uk

Complaints

If you have any complaints about the way in which this study has been carried out please contact the Chair of the University of Exeter Medical School Research Ethics Committee:-

Peta Foxall, PhD
Chair, UEMS Research Ethics Committee
Email : P.J.D.Foxall@exeter.ac.uk

This project has been reviewed and approved by the University of Exeter Medical School Research Ethics Committee

Appendix 11: Participant information sheet for 3rd year radiography students for second test

Can CSPINE-CAD software for the cervical spine assist third year radiography students in assessing lateral c-spine radiographs and aid accurate diagnoses?

CEMPS REFERENCE NUMBER: 1410

INFORMATION SHEET FOR *PARTICIPANTS*
VERSION NUMBER 1 : DATE 09/01/2015

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you decide to participate we thank you. If you decide not to take part we thank you for considering our request.

What is the aim of the project?
Aims:

- The aim of this study is to evaluate the acceptability and efficacy of CSPINE-CAD software for the diagnosis of fractures and dislocations in this key anatomical area.

Objectives:

- To evaluate the accuracy of third year radiography students in diagnosing C-spine bony injuries with and without the use of CSPINE-CAD software;

- To evaluate the acceptability of the CSPINE-CAD software by third year radiography students.

Description of participants required
We require third year radiography students

What will participants be asked to do?

Should you agree to take part in this project, you will be asked to review a set of 20 C-Spine images and using our answer sheet write down anything you see, For each image CAD will be applied and any modifications to your diagnosis will be noted underneath. At the end you will be asked to fill in a questionnaire asking you about your experiences.

Time commitment
The time to complete this study will take about 1-1.5 hours (roughly an hour for the image analysis and 15 minutes to fill in the questionnaire)

Can participants change their mind and withdraw from the Project?

You may withdraw from participation in the project at any time without any disadvantage to yourself of any kind.

What data or information will be collected and what use will be made of it?

The data collected from the answer sheet and questionnaire will be used to analyse the accuracy of the CAD software, this will involve comparing the results received against the "gold standard" and inter comparison between all involved especially on confidence and opinion questions

Results of this project may be published but any data included will not be individually identifiable.

Participants in this project will be provided with a copy of the final report.

The data collected will be securely stored and final results and CPD certificates emailed to the individuals taking part

Why me?

. We are looking at specifically third year radiography students as this software will primarily affect you as you become radiographers and will in future help you in diagnosing C-Spine fractures more accurately and quickly and thus the movement of patients to CT allowing a better service.

What if participants have any questions?

If you have any questions about our project, either now or in the future, please feel free to contact either:-

Michael Gundry (Masters by research student) or Professor Karen Knapp
Exeter university Exeter University
mg361@exeter.ac.uk K.M.Knapp@exeter.ac.uk

Complaints

If you have any complaints about the way in which this study has been carried out please contact the Chair of the University of Exeter Medical School Research Ethics Committee:-

Peta Foxall, PhD
Chair, UEMS Research Ethics Committee
Email : P.J.D.Foxall@exeter.ac.uk

This project has been reviewed and approved by the University of Exeter Medical School Research Ethics Committee

Appendix 12: Consent form for first and second testing

Can CSPINE-CAD software for the cervical spine assist third year radiography students in assessing lateral c-spine radiographs and aid accurate diagnoses?

UEMS REC REFERENCE NUMBER: 1410
CONSENT FORM FOR
***PARTICIPANTS* VERSION NUMBER :1 DATE 09/01/2015**

I have read the Information Sheet Version Number [1] Dated [09/01/2015] concerning this project and understand what it is about. All my questions have been answered to my satisfaction. I understand that I am free to request further information at any stage.

I know that:

1. my participation in the project is entirely voluntary; Y/N

2. I am free to withdraw from the project at any time without any disadvantage; Y/N

3. the data email addresses, questionnaires and answer sheets will be retained in secure storage; Y/N

4. Data will be retained for up to 5 years in an anonymous format and I consent for its use in related studies and systematic reviews Y/N

5. the results of the project may be published but my anonymity will be preserved. Y/N

I agree to take part in this project.

..... ……. .....
(Printed name of participant) (Signature of participant) (Date)

..... ……. .....
(Printed name of researcher) (Signature of researcher) (Date)

This project has been reviewed and approved by the University of Exeter Medical School Research Ethics Committee

Appendix 13: Consent form for third test

Royal Devon and Exeter NHS Foundation Trust

NHS UNIVERSITY OF EXETER | MEDICAL SCHOOL

Can CSPINE-CAD software for the cervical spine assist junior doctors and radiographers in assessing lateral c-spine radiographs and aid accurate diagnoses?

UEMS REC REFERENCE NUMBER: *Apr15/B/064*

CONSENT FORM FOR PARTICIPANTS VERSION NUMBER: 2.1 DATE 22/04/2015

I have read the Information Sheet Version Number 2.1 Dated 22/04/2015 concerning this project and understand what it is about. All my questions have been answered to my satisfaction. I understand that I am free to request further information at any stage. I know that:

		Initials
1.	my participation in the project is entirely voluntary;	
2.	I am free to withdraw from the project at any time without any disadvantage;	
3.	the data email addresses, questionnaires and answer sheets will be retained in secure storage;	
4.	Data will be retained for up to 5 years in an anonymous format and I consent for its use in related studies and systematic reviews	
5.	The results of the project may be published but my anonymity will be preserved.	
6.	I understand that data collected during the study may be looked at by individuals from the Research Team only; from regulatory authorities or from the NHS Trust, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my records. I understand that the information will be kept confidential.	

I agree to take part in this project.

....
(Printed name of participant) (Signature of participant) (Date)
....
(Printed name of researcher) (Signature of researcher) (Date)

This project has been reviewed and approved by the University of Exeter Medical School Research Ethics Committee

Appendix 14: Answer sheet for first test

Answer sheet

Number _____

Date _____

.

For any deletions or additions to the original diagnosis after seeing the CAD image please put it in in the “After CAD” box please state “delete…..” do not amend the original diagnosis above but just state what you would change to the diagnosis in the after CAD diagnosis box.

Image	Normal?	Diagnosis
1	Yes ☐ No ☐	
1 After CAD	Yes ☐ No ☐	
2	Yes ☐ No ☐	
2 After CAD	Yes ☐ No ☐	
3	Yes ☐ No ☐	
3 After CAD	Yes ☐ No ☐	
4	Yes ☐ No ☐	
4 After CAD	Yes ☐ No ☐	

5	Yes ☐ No ☐	
5 After CAD	Yes ☐ No ☐	

Appendix 15: Questionnaire used in the first and second test

Questionnaire

Number _____

Date _____

1. Did any of your assessments on placement involve doing a C-Spine ?
   Yes ☐ No ☐

2. On a scale of 1 to 5, where 5 if very confident and 1 is not confident at all, how confident do you feel when interpreting cervical-spine radiographs?

   1☐ 2☐ 3☐ 4☐ 5☐

3. On a scale of 1 to 5, where 5 if very confident and 1 is not confident at all, how confident did you feel when making a diagnosis on the test images?

   1☐ 2☐ 3☐ 4☐ 5☐

4. On a scale of 1 to 5, where 5 if very confident and 1 is not confident at all, how confident did you feel when making a diagnosis on the test images with the assistance of the CSPINE-CAD software?
   1☐ 2☐ 3☐ 4☐ 5☐

5. In practice, would you find the CSPINE-CAD software helpful to as an additional “pair of eyes”?

   Yes ☐ No ☐

6. Are there any other additions or features you would like to see in the CSPINE-CAD software?

_____
__

7. If you did find this useful what other types of examination/body part would you
like to see this sort of CAD software applied to?

_____

Appendix 16: Answer sheet for second test

Answer sheet

Number _____

Date _____

For any deletions or changes after seeing CAD applied to the image please put it in the “After CAD” box and for deletions please state “delete…..” do not amend the original diagnosis above.

Image	Normal?	Diagnosis
1	Yes ☐ No ☐	
1 After CAD	Yes ☐ No ☐	
2	Yes ☐ No ☐	
2 After CAD	Yes ☐ No ☐	
3	Yes ☐ No ☐	
3 After CAD	Yes ☐ No ☐	

4	Yes ☐ No ☐	
4 After CAD	Yes ☐ No ☐	
5	Yes ☐ No ☐	
5 After CAD	Yes ☐ No ☐	
6	Yes ☐ No ☐	
6 After CAD	Yes ☐ No ☐	
7	Yes ☐ No ☐	
7 After CAD	Yes ☐ No ☐	
8	Yes ☐ No ☐	
8 After CAD	Yes ☐ No ☐	
9	Yes ☐ No ☐	
9 After CAD	Yes ☐ No ☐	

10	Yes ☐ No ☐	
10 After CAD	Yes ☐ No ☐	
11	Yes ☐ No ☐	
11 After CAD	Yes ☐ No ☐	
12	Yes ☐ No ☐	
12 After CAD	Yes ☐ No ☐	
13	Yes ☐ No ☐	
13 After CAD	Yes ☐ No ☐	
14	Yes ☐ No ☐	
14 After CAD	Yes ☐ No ☐	
15	Yes ☐ No ☐	
15 After CAD	Yes ☐ No ☐	

16	Yes ☐ No ☐	
16 After CAD	Yes ☐ No ☐	
17	Yes ☐ No ☐	
17 After CAD	Yes ☐ No ☐	
18	Yes ☐ No ☐	
18 After CAD	Yes ☐ No ☐	
19	Yes ☐ No ☐	
19 After CAD	Yes ☐ No ☐	
20	Yes ☐ No ☐	
20 After CAD	Yes ☐ No ☐	

Appendix 17: Questionnaire for third test (junior doctors and radiographers)

Royal Devon and Exeter NHS Foundation Trust

University of Exeter Medical School

CSPINE-CAD project Questionnaire

ID Number _____

Date _____

Email address (in order to send you the results of the study and your CPD certificate)

_____

1. What is your professional background?:
   Radiographer ☐Medical Doctor ☐

2. How many years have you worked full time (37.5hrs or more) or part time (please state hours worked)?

_____

3. Do you have any postgraduate qualifications in image interpretation or reporting? If yes, please state what and when you obtained the qualifications.

_____

4. On a scale of 1 to 5, (where 5 is very confident and 1 is not confident at all), how confident do you feel when interpreting cervical-spine radiographs?

   Not confident Very confident
   1☐ 2☐ 3☐ 4☐ 5☐

5. On a scale of 1 to 5 (where 5 if very confident and 1 is not confident at all), how confident did you feel when making a diagnosis on the test datasets?

   Not confident Very confident
   1☐ 2☐ 3☐ 4☐ 5☐

6. On a scale of 1 to 5 (where 5 if very confident and 1 is not confident at all), how confident did you feel when making a diagnosis on the test datasets with the assistance of the CSPINE-CAD software?

Not confident Very confident
1☐ 2☐ 3☐ 4☐ 5☐

7. In practice, would you find the CSPINE-CAD software helpful to as an additional “pair of eyes”?

_____

8. Are there any other features you would like to see in the CSPINE-CAD software?

_____
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_____
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9. If you found this useful, what other types of examination/body part would you
like to see this sort of CAD software applied to?

_____

Appendix 18: Answer sheet for the third test (junior doctors and radiographers)

Royal Devon and Exeter NHS Foundation Trust

University of Exeter Medical School

CSPINE-CAD Answer sheet

ID Number _____ Date _____

For each case reviewed, please rate the boxes relating to the corresponding vertebra to indicate a fracture if one is present and the boxes corresponding to the inter-vertebral disc space to indicate misalignment (which may be associated with fracture/dislocations) between two or more vertebrae. This needs to be done for the first read, without the use of CSPINE-CAD and for the second read with the use of CSPINE-CAD. Please note your level of confidence for the presence of a fracture or misalignment when **1 is equal to no fracture or misalignment, 3 is equivocal and 6 is where you are certain there is a fracture or misalignment**.

Please add any comments on the image as you wish, for example if the image is sub-optimal or if degenerative change is confounding your diagnosis.

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
EXAMPLE	[1] C1 [1] C2 [1] C3 [1] C4 [1] C5 [1] C6 [1] C7 [1] C1-C2 [1] C2-C3 [3] C3-C4 [1] C4-C5 [1] C5-C6 [1] C6-C7 [1] C7-T1	[1] C1 [1] C2 [1] C3 [1] C4 [1] C5 [1] C6 [1] C7 [1] C1-C2 [1] C2-C3 [5] C3-C4 [1] C4-C5 [1] C5-C6 [1] C6-C7 [1] C7-T1	Minor degenerative changes noted C3 to C6.
1	[ ] C1 [ ] C2 [ ] C3 [ ] C4 [ ] C5 [ ] C6 [ ] C7 [ ] C1-C2 [ ] C2-C3 [ ] C3-C4 [ ] C4-C5 [ ] C5-C6 [ ] C6-C7 [ ] C7-T1	[ ] C1 [ ] C2 [ ] C3 [ ] C4 [ ] C5 [ ] C6 [ ] C7 [ ] C1-C2 [ ] C2-C3 [ ] C3-C4 [ ] C4-C5 [ ] C5-C6 [ ] C6-C7 [ ] C7-T1	
2	[ ] C1 [ ] C2 [ ] C3 [ ] C4 [ ] C5 [ ] C6 [ ] C7 [ ] C1-C2 [ ] C2-C3 [ ] C3-C4 [ ] C4-C5 [ ] C5-C6 [ ] C6-C7 [ ] C7-T1	[ ] C1 [ ] C2 [ ] C3 [ ] C4 [ ] C5 [ ] C6 [ ] C7 [ ] C1-C2 [ ] C2-C3 [ ] C3-C4 [ ] C4-C5 [ ] C5-C6 [ ] C6-C7 [ ] C7-T1	

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
3	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
4	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
5	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
6	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
7	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
8	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
9	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
10	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
11	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
12	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
13	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
14	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
15	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
16	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
17	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
18	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
19	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
20	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
21	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
22	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
23	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
24	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
25	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
26	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
27	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
28	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
29	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
30	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
SPARE CASE NO:	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
SPARE CASE NO:	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	

Appendix 19: Checklist used during the third test

Checklist

Check all blinds are closed
Check all doors are closed
Check the software works before starting (load and run the first example image)
Take pictures of the room being used (remember room number and area)
Take pictures of the researchers' position and the participants before starting
Screen grab the MATLAB program, the desktop and the version of the CSPINE CAD software
Record time spent at each interval (software explanation, 30 images, and the questionnaire)

Give each participant an **Information sheet** and address any questions they might have (just to make sure they have seen it before and understand the test)
Then give each participant a **Consent form** (make sure they know they can withdraw at any point and reemphasise that the data are anonymous and that the email address is for giving the true answers overall and sending out the CPD certificate)

Software
Load MATLAB and click on the most current version of the CSPINE CAD software under the Apps heading, then load the first image (lowest number) from the folder containing the 31 test images, this will always be the example image (Figure 1)

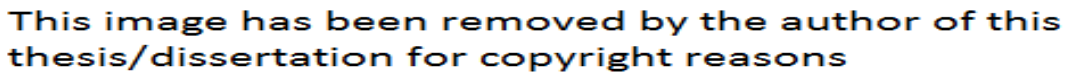

Figure 3. CSPINE CAD software and lateral C-Spine x-ray image

- First discuss with the participant that the image has to be facing towards the control panel, so talk through **rotate** and **flip** (bottom)

- Then how to **zoom** in and out and how to **reset** it
- And how to use the **contrast** buttons from min to max and how to **reset** it

- Then discuss the **Answer sheet** what the scores mean and confidence levels (discuss that 1 means no injury i.e. normal and 2-6 are gradual increases in confidence with 6 being certain there is an injury), explain there are 3 sections; **fracture, misalignment and comments** (Figure 2)

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
EXAMPLE	1 C1 1 C1-C2 1 C2 1 C2-C3 1 C3 3 C3-C4 1 C4 1 C4-C5 1 C5 1 C5-C6 1 C6 1 C6-C7 1 C7 1 C7-T1	1 C1 1 C1-C2 1 C2 1 C2-C3 1 C3 5 C3-C4 1 C4 1 C4-C5 1 C5 1 C5-C6 1 C6 1 C6-C7 1 C7 1 C7-T1	Minor degenerative changes noted C3 to C6.

Figure 4. Example of the Answer sheet and how it should be used

- The participant should then make a rough diagnosis of the example image and then apply the **CAD CSPINE software** to the same image

- To do this the participant numbers the vertebral bodies C1-C7 (Figure 3) by clicking on the start button under **"choose vertebral centres"** they should be shown how to amend the position should they mistakenly place the dot in the wrong place, this is done using the **"remove last point"** button.

Figure 5. Lateral x-ray C-Spine image with numbered vertebrae

- After numbering the vertebral bodies the participant should then click the **"perform segmentation"** button, this segments the vertebral bodies in yellow

- What the CSPINE-CAD software shows should be discussed by using the options in the **show graphics** box (Figure 4)

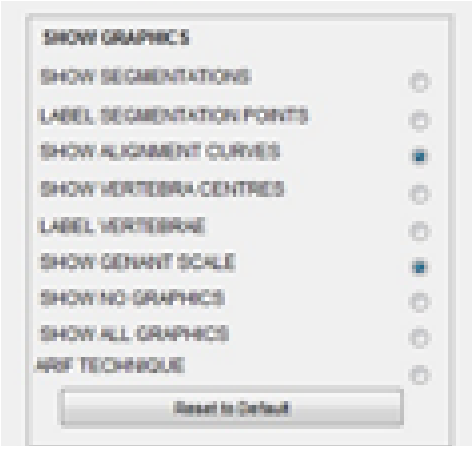

Figure 6. "Show graphics" box

- The first use of CAD should be with just the **"show segmentations"**, and **"show genant scale"** (Figure 5) ticked this should show up any suspected fractures of the vertebral bodies. **State limitations of software i.e. it does not segment C1 or C2**

- Then just the **"show alignment curves"** button should be pressed, this will show and indicate any misalignment present (Figure 6) **State limitations of software i.e. it does not indicate alignment of C2/C3 or C7/T1 and that it indicates the vertebral body and not the precise joint so to look at both joints**

- The rest of the buttons can be talked through but are not necessary

- The participant should then make a new diagnosis putting their new answer in the **"With CSPINE CAD"** boxes (using the same scoring method as before).

- The participant is told that by clicking the **next button** it loads the next image and in this case the first image of the test, they are then told this process of without and with CAD should be followed for all 30 images.

- The software is then closed and the example (first image) is reloaded, the participant is asked to go through it on their own like they have just been shown, asking any questions as they go.

- At the end of the example image, the participant is informed of the **questionnaire** attached to the back of the answer sheet which needs to be filled in at the end.

- The participant is then informed that the researcher (myself; Michael Gundry) will remain in the room with my back to the participant at all times, and should there be any issues; software problems, image issues, extra paper etc.. that they should just ask.

- All personal information data will then be stored at St Lukes (University of Exeter) in a locked draw/office for the agreed amount of time according to the ethics protocol.

Appendix 20: Raw first test data including benefit of the doubt data

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
3				2	2						3	1						3			
4											1	1						1			
5											3	3						3			
6											3	1						3			
9											1	1						1			

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
3				2	2					2	1	1						1			
4											1	1						1			
5											1	3						3			
6											3	1	2					1	2		
9					2						1	1						1			

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
3					2																
4																					
5																					
6																					
9																					

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
3					2																
4																					
5																					
6																					
9																					

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
3				2					3	1	1	3				3	1	3			
4			2	2					3	3	3	3				3	3	3			
5				2					3	1	3	3				3	3	3			
6									3	1	1	3				3	1	3			
9			2	2	2				3	1	1	1				3	1	1			

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
3				2					3	1	1	3				3	1	3			
4			2	2					3	3	3	3				3	3	3			
5									3	1	3	3				3	3	3			
6									3	1	1	3				3	1	3			
9			2	2	2				3	1	1	1				3	1	1			

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
3				2	2		2					1	3						3		
4					2							3	3						3		
5												3	3						3		
6												3	1	2					3	2	
9					2							1	3						3		

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
3				2	2		2					1	3						3		
4					2							3	3						3		
5												3	3						3		
6												1	1	2					1	2	
9					2							1	1						1		

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
3																					
4																					
5																					
6																					
9																					

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
3																					
4																					
5										2	2						2				
6																					
9																					

Raw first test data after the “benefit of the doubt” has been applied

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
3				2	2							1						3			
4											1							1			
5											3							3			
6												1						3			
9												1						1			

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
3				2	2					2	1							1			
4											1							1			
5											1							3			
6												1	2					1	2		
9					2							1						1			

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
3					2																
4																					
5																					
6																					
9																					

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
3					2																
4																					
5																					
6																					
9																					

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
3				2						1	1	1				3	1	3			
4			2	2						3	3	3				3	3	3			
5				2						1	1	3				3	3	3			
6										1	1	1				3	1	3			
9			2	2	2					1	1	1				3	1	1			

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
3				2						1	1	1				3	1	3			
4			2	2						3	3	3				3	3	3			
5										1	1	3				3	3	3			
6										1	1	1				3	1	3			
9			2	2	2					1	1	1				3	1	1			

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
3				2	2		2					1							3		
4					2								3						3		
5													3						3		
6													1	2					3	2	
9					2							1							3		

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
3				2	2		2					1							3		
4					2								3						3		
5													3						3		
6													1	2					1	2	
9					2								1						1		

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
3																					
4																					
5																					
6																					
9																					

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
3																					
4																					
5										2	2						2				
6																					
9																					

Appendix 21: Raw second test data including benefit of the doubt data

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
14																					
15																					
16																					
17																					
18																					
20																					
21																					
39																					
41																					
44																					

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
14																					
15																					
16																					
17																					
18																					
20																					
21																					
39																					
41																					
44																					

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8												1	3						3		
14												1	3						3		
15												1	1						1		
16												3	1	2					3	2	
17												1	3						3		
18												3	3						3		
20					2							1	3						3		
21					2							1	3						3		
39					2							3	3						3		
41					2							1	3						3		
44												3	3						3		

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8												1	3						3		
14												1	3						3		
15												1	1						1		
16												1	1	2					1	2	
17												1	3						3		
18												3	3						3		
20												1	3						3		
21					2							1	3						3		
39					2							3	3						3		
41					2							1	3						3		
44												3	3						3		

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
14								2													
15																					
16																					
17																					
18																					
20																					
21																					
39																					
41																					
44																					

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
14								2													
15																					
16																					
17																					
18																					
20																					
21																					
39																					
41																					
44																					

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8								3													
14								3													
15								3													
16								1													
17	2							3													
18								3													
20								3													
21								3						2							
39								3													
41								1													
44								3													

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8								3													
14								3													
15								3													
16								1													
17	2							3													
18								3													
20								3													
21								3						2							
39								3													
41								1													
44								3													

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
14																					
15																					
16																					
17																					
18																					
20							2														
21																					
39																					
41																					
44																					

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
14														2							2
15																					
16																					
17																					
18																					
20							2														
21																					
39																					
41																					
44																					

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8						3															
14						3															
15						3															
16						3															
17						3															
18						3															
20						3															
21						3															
39						3															
41						3															
44						3															

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8						3															
14						3															
15						3															
16						3															
17						3															
18						3															
20						3					2										
21						3															
39						3															
41						3															
44						3															

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8									3	1	1	3				3	1	3			
14			2	2					3	1	1	3				3	1	3			
15									3	1	3	3				3	3	3			
16									3	1	3	3				3	3	3			
17									3	1	1	3				3	1	3			
18			2			2			3	3	1	3				3	3	3			
20			2	2					3	1	1	3				3	1	3			
21									3	1	1	1				3	1	1			
39			2	2					3	1	1	3				3	1	3			
41									1	1	3	3				1	3	3			
44			2	2	2				3	1	1	1				3	1	1			

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8									3	1	1	3				3	1	3			
14			2	2					3	1	1	3				3	1	3			
15			2			2			3	1	3	3				3	3	3			
16									1	1	3	3				1	3	3			
17									3	1	1	1				3	1	1			
18			2			2	2		3	3	1	3				3	3	3			
20			2	2					3	1	1	3				3	1	3			
21									3	1	1	1				3	1	1			
39			2	2					3	1	1	3				3	1	3			
41									1	1	3	3				1	3	3			
44			2	2	2				3	1	1	1				3	1	1			

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8									1	1						1					
14									3	3						3					
15									3	3						3					
16						2			3	3						3					
17						2	2		3	3						3					
18									3	3						3					
20						2			3	3						3					
21									3	3						3					
39									3	3						3					
41									3	3						3					
44									3	3						3					

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8									1	1						1					
14									3	3						3					
15									3	3						3					
16						2			3	3						3					
17						2	2		3	3						3					
18									3	3						3					
20						2			3	3						3					
21									3	3						3					
39									3	3						3					
41									3	3						3					
44									3	3						3					

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8													3	1						3	
14													1	1						1	
15													3	3						3	
16													3	3						3	
17													3	3						3	
18													3	3						3	
20													3	3						3	
21													1	3						3	
39													3	3						3	
41													3	3						3	
44													3	3						3	

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8													3	3						3	
14													1	1						1	
15													3	3						3	
16													3	3						3	
17													3	3						3	
18													3	3						3	
20													3	3						3	
21													3	3						3	
39													3	3						3	
41													3	3						3	
44													3	3						3	

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
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41																					
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Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
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Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
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Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
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39																					
41																					
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Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8									1	1						1					
14									3	3						3					
15									1	1						1					
16									3	3						3					
17									3	1	2					3	2				
18									3	3						3					
20									3	3						3					
21									3	3						3					
39									3	1						3					
41					2				3	3						3					
44									1	3						3					

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8								2	1	1						1					
14									3	3						3					
15									3	3						3					
16									3	3						3					
17									3	1	2					3	2				
18									3	3						3					
20									3	3						3					
21									3	3						3					
39									3	1						3					
41					2				3	3						3					
44									1	3						3					

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
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39																					
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44																					

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
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Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8												1	3						3		
14					2							1	3						3		
15												1	3						3		
16											2	1	3					2	3		
17												1	3						3		
18												1	3						3		
20												1	3						3		
21						2						1	3						3		
39												1	3						3		
41					2							3	3						3		
44												1	3						3		

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8												1	3	2					3		
14					2							1	3						3		
15												1	3						3		
16											2	1	3	2				2	3		
17												1	3						3		
18												1	3						3		
20												1	3						3		
21						2						1	1						1		
39												1	3						3		
41					2							3	3						3		
44												1	3						3		

Raw second test data the “benefit of the doubt” has been applied

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
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Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
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Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8					1														3		
14					1														3		
15					1														1		
16						1	2												3	2	
17					1														3		
18					3														3		
20				2	1														3		
21				2	1														3		
39				2	3														3		
41				2	1														3		
44					3														3		

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8					1														3		
14					1														3		
15					1														1		
16						1	2												3	2	
17					1														3		
18					3														3		
20				2	1														3		
21				2	1														3		
39				2	3														3		
41				2	1														3		
44					3														3		

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
14								2													
15																					
16																					
17																					
18																					
20																					
21																					
39																					
41																					
44																					

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8					1														3		
14					1														3		
15					1														1		
16					1		2												1	2	
17					1														3		
18					3														3		
20					1														3		
21				2	1														3		
39				2	3														3		
41				2	1														3		
44					3														3		

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
14																					
15																					
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18																					
20							2														
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41																					
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Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
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41																					
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Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8								3													
14								3													
15								3													
16								1													
17								3						2							
18								3													
20								3													
21								3													
39	2							3													
41								1													
44								3													

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8								3													
14								3													
15								3													
16								1													
17								3						2							
18								3													
20								3													
21								3													
39								3													
41								1													
44								3													

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
14																					
15																					
16																					
17																					
18																					
20							2						2								
21																					
39																					
41																					
44																					

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
14																					
15																					
16																					
17																					
18																					
20							2						2								
21																					
39																					
41																					
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Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8						3															
14						3															
15						3															
16						3															
17						3															
18						3															
20						3															
21						3															
39						3															
41						3															
44						3															

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8						3															
14						3															
15						3															
16						3															
17						3															
18						3															
20						3					2										
21						3															
39						3															
41						3															
44						3															

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8										1	1	1				3	1	3			
14			2	2						1	1	1				3	1	3			
15										1	1	3				3	3	3			
16										1	1	3				3	3	3			
17										1	1	1				3	1	3			
18			2		2					1	1	1				3	3	3			
20			2	2						1	1	1				3	1	3			
21										1	1	1				3	1	1			
39			2	2						1	1	1				3	1	3			
41										1	1	3				1	3	3			
44			2	2	2					1	1	1				3	1	1			

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8										1	1	1				3	1	3			
14			2	2						1	1	1				3	1	3			
15			2		2					1	1	3				3	3	3			
16										1	1	3				1	3	3			
17										1	1	1				3	1	1			
18			2		2	2				1	1	1				3	3	3			
20			2	2						1	1	1				3	1	3			
21										1	1	1				3	1	1			
39			2	2						1	1	1				3	1	3			
41										1	1	3				1	3	3			
44			2	2	2					1	1	1				3	1	1			

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8									1							1					
14									3							3					
15									3							3					
16						2			3							3					
17						2	2		3							3					
18									3							3					
20						2			3							3					
21									3							3					
39									3							3					
41									3							3					
44									3							3					

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8									1							1					
14									3							3					
15									3							3					
16						2			3							3					
17						2	2		3							3					
18									3							3					
20						2			3							3					
21									3							3					
39									3							3					
41									3							3					
44									3							3					

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8													1							3	
14													1							1	
15													3							3	
16													3							3	
17													3							3	
18													3							3	
20													3							3	
21												1								3	
39												3								3	
41												3								3	
44												3								3	

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8													3							3	
14													1							1	
15													3							3	
16													3							3	
17													3							3	
18													3							3	
20													3							3	
21													3							3	
39													3							3	
41													3							3	
44													3							3	

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
14																					
15																					
16																					
17																					
18																					
20																					
21																					
39																					
41																					
44																					

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
14																					
15																					
16																					
17																					
18																					
20																					
21																					
39																					
41																					
44																					

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
14																					
15																					
16																					
17																					
18																					
20																					
21																					
39																					
41																					
44																					

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
14																					
15																					
16																					
17																					
18																					
20																					
21																					
39																					
41																					
44																					

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8									1							1					
14									3							3					
15									1							1					
16									3							3					
17										1	2					3	2				
18										3						3					
20										3						3					
21										3						3					
39										1						3					
41					2					3						3					
44									1							3					

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8								2	1							1					
14									3							3					
15									3							3					
16									3							3					
17										1	2					3	2				
18										3						3					
20										3						3					
21										3						3					
39										1						3					
41					2					3						3					
44									1							3					

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
14																					
15																					
16																					
17																					
18																					
20																					
21																					
39																					
41																					
44																					

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8																					
14																					
15																					
16																					
17																					
18																					
20																					
21																					
39																					
41																					
44																					

Participant	Without CAD Vertebrae							Without CAD Alignment							Without CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8												1							3		
14					2							1							3		
15												1							3		
16											2	1						2	3		
17												1							3		
18												1							3		
20												1							3		
21						2						1							3		
39												1							3		
41					2							3							3		
44												1							3		

Participant	With CAD Vertebrae							With CAD Alignment							With CAD Alignment ("true" report)						
	C1	C2	C3	C4	C5	C6	C7	C1	C2	C3	C4	C5	C6	C7	C1-2	C2-3	C3-4	C4-5	C5-6	C6-7	C7-T1
8												1		2					3		
14					2							1							3		
15												1							3		
16											2	1		2				2	3		
17												1							3		
18												1							3		
20												1							3		
21						2						1							1		
39												1							3		
41					2							3							3		
44												1							3		

Appendix 22: Answers from third testing in format of an answer sheet

Royal Devon and Exeter NHS Foundation Trust

University of Exeter Medical School

CSPINE-CAD Answers

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Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
EXAMPLE	1 C1, 1 C2, 1 C3, 1 C4, 1 C5, 1 C6, 1 C7 1 C1-C2, 1 C2-C3, 3 C3-C4, 1 C4-C5, 1 C5-C6, 1 C6-C7, 1 C7-T1	1 C1, 1 C2, 1 C3, 1 C4, 1 C5, 1 C6, 1 C7 1 C1-C2, 1 C2-C3, 5 C3-C4, 1 C4-C5, 1 C5-C6, 1 C6-C7, 1 C7-T1	Minor degenerative changes noted C3 to C6.
1	C1, C2, C3, C4, C5, C6, C7 C1-C2, C2-C3, 6 C3-C4, C4-C5, C5-C6, C6-C7, C7-T1	C1, C2, C3, C4, C5, C6, C7 C1-C2, C2-C3, C3-C4, C4-C5, C5-C6, C6-C7, C7-T1	Marked Degen C3-C7
2	C1, C2, C3, C4, C5, C6, C7 C1-C2, C2-C3, C3-C4, 6 C4-C5, C5-C6, C6-C7, C7-T1	C1, C2, C3, C4, C5, C6, C7 C1-C2, C2-C3, C3-C4, C4-C5, C5-C6, C6-C7, C7-T1	Marked narrowing of the C5-C6 And C6-C7 disc spaces with anterior and posterior osteophytes

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
3	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 6 C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	Disruption to PLL, ALL maintained
4	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 6 C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	Marginal osteophyte formation, moderate degen
5	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 6 C5-C6 ☐ C6 6 C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	degen
6	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 6 C3-C4 ☐ C4 6 C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
7	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 6 C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
8	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☒ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
9	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	Normal
10	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☒ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
11	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☒ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
12	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	Normal

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
13	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	Normal, degen
14	☐ C1 ☐ C1-C2 ☐ C2 6 C2-C3 ☐ C3 6 C3-C4 ☐ C4 6 C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
15	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 6 C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	Degen C5/C6/C7
16	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 6 C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
17	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	Airgun pellet posterior to C2

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
18	☐ C1 ☐ C2 ☐ C3 ☐ C4 ☐ C5 ☐ C6 ☐ C7 ☐ C1-C2 ☐ C2-C3 ☐ C3-C4 ☐ C4-C5 ☐ C5-C6 ☐ C6-C7 ☐ C7-T1	☐ C1 ☐ C2 ☐ C3 ☐ C4 ☐ C5 ☐ C6 ☐ C7 ☐ C1-C2 ☐ C2-C3 ☐ C3-C4 ☐ C4-C5 ☐ C5-C6 ☐ C6-C7 ☐ C7-T1	Normal
19	☐ C1 ☐ C2 ☐ C3 ☐ C4 6 C5 ☐ C6 ☐ C7 ☐ C1-C2 ☐ C2-C3 ☐ C3-C4 ☐ C4-C5 ☐ C5-C6 ☐ C6-C7 ☐ C7-T1	☐ C1 ☐ C2 ☐ C3 ☐ C4 ☐ C5 ☐ C6 ☐ C7 ☐ C1-C2 ☐ C2-C3 ☐ C3-C4 ☐ C4-C5 ☐ C5-C6 ☐ C6-C7 ☐ C7-T1	Narrowing intervertebral spaces from C3-C6 inclusive with moderate body degen changes
20	☐ C1 ☐ C2 ☐ C3 ☐ C4 ☐ C5 ☐ C6 ☐ C7 ☐ C1-C2 ☐ C2-C3 ☐ C3-C4 6 C4-C5 ☐ C5-C6 ☐ C6-C7 ☐ C7-T1	☐ C1 ☐ C2 ☐ C3 ☐ C4 ☐ C5 ☐ C6 ☐ C7 ☐ C1-C2 ☐ C2-C3 ☐ C3-C4 ☐ C4-C5 ☐ C5-C6 ☐ C6-C7 ☐ C7-T1	
21	☐ C1 ☐ C2 ☐ C3 ☐ C4 ☐ C5 ☐ C6 ☐ C7 ☐ C1-C2 ☐ C2-C3 ☐ C3-C4 ☐ C4-C5 ☐ C5-C6 ☐ C6-C7 ☐ C7-T1	☐ C1 ☐ C2 ☐ C3 ☐ C4 ☐ C5 ☐ C6 ☐ C7 ☐ C1-C2 ☐ C2-C3 ☐ C3-C4 ☐ C4-C5 ☐ C5-C6 ☐ C6-C7 ☐ C7-T1	Normal
22	☐ C1 ☐ C2 ☐ C3 ☐ C4 ☐ C5 ☐ C6 ☐ C7 ☐ C1-C2 ☐ C2-C3 ☐ C3-C4 ☐ C4-C5 ☐ C5-C6 ☐ C6-C7 ☐ C7-T1	☐ C1 ☐ C2 ☐ C3 ☐ C4 ☐ C5 ☐ C6 ☐ C7 ☐ C1-C2 ☐ C2-C3 ☐ C3-C4 ☐ C4-C5 ☐ C5-C6 ☐ C6-C7 ☐ C7-T1	Normal

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
23	☐ C1 ☐ C2 ☐ C3 ☐ C4 ☐ C5 ☐ C6 ☐ C7 ☐ C1-C2 ☐ C2-C3 ☐ C3-C4 6 C4-C5 ☐ C5-C6 ☐ C6-C7 ☐ C7-T1	☐ C1 ☐ C2 ☐ C3 ☐ C4 ☐ C5 ☐ C6 ☐ C7 ☐ C1-C2 ☐ C2-C3 ☐ C3-C4 ☐ C4-C5 ☐ C5-C6 ☐ C6-C7 ☐ C7-T1	Degen present
24	☐ C1 ☐ C2 ☐ C3 ☐ C4 ☐ C5 ☐ C6 ☐ C7 ☐ C1-C2 ☐ C2-C3 ☐ C3-C4 6 C4-C5 ☐ C5-C6 ☐ C6-C7 ☐ C7-T1	☐ C1 ☐ C2 ☐ C3 ☐ C4 ☐ C5 ☐ C6 ☐ C7 ☐ C1-C2 ☐ C2-C3 ☐ C3-C4 ☐ C4-C5 ☐ C5-C6 ☐ C6-C7 ☐ C7-T1	Multilevel moderate disc and facet joint degen
25	☐ C1 ☐ C2 ☐ C3 ☐ C4 ☐ C5 ☐ C6 ☐ C7 ☐ C1-C2 ☐ C2-C3 6 C3-C4 ☐ C4-C5 ☐ C5-C6 ☐ C6-C7 ☐ C7-T1	☐ C1 ☐ C2 ☐ C3 ☐ C4 ☐ C5 ☐ C6 ☐ C7 ☐ C1-C2 ☐ C2-C3 ☐ C3-C4 ☐ C4-C5 ☐ C5-C6 ☐ C6-C7 ☐ C7-T1	There is quite diffuse mid cervical spondylosis with multilevel disc osteophyte changes , there is obliteration of cervical lordosis from C2-C6, disc changes most prominent at C5-C6
26	☐ C1 ☐ C2 ☐ C3 ☐ C4 ☐ C5 ☐ C6 ☐ C7 ☐ C1-C2 ☐ C2-C3 ☐ C3-C4 ☐ C4-C5 6 C5-C6 ☐ C6-C7 ☐ C7-T1	☐ C1 ☐ C2 ☐ C3 ☐ C4 ☐ C5 ☐ C6 ☐ C7 ☐ C1-C2 ☐ C2-C3 ☐ C3-C4 ☐ C4-C5 ☐ C5-C6 ☐ C6-C7 ☐ C7-T1	Multilevel disc and facet joint degen
27	☐ C1 ☐ C2 ☐ C3 ☐ C4 ☐ C5 ☐ C6 ☐ C7 ☐ C1-C2 ☐ C2-C3 ☐ C3-C4 ☐ C4-C5 ☐ C5-C6 6 C6-C7 ☐ C7-T1	☐ C1 ☐ C2 ☐ C3 ☐ C4 ☐ C5 ☐ C6 ☐ C7 ☐ C1-C2 ☐ C2-C3 ☐ C3-C4 ☐ C4-C5 ☐ C5-C6 ☐ C6-C7 ☐ C7-T1	Associating swelling of the precervical soft tissue and widening of the C6/C7 interspinous space indicating ligamentous injury

Case	Without CSPINE-CAD	With CSPINE-CAD	Comments
28	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 6 C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	Multilevel degen changes
29	6 C1 ☐ C1-C2 6 C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 6 C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
30	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	Normal
SPARE CASE NO:	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	
SPARE CASE NO:	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	☐ C1 ☐ C1-C2 ☐ C2 ☐ C2-C3 ☐ C3 ☐ C3-C4 ☐ C4 ☐ C4-C5 ☐ C5 ☐ C5-C6 ☐ C6 ☐ C6-C7 ☐ C7 ☐ C7-T1	

Appendix 23: An example of raw data for CAD reliability from participant 1

						CAD diagnosis						
Out of 10 or 20	**Question number**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	Answer
10/10	**1 (C7 not visualised)**	Misalignment C3/C4, C4/C5	Misalignment C3/C4, C4/C5	Misalignment C3/C4, C4/C5	Misalignment C3/C4, C4/C5, C5/C6 and C6/C7	Misalignment C3/C4, C4/C5	Misalignment C3/C4, C4/C5, C5/C6, C6/C7	Misalignment C3/C4, C4/C5	Misalignment C3/C4, C4/C5, C5/C6	C3 fracture, Misalignment C3/C4, C4/C5, C5/C6	Misalignment C3/C4, C4/C5	C3-C4
	2	C3 fractured Misalignment C4/C5 and C5/C6	C5 fractured Misalignment C4/C5 and C5/C6	C3 and C5 fractured Misalignment C4/C5	C5 fracture	C3 fracture	Misalignment C3/C4, C4/C5, C5/C6	Misalignment C3/C4 and C4/C5	Misalignment C4/C5, C5/C6 and C6/C7	Misalignment C4/C5, C5/C6	C5 fracture Misalignment C4/C5 and C5/C6	C4-C5
8/10	**3**	Normal	Misalignment C3/C4, C4/C5, C5/C6, C6/C7	Normal	Misalignment C3/C4, C6/C7, and C7/T1	Misalignment C6/C7 and C7/T1	Normal	Normal	Misalignment C3/C4, C5/C6, C6/C7,	Normal	Misalignment C3/C4, C4/C5, C5/C6, C6/C7	C3-C4
4/10	**4**	C3 fractured Misalignment C3/C4 and C4/C5	C3 fracture Misalignment C3/C4 and C4/C5	C3 fracture Misalignment C3/C4 and C4/C5	Normal	C3 fracture Misalignment C3/C4 and C4/C5	C3 fracture Misalignment C3/C4, C4/C5	Misalignment C3/C4, C4/C5	C3 fracture Misalignment C3/C4, C4/C5	C3 fracture Misalignment C3/C4, C4/C5	Misalignment C3/C4, C4/C5, C5/C6, C6/C7	C3-C4
8/10	**5**	C5 fractured Misalignment C4/C5 and C5/C6	Misalignment and C3/C4	Normal	Misalignment C6/C7 and C7/T1	Normal	Misalignment C3/C4, C4/C5, C5/C6, C6/C7	Normal	Misalignment C4/C5 and C5/C6	Normal	Misalignment C3/C4, C4/C5	C5-C6 C6-C7
2/20	**6**	C5 fractured Misalignment C4/C5 and C5/C6	C4, C5 fractured	C4 fracture	Normal	C5 fracture	Misalignment C3/C4, C4/C5, C5/C6, C6/C7	C3 and C5 fractured Misalignment C4/C5 and C5/C6	Normal	C5 fracture	C3, C4 fracture Misalignment C3/C4, C4/C5	
0/10	**7**	C5 fractured	Normal	Normal	C4 fracture	Misalignment C3/C4, C4/C5, C5/C6, C6/C7	Normal	C5 fractured	Misalignment C3/C4, C4/C5 and C5/C6	Normal	Normal	C3-C4 C4-C5 C6-C7
6/20	**8**	Misalignment C3/C4, C4/C5 and C5/C6	C5 fractured Misalignment C4/C5 and C5/C6	Misalignment C4/C5, C5/C6 and C6/C7	Misalignment C3/C4, C4/C5, C5/C6, C6/C7	Normal	C4 fractured Misalignment C4/C5 and C5/C6	C3 fractured Misalignment C4/C5, C5/C6, C6/C7	Misalignment C3/C4, C4/C5 and C5/C6	Misalignment C3/C4, C4/C5 and C5/C6	C5 fracture Misalignment C4/C5, C5/C6, C6/C7	C4-C5
9/10	**9**	Misalignment C4/C5 and C5/C6	Normal	Misalignment C4/C5, C5/C6 and C6/C7	Misalignment C4/C5, C5/C6 and C6/C7	Normal	C5 fracture Misalignment C4/C5, C5/C6, and C6/C7	Normal	Misalignment C4/C5, C5/C6 and C6/C7	Normal	C5 fractured Misalignment C4/C5 and C5/C6	NORMAL
10/10	**10**	C4 and C5 fractured Misalignment C3/C4, C4/C5,C5/C6, C6/C7	Misalignment C3/C4, C4/C5,C5/C6	C3 and C5 fractured Misalignment C3/C4, C4/C5 and C5/C6	C3 fractured Misalignment C3/C4 and C4/C5	Misalignment C3/C4, C4/C5,C5/C6	Misalignment C3/C4, C4/C5, C5/C6	Misalignment C3/C4, C4/C5 fracture	C5 fracture Misalignment C4/C5	C5 fracture Misalignment C4/C5, C5/C6 and C6/C7	C5 fractured Misalignment C4/C5 and C5/C6	C5-C6
8/10	**11**	Misalignment C3/C4	Misalignment C3/C4	C5 fractured Misalignment C3/C4	Misalignment C3/C4	Misalignment C3/C4	C3 and C5 fractured Misalignment C3/C4, C4/C5	Misalignment C3/C4, C4/C5, C5/C6	C4/C5 fracture	C5 fracture Misalignment C4/C5, C5/C6 and C6/C7	Misalignment C4/C5, C5/C6, C6/C7	C4-C5
8/10	**12**	Normal	Misalignment C3/C4, C4/C5 and C5/C6	Misalignment C3/C4, C4/C5	Normal	Normal	Normal	Normal	Misalignment C4/C5 and C5/C6	Normal	Normal	NORMAL
8/10	**13**	Misalignment C3/C4	Misalignment C4/C5 and C5/C6	Normal	Normal	Normal	Normal	Misalignment C4/C5 and C5/C6	Normal	Normal	Normal	NORMAL
11/20	**14**			C5 fractured Misalignment C3/C4	Misalignment C3/C4	Normal	C3 and C5 fractured Misalignment C3/C4, C4/C5	Misalignment C3/C4	C3 fracture Misalignment C3/C4, C6/C7	Misalignment C3/C4	Misalignment C3/C4	
7/10	**15**	C3 fractured Misalignment C4/C5, C5/C6, C6/C7	Normal	Misalignment C4/C5 and C5/C6	Misalignment C4/C5 and C5/C6	Misalignment C4/C5 and C5/C6	Misalignment C4/C5 and C5/C6	Misalignment C4/C5 and C5/C6	C3 fracture Misalignment C4/C5, C5/C6 and C6/C7	Misalignment C4/C5, C5/C6	Misalignment C4/C5, C5/C6	C3-C4 C4-C5 C5-C6
4/10	**16**	Misalignment C4/C5 and C5/C6	Normal	Misalignment C3/C4	Misalignment C3/C4	Normal	Misalignment C3/C4	C5 fracture Misalignment C4/C5, C5/C6	Normal	Misalignment C3/C4	Normal	NORMAL
7/10	**17**	Normal	Normal	Normal	Misalignment C4/C5 and C5/C6	Misalignment C5/C6 and C6/C7	Misalignment C3/C4, C4/C5	Normal	Misalignment C4/C5, C5/C6, C6/C7, C7/T1	Normal	Normal	NORMAL
4/10	**18**	Misalignment C3/C4	Normal	Misalignment C4/C5 and C5/C6	C5 fracture Misalignment C4/C5 and C5/C6	C5 fracture	C5 fracture	Normal	Misalignment C3/C4, C4/C5, C5/C6	Misalignment C4/C5, C5/C6, C6/C7, C7/T1	Normal	NORMAL
3/10	**19**	Misalignment C3/C4, C4/C5, C5/C6, C6/C7	C5 fractured Misalignment C3/C4, C4/C5 and C5/C6	Misalignment C3/C4, C4/C5 and C5/C6	C5 fracture Misalignment C4/C5 and C5/C6	Misalignment C4/C5 and C5/C6	Misalignment C4/C5 and C5/C6	Misalignment C3/C4	Misalignment C3/C4, C4/C5, C5/C6	Misalignment C4/C5 and C5/C6	Misalignment C4/C5 and C5/C6	C5
	20 (C7 not visualised)	C4/C5, C5/C6, C6/C7	C4/C5, C5/C6	Normal	Misalignment C4/C5 and C5/C6	Normal	Normal	Misalignment C4/C5 and C5/C6	Misalignment C3/C4, C4/C5, and C5/C6	Normal	Normal	C4-C5
6/10	**21**	Normal	Normal	Normal	Misalignment C6/C7 and C7/T1	Misalignment C2/C3, C3/C4,	Normal	Normal	Normal	Misalignment C3/C4	Normal	NORMAL
8/10	**22**	Misalignment C6/C7	Misalignment C2/C3, C3/C4, C5/C6 and C6/C7	Normal	Misalignment C6/C7	Normal	Normal	Normal	Misalignment C6/C7	Misalignment C3/C4, C4/C5 C5/C6, C6/C7	Misalignment C3/C4, C4/C5, C6/C7	NORMAL
4/10	**23**	C4 and C5 fractured Misalignment C3/C4, C4/C5, and C5/C6	Misalignment C4/C5 and C5/C6	C3 fractured Misalignment C3/C4, C4/C5, C5/C6, C6/C7, C7/T1	Misalignment C3/C4, C4/C5	Misalignment C4/C5, C5/C6 and C6/C7	C4 fractured Misalignment C3/C4, C4/C5, and C5/C6	C4 fractured Misalignment C3/C4, C4/C5, and C5/C6	Misalignment C4/C5, C5/C6, C6/C7, C7/T1	C4 and C5 fracture Misalignment C3/C4, C4/C5, C5/C6	Misalignment C4/C5 and C5/C6	C4-C5
10/10	**24**	Misalignment C3/C4, C4/C5, and C5/C6	Misalignment C5/C6, and C6/C7	Normal	C3 and C5 fracture Misalignment C4/C5 and C5/C6, C6/C7	Misalignment C4/C5, C5/C6, C6/C7	Misalignment C4/C5 and C5/C6	C3 fracture	Misalignment C4/C5, C5/C6, C6/C7,	Misalignment C4/C5, C5/C6	Misalignment C4/C5 and C5/C6	C4-C5
7/10	**25 (C7 not visualised)**	C5 fractured	Misalignment C4/C5 and C5/C6	Normal	C3 and C5 fracture Misalignment C4/C5 and C5/C6, C6/C7	Normal	C3 fracture	Normal	Misalignment C4/C5 and C5/C6	Normal	C3 and C5 fracture	C4-C5
1/10		Misalignment C3/C4, C4/C5, and C5/C6	Misalignment C4/C5 and C5/C6	C5 fracture	Misalignment C4/C5 and C5/C6	Normal	Misalignment C4/C5, C5/C6, C6/C7, C7/T1	Normal	Misalignment C4/C5 and C5/C6	Misalignment C4/C5, C5/C6, C6/C7	Misalignment C4/C5 and C5/C6	C3-C4
6/10	**26**											
8/10	**27**	C5 fractured Misalignment C5/C6, C6/C7 and C7/T1	C3, C5 fractured Misalignment C5/C6, C6/C7 and C7/T1	Misalignment C5/C6, C6/C7	Misalignment C5/C6, C6/C7, C7/T1	Misalignment C4/C5, C5/C6, C6/C7, C7/T1	Misalignment C5/C6, C6/C7	C5 fracture	Misalignment C5/C6, C6/C7, C7/T1	C5 fracture Misalignment C5/C6, C6/C7, C7/T1	C5 fracture	C5-C6
	28	Misalignment C3/C4, C4/C5 and C5/C6	C5 fractured Misalignment C3/C4, C4/C5, C5/C6	Misalignment C3/C4, C4/C5 and C6/C7	C5 fractured Misalignment C3/C4, C4/C5, C5/C6, C6/C7	Misalignment C3/C4, C4/C5 and C5/C6	Misalignment C3/C4, C4/C5, C5/C6, C6/C7	C4,C5 fracture Misalignment C3/C4, C4/C5, C5/C6, C6/C7, C7/T1	C5 fractured Misalignment C3/C4	Misalignment C3/C4, C4/C5, C5/C6	Fracture C4 and C5 Misalignment C3/C4, C4/C5, C5/C6	C6-C7
8/10												
9/10	**29**	Misalignment C4/C5 and C5/C6	Misalignment C4/C5 and C5/C6	Misalignment C4/C5 and C5/C6	C5 fracture Misalignment C4/C5 and C5/C6	C5 fracture Misalignment C4/C5 and C5/C6	C5 fracture Misalignment C4/C5 and C5/C6	Misalignment C4/C5, C5/C6, C6/C7, C7/T1	C5 fracture Misalignment C4/C5, C5/C6, C6/C7	Normal	Normal	C4-C5
7/10												
8/10	**30 (C7 not visualised)**	Normal	Normal	Normal	Normal	C3 fracture	Normal	Normal	Normal	Normal	Misalignment C3/C4	NORMAL

Appendix 24: An example of raw data for CAD reliability from participant 2

		CAD diagnosis										Answers
Out of 10 or 20	Question number	1	2	3	4	5	6	7	8	9	10	
6	1 (C7 not visualised)	C3, C4 and C5 orange arrows	C3 and C5 orange arrow // C5 red arrow	C3 and C4 orange arrow	normal	C3, C4 and C5 orange arrows // C5 red arrow	C5 red and orange arrows	C5 orange arrow	C4 orange arrow	C3 orange arrow	C3-C4	
	2	normal	normal	normal	normal	normal	C6 orange arrow	normal	C5 and C6 orange arrows	normal	C4-C5	
1		normal	normal	normal	C3 and C4 orange arrows	C4 and C5 orange arrows	C6 and C7 orange arrows	normal	normal	normal	C3-C4	
3	3	C3, C4 and C6 orange arrows	C4 orange arrow	C3 orange arrow	C3, C4 and C5 orange arrows	C3 orange arrow	normal	C5 orange arrow	C6 orange arrow	C4, C5 and C7 orange arrow	C3-C4	
6	4	normal	normal	normal	C5 orange arrow	normal	C3 and C5 orange arrows	C5 orange arrow	normal	normal	C5-C6 C6-C7	
3	5	C5 red arrow	normal	C5 orange arrow	C3 , C5 and C6 orange arrows	C5 red arrow	normal	normal	normal	normal	C3-C4 C4-C5	
3	6	normal	normal	C3 red arrow // C5 orange arrow	normal	normal	normal	normal	normal	normal	C6-C7	
0	7	C4 and C5 orange arrow // C5 red arrow	normal	normal	normal	C4 and C5 orange arrows // C5 red arrow	normal	normal	normal	C5 orange arrow		
3	8	normal	normal	normal	normal	C3 orange arrow	normal	normal	normal	normal	C4-C5	
8	9	C5 orange arrow	C5 and C7 orange arrow	C4 orange arrow	C5, C6 and C7 orange arrows	C6 orange arrow	C7 orange arrow	C5 and C6 orange arrows	C5 and C6 orange arrows	C4, C5 and C6 orange arrow	NORMAL	
8	10	C3 and C4 orange arrow // C5 red arrow	C3, C4, C5, C6 and C7 orange arrow	C7 orange arrow	C5 red and orange arrows	C3, C4, c5 and C6 orange	C6 orange arrow	C5 and C6 orange arrows	C3, C4, C5 and C6 orange arrows // C5	C4 orange arrow	C5-C6	
8	11	C5 red arrow	normal	normal	C4 orange arrow	normal	normal	C3 and C4 orange arrows	normal	C4 orange arrow	C4-C5	
5	12	C5 orange arrow	normal	normal	normal	C5 red arrow	normal	C5 red and orange arrows	normal	normal	NORMAL	
7	13	C3 and C4 orange arrow // C3 red arrow	C3 and C4 orange arrows	C3 and C4 orange arrow // C4 red arrow	C3 and C4 orange arrow	C3 and C4 orange arrows // C3 red arrow	C3 red and orange arrows	C3 red arrows // C3 and C4 orange arrows	C3 and C4 orange arrows	C3 red arrow // C3 and C4 orange arrow	NORMAL	
19/20	14	normal	normal	C3 red arrow	normal	C5 orange arrow	normal	normal	C5 orange arrows	C5 orange arrow	C3-C4 C4-C5	
3	15	normal	C5 orange arrow	normal	normal	C4 orange arrow	normal	C5 orange arrow	normal	C4 orange arrow	C5-C6	
6	16	normal	normal	normal	normal	normal	normal	normal	normal	normal	NORMAL	
10	17	normal	C3 orange arrow	normal	C3 and C5 orange arrows	C3 red arrow	C3 orange arrow	C4, C5 and C6 orange arrows // C5 red arrow	C3, C4 and C5 orange arrows // C3 red arrow	normal	NORMAL	
3	18	normal		normal	C5 orange arrow	C5 red and orange arrows	C3 red and orange arrows	C4 orange arrow	C5 red and orange arrows	normal	C5	
2	19	normal	normal	C5 orange arrow	C3 red arrow	normal	normal	C3 red arrows // C4 and C5 orange arrows	normal	C5 red arrow	C4-C5	
2	20 (C7 not visualised)	normal	normal	normal	normal	normal	normal	normal	C6 orange arrow	normal	NORMAL	
9	21	normal	normal	normal	normal	normal	normal	normal	normal	normal	NORMAL	
10	22	normal	normal	normal	normal	normal	normal	normal	normal	normal	NORMAL	
7	23	C5 orange arrow	C5 orange arrow	C5 orange arrow	normal	C3 red arrow	C5 orange arrow	C5 and C6 orange arrows	C5 and C6 orange arrows	C3, C4 and C5 orange arrows	C4 orange arrow	
2	24	C3 orange arrow	C3 red arrow	C5 orange arrow	normal	normal	normal	normal	C5 orange arrow	normal	C4-C5	
3	25 (C7 not visualised)	C3 red arrow	C3 red arrow	C5 red and orange arrows	normal	C4 orange arrow	normal	C6 and C7 orange arrows	C5 orange arrow	C4 orange arrow	C4-C5	
6	26	C5 orange arrow	normal	normal	normal	normal	normal	C5 orange arrow	C5 orange arrow	C5 orange arrow	C3-C4	
5	27	C6 orange arrow // C5 red arrow	C5 orange arrow	C5, C6 and C7 orange arrows // C5 red arrow	C5 red arrow // C6 and C7 orange arrows	C3 and C5 red arrow and C6 orange arrow	normal	C4 orange arrow	C4 orange arrow // C5 red arrow	C5 orange arrow	C5-C6	
7	28	C5 and C6 orange arrow // C5 red arrow	C4 and C5 orange arrow	C5 orange arrow	C6 and C7 orange arrows	C6 orange arrow	normal	C4 orange arrow	C5 orange arrow	C5 orange arrow	C6-C7	
	29	C5 orange arrow	normal	C5 orange arrow	normal	normal	normal	C5 red arrow	C7 orange arrow	C3 orange arrow	C4-C5	
3	30 (C7 not visualised)	normal	normal	normal	normal	normal	normal	normal	normal	normal	C4-C5 NORMAL	

Appendix 25: Combined raw data averaged across the two participants

	score out of 10 or 20		
Image number	**participant 1**	**participant 2**	**Average score out of 10**
1	10	6	8
2	8	1	4.5
3	4	3	3.5
4	8	6	7
5	2/20	3/20	1.25
6	6/20	3/20	2.25
7	0	0	0
8	9	3	6
10	10	8	9
11	8	8	8
14	11/20	19/20	7.5
15	7	3	5
19	3	2	2.5
20	6	2	4
23	10	7	8.5
24	7	2	4.5
25	1	3	2
26	6	6	6
27	8	5	6.5
28	9	7	8
29	7	3	5

Appendix 26: List of 48 images chosen for the Genant SQ testing

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Appendix 27: Researcher 1s raw data gathered using CSPINE-CAD during the Genant SQ testing

CS Number	Results of CAD software C3-C7	Was manual correction needed if so which vertrebrae	Results after correction
0002	Mild/Biconcave C3, Mild Biconcave C5 (cant visualise C7)	Yes Manual segmentation of C5 and C6	Mild/Biconcave C3, Moderate wedge C5
0003	nothing seen	no	N/A
0004	Moderate/Biconcave C5	Yes Manual segmentation of C3,C4,C5,C6,C7	Mild/Biconcave C3, Mild/Biconcave C4, Moderate/Biconcave C5, Moderate/Biconcave C6
0006	nothing seen	Yes Manual segmentation of C4,C5,C6,C7	Mild/Biconcave C4, Mild/Biconcave C6, Mild/Biconcave C7
0007	nothing seen	no	N/A
0011	nothing seen	Yes Manual segmentation of C3 and C5	Moderate/Wedge C5
0012	nothing seen	Yes Manual segmentation of C5 and C7	nothing seen
0014	nothing seen (can't fully visualise C7)	Yes Manual segmentation of C3,C4,C5,C6	Mild/Biconcave C4
0015	Mild/Biconcave C3	Yes Manual segmentation of C4,C5,C6	Mild/Biconcave C3, Moderate/Biconcave C5
0020	Mild/Wedge C4	Yes Manual segmentation of C3,C4,C5, C6	Moderate/Biconcave C3, Moderate/Biconcave C4, Mild/wedge C5, Mild/Biconcave C6
0024	nothing seen (artefacts such as metal work in the vertebral bodies)	Yes Manual segmentation of C3,C4,C5,C6,C7	Mild/Biconcave C3
0034	Nothing seen	Yes Manual segmentation of C3,C4,C5,C6,C7	Mild/Wedge C4, Moderate/Wedge C5, Mild/Wedge C6
0035	nothing seen	Yes Manual segmentation of C5	nothing seen
0040	nothing seen (cant fully visualise C7)	Yes Manual segmentation of C3,C4,C5,C6	Mild/Biconcave C3, Mild/Biconcave C4, Mild/Biconcave C5, Mild/Biconcave C6
0044	nothing seen	Yes Manual segmentation of C3,C4,C5	Mild/Biconcave C5
0045	nothing seen	Yes Manual segmentation of C3,C4,C5	Moderate/Biconcave C4, Moderate/Biconcave C5
0047	nothing seen	Yes Manual segmentation of C3,C4,C5,C6,C7	Mild/Biconcave C3, Mild/Biconcave C5, Mild/Wedge C6, Moderate/Biconcave C7
0048	nothing seen	Yes Manual segmentation of C3,C4,C5,C6,C7	Mild/Biconcave C3, Mild/Biconcave C4, Mild/Biconcave C6
0051	nothing seen	Yes Manual segmentation of C3,C4,C5,C6,C7	Mild/Biconcave C3, Mild/Biconcave C6
0052	nothing seen (cant fully visualise C7)	Yes Manual segmentation of C3,C4,C5,C6	nothing seen
0053	nothing seen (C7 not fully visualised)	Yes Manual segmentation of C3,C4,C5,C6	Mild/Biconcave C5, Mild/Biconcave C6
0054	Mild/Biconcave C3, Mild Biconcave C5	Yes Manual segmentation of C3,C4,C5,C6,C7	Mild/Biconcave C6
0060	Mild/Biconcave C3	Yes Manual segmentation of C3,C4,C5,C6,C7	nothing seen
0064	nothing seen	Yes Manual segmentation of C3,C4,C5,C6,C7	Moderate/Biconcave C3, Moderate/Wedge C4, Moderate/Biconcave C5, Mild/Biconcave C7
0065	Mild/Biconcave C3, Mild/Biconcave C4	Yes Manual segmentation of C3,C4,C5,C6,C7	Moderate/Biconcave C3, Moderate/Biconcave C4, Mild/Biconcave C5, Mild/Biconcave C6, Moderate/Biconcave C7
0074	nothing seen (cant fully visualise C7)	Yes Manual segmentation of C3,C4,C5,C6	Moderate/Biconcave C3, Mild/Biconcave C4, Moderate/Biconcave C6
0078	CORRUPT FILE WOULD NOT READ		
0079	nothing seen	Yes Manual segmentation of C3,C5,C6,C7	Moderate/Wedge C5, Mild/Wedge C7
0081	Mild/Biconcave C5	Yes Manual segmentation of C4,C5,C6	Mild/Biconcave C5, Mild/Biconcave C6
0087	nothing seen	Yes Manual segmentation of C3,C4,C5,C6,C7	nothing seen
0088	nothing seen	Yes Manual segmentation of C3,C4,C5,C6,C7	Moderate /Wedge C5
0090	nothing seen	Yes Manual segmentation of C3,C4,C5,C6,C7	Mild/Wedge C4, Mild/Biconcave C6, Mild/Biconcave C7
0092	nothing seen	Yes Manual segmentation of C3,C4,C5,C6,C7	Mild/Biconcave C3, Mild/Biconcave C4, Moderate/Biconcave C5, Mild/Biconcave C6
0098	nothing seen	Yes Manual segmentation of C4,C5,C6,C7	Mild/Biconcave C5, Moderate/Biconcave C6, Mild/Biconcave C7
0099	nothing seen	Yes Manual segmentation of C3,C4,C5,C6,C7	Mild/Biconcave C3, Mild/Biconcave C6
0105	nothing seen	Yes Manual segmentation of C3,C4,C5,C6	Mild/Biconcave C3
0114	nothing seen	Yes Manual segmentation of C3,C4,C5,C6,C7	Mild/Biconcave C4, Moderate/Biconcave C5, Mild/Biconcave C6
0115	nothing seen	Yes Manual segmentation of C3,C4,C5,C6,C7	Mild/Wedge C4, Moderate/Wedge C5, Mild/Biconcave C6, Moderate/Biconcave C7
0119	nothing seen	Yes Manual segmentation of C4,C5,C6	Mild/Biconcave C6
0128	Mild/Biconcave C3	Yes Manual segmentation of C3,C4,C5,C6,C7	Mild/Biconcave C3, Moderate/Biconcave C4
0132	Mild/Biconcave C3	Yes Manual segmentation of C3,C4,C5,C6,C7	Mild/Biconcave C4, Mild/Wedge C5, Moderate/Biconcave C6
0133	nothing seen	Yes Manual segmentation of C3,C4,C5,C6,C7	Moderate /Wedge C5, Moderate/Biconcave C6, Moderate/Biconcave C7
0140	nothing seen	Yes Manual segmentation of C3,C4,C5,C6,C7	Mild/Biconcave C7
0141	nothing seen	Yes Manual segmentation of C3,C4,C5,C6,C7	Mild/Biconcave C3, Moderate/Biconcave C4
0145	nothing seen	Yes Manual segmentation of C3,C4,C5,C6,C7	Mild/Biconcave C3, Mild/Biconcave C4, Moderate/Biconcave C5, Mild/Biconcave C7
0146	nothing seen	Yes Manual segmentation of C3,C4,C5,C6,C7	Moderate/Biconcave C5
0149	nothing seen (cant fully visualise C7)	Yes Manual segmentation of C3,C4,C5,C6,C7	Moderate/Wedge C4, Mild/Biconcave C5
0150	Mild/Biconcave C5	Yes Manual segmentation of C3,C4,C5,C6,C7	Moderate/Biconcave C3, Moderate/Biconcave C4, Moderate/Biconcave C5, Mild/Biconcave C6

Appendix 28: Researcher 2s raw data gathered using CSPINE-CAD during the Genant SQ testing

ID	Age	Gender	C3	C4	C5	C6	C7
CS0002	46	M		7	7	2	
CS0003	50	F	1	2			
CS0004	25	F	1	2	5	2	
CS0006	19	F	2	4		1	
CS0007	48	M					
CS0011	32	M		4			
CS0012	20	F					
CS0014	23	M					
CS0015	37	M			2		
CS0020	29	M		1			
CS0024	44	M					
CS0034	42	F		5	6		
CS0035	46	F					
CS0040	34	M	1			1	
CS0044	22	M				2	
CS0045	39	M		2	2		
CS0047	45	M					
CS0048	40	F					
CS0051	45	F	1			2	
CS0052	43	F	1		2	8	
CS0053	49	M	4			6	
CS0054	30	F		1	1		
CS0060	30	M					
CS0064	50	M	1	5	4		
CS0065	48	F	1	1	1		1
CS0074	44	M	2	1	1	1	
CS0079	44	F	1		6		
CS0081	25	M	1		1		
CS0087	31	M					
CS0088	18	F					
CS0090	44	F		4	5	2	
CS0092	24	M	1		2		
CS0098	41	F			2		
CS0099	41	F			1	1	
CS0105	42	M		2			
CS0114	25	M					
CS0115	45	M		2	6		
CS0119	39	F				4	
CS0128	48	F					
CS0132	40	M		2	5	5	
CS0133	32	M			7		
CS0140	36	M					
CS0141	41	F	1	1	1	1	
CS0145	43	F		5	5		1
CS0146	50	M	1		1		
CS0149	50	M		7	7		
CS0150	28	F	2	2	2	1	

Appendix 29: Researcher 3s raw data gathered using DICOM viewer measurements

	C3	C3	C3	C4	C4	C4	C5	C5	C5	C6	C6	C6	C7	C7	C7	C3	C3	C3	C4	C4	C4	C5	C5	C5	C6	C6	C6	C7	C7	C7			
FileName	A	M	P	A	M	P	A	M	P	A	M	P	A	M	P	A:M	M:P	A:P	A:M	M:P	A:P	A:M	M:P	A:P	A:M	M:P	A:P	A:M	M:P	A:P			
C30002	154.9349	139.8078	156.8631	137.0753	134.1025	159.7013	108.4516	144.4252	162.2906	142.1241	127.7474	152.5702	0	0	0	10%	11%	1%	2%	16%	14%	5%	29%	33%	10%	16%	7%						
C30003	95.78144	91.56663	101.1173	84.32783	86.02397	100.1994	83.36008	80.35307	87.15531	85.41069	85.94382	100.3708	101.2359	97.98754	106.1923																		
C30004	125.5969	103.9857	120.4227	114.8543	94.83211	124.8831	107.3015	100.1114	129.077	126.7967	109.4913	137.0456	141.5312	118.7824	137.5038	4%	9%	5%	17%	14%	4%	17%	22%	17%	14%	20%	15%	3%	8%	5%			
C30006	123.224	95.20135	121.9965	104.6513	103.4589	130.2631	106.8018	109.1511	129.654	118.5412	105.6078	122.5594	137.7115	124.4583	140.878	23%	22%	1%	1%	21%	24%	2%	2%	16%	18%	11%	14%	3%	10%	12%	2%	20% to 25%	
C30007	119.242	114.2805	146.7421	115.4011	108.1203	130.0733	123.2928	111.7992	131.6783	114.9439	113.6517	125.2167	127.8056	120.6965	132.1665	4%	22%	19%	6%	17%	11%	9%	15%	6%	1%	9%	8%	6%	9%	9%	3%	25% to 40%	
C30011	116.2979	110.5518	116.2689	110.2183	109.2069	130.6604	83.81501	112.0327	138.3725	103.5481	107.3879	125.1751	134.2394	124.6702	130.1753	5%	5%	0%	1%	16%	16%	25%	19%	39%	4%	14%	17%	7%	7%	3%	3%	40% to 100	
C30012	103.1416	101.0786	109.1491	99.96068	97.10204	107.2955	96.4142	95.34377	102.9132	98.20292	91.0683	99.01034	126.6357	118.2144	122.3861	2%	7%	6%	3%	7%	6%	7%	7%	6%	7%	8%	1%	7%	3%	3%			
C30014	167.6961	157.693	172.0899	146.6109	138.6653	153.0673	132.7318	118.9935	142.1059	130.4097	119.0245	133.5649	0	0	0	6%	8%	3%	3%	5%	9%	10%	16%	7%	9%	11%	2%						
C30015	119.3047	103.5562	117.746	114.0747	105.0994	124.9056	123.6521	97.01124	113.3228	120.5245	106.308	114.4822	109.5077	112.5026	118.1687	13%	12%	1%	8%	16%	9%	22%	14%	8%	12%	7%	5%	5%	5%	7%			
C30020	137.4065	119.688	132.367	114.9267	108.1026	114.3311	112.3841	114.4752	107.2389	113.9392	97.16715	111.3266	124.2906	123.9919	0	13%	10%	4%	6%	5%	1%	2%	6%	5%	15%	13%	2%	0%					
C30024	131.6328	117.8927	131.4354	109.2407	117.7415	143.3758	0	0	130.3751	115.6987	129.7949	137.9115	134.9975	131.2622		10%	10%	0%	7%	18%	24%				11%	11%	3%	12%	0%	2%	5%			
C30034	154.1769	132.0887	161.3566	121.5584	129.5257	161.2344	127.4666	134.1856	161.2344	132.8749	146.5086	151.0934	0	0	0	14%	18%	4%	6%	20%	25%	5%	17%	21%	9%	3%	12%						
C30035	88.66074	85.38808	98.01973	90.56494	84.14018	95.68801	89.85814	89.66882	100.6146	87.55289	89.25279	96.54718	98.9779	96.27915	98.73212	4%	13%	10%	7%	12%	5%	4%	11%	1%	2%	8%	9%	3%	2%	0%			
C30040	153.6906	134.5001	158.0131	144.4704	127.8804	150.0841	142.2155	127.9867	143.6201	127.9867	121.306	144.7998	0	0	0	12%	15%	3%	11%	15%	4%	10%	11%	1%	5%	16%	12%						
C30044	161.9597	138.5074	164.9829	145.7554	140.0281	141.0867	134.9117	133.2658	148.7319	141.234	125.5814	143.223	155.9227	139.8047	151.5437	14%	18%	2%	4%	1%	3%	1%	10%	21%	9%	11%	12%	1%	1%	10%	8%	3%	
C30045	106.2377	113.9161	113.7965	87.67238	85.85295	105.7749	84.93376	83.40539	105.3308	96.17912	88.38079	97.44708	114.2935	113.3299	111.5683	7%	0%	7%	2%	19%	17%	2%	6%	19%	8%	6%	9%	1%	1%	8%	2%		
C30047	88.48244	75.29047	88.19467	88.60494	77.57083	90.91597	74.89324	72.49696	78.58149	72.06836	68.44743	72.42679	78.39406	77.65206	84.04068	15%	15%	0%	12%	15%	3%	3%	8%	5%	5%	6%	0%	0%	1%	8%	7%		
C30048	94.43325	86.39215	101.1812	91.02197	80.78879	96.24313	91.15149	83.11731	93.71944	97.15477	82.18404	96.87147	106.5787	95.78541	109.4957	9%	15%	7%	11%	16%	5%	9%	11%	3%	15%	15%	0%	10%	13%	3%	8%		
C30051	134.0631	127.5568	146.2335	124.5104	121.1996	133.1297	132.9323	120.2347	131.4073	152.0408	128.2891	137.2732	158.4273	146.1661	146.0677	5%	13%	8%	3%	9%	6%	10%	9%	1%	16%	7%	10%	8%	0%	8%			
C30052	131.2133	130.1207	129.0458	128.2554	131.3651	134.6685	133.9788	127.1939	130.3604	132.9351	133.4995	140.2635	0	0	0	1%	1%	2%	2%	2%	5%	5%	2%	3%	0%	5%	5%						
C30053	151.7731	141.6263	160.8146	149.2329	146.7118	163.1721	149.4159	133.3795	145.7396	136.8055	131.9876	144.8248	0.640981	0	0	7%	12%	6%	2%	10%	9%	8%	12%	2%	4%	9%	6%						
C30054	124.2412	117.4535	136.6507	125.3048	115.5278	136.0481	124.4559	120.4941	136.9015	139.4483	136.5033	137.9375	166.0635	153.7339	157.0874	5%	14%	9%	8%	15%	8%	3%	12%	9%	2%	1%	1%	7%	2%	5%			
C30060	116.5769	119.9804	135.7444	130.713	121.3074	132.0093	111.0059	120.2734	123.5775	128.0695	118.2149	127.5504	147.003	136.0113	139.1656	3%	12%	7%	4%	8%	7%	3%	10%	8%	7%	7%	0%	7%	2%	5%			
C30064	164.0923	144.2904	170.6466	137.1714	131.626	165.0697	129.0411	124.583	153.1126	124.4658	128.9073	151.792	156.8099	146.4988	161.4368	12%	15%	4%	4%	20%	17%	3%	19%	16%	3%	15%	18%	7%	9%	3%			
C30065	142.3456	126.8207	164.4544	130.6578	120.8006	165.1274	122.4116	109.608	133.6293	146.1545	107.7197	144.3075	146.3008	126.6208	143.0085	11%	23%	8%	8%	27%	21%	10%	18%	8%	26%	25%	1%	13%	11%	2%			
C30074	155.279	118.5095	138.7682	149.5963	124.8812	145.0062	142.2096	129.4961	150.8917	142.3539	122.3328	140.2821	0	0	0	24%	15%	11%	17%	14%	3%	9%	14%	6%	1%	13%	1%						
C30079	109.4439	107.3807	125.7461	97.82776	99.0983	120.1008	78.20624	99.03516	118.5144	105.12	109.1521	118.3496	123.4256	123.1607	123.3809	2%	15%	13%	1%	17%	19%	21%	16%	34%	4%	8%	13%	0%	0%	0%			
C30081	94.78184	97.98152	107.0896	96.81622	92.46251	99.84367	95.38904	88.90337	100.9712	95.82207	88.90337	101.9621	111.0988	102.3839	111.1824	3%	9%	11%	4%	7%	3%	7%	12%	6%	7%	13%	6%	8%	8%	0%			
C30087	131.4205	116.2111	126.1944	123.7663	111.6949	127.0528	115.2478	108.8353	118.6659	125.5796	112.9855	105.6537	130.0249	122.8232	132.5638	12%	8%	4%	10%	12%	6%	8%	8%	3%	10%	6%	16%	6%	7%	2%			
C30088	108.7458	95.76609	100.4263	101.0299	96.30542	107.7394	98.64746	95.87772	108.9708	104.328	95.59403	107.4806	105.9106	99.76824	102.0943	12%	5%	8%	5%	11%	6%	3%	12%	9%	8%	11%	3%	6%	2%	4%			
C30090	144.8452	152.5619	168.1372	136.0005	143.1557	154.4417	133.5337	139.9127	152.2999	147.8261	140.1116	154.6474	166.2853	154.9526	144.2595	5%	9%	14%	5%	7%	12%	5%	8%	12%	5%	9%	4%	7%	7%	13%			
C30092	108.9393	113.818	117.0689	120.7531	106.7859	119.7463	104.7711	100.7518	111.9801	108.9264	102.4285	119.2775	128.8201	130.0233	137.8011	4%	3%	7%	12%	11%	8%	5%	10%	6%	6%	14%	9%	1%	6%	7%			
C30098	115.459	110.6751	129.2684	116.9125	107.3361	127.4454	110.6751	103.4544	126.1392	107.7356	109.0195	120.0846	121.5213	101.0591	118.4792	4%	14%	11%	8%	16%	8%	7%	18%	12%	1%	9%	10%	17%	15%	3%			
C30099	111.4734	103.5497	105.0238	107.5828	103.0823	111.976	104.9573	99.43341	104.8966	100.9677	93.88837	113.022	0	0	0	7%	1%	6%	4%	8%	4%	5%	5%	0%	7%	17%	11%						
C30105	105.8796	104.3723	109.2702	108.645	106.073	121.2994	108.8708	104.1655	107.5803	99.32979	94.34824	104.3437	118.7642	111.3781	121.1127	1%	4%	2%	3%	13%	10%	4%	3%	1%	5%	10%	5%	6%					
C30114	114.0266	107.8703	123.8288	113.7192	101.4921	117.2835	102.1516	93.31276	111.637	99.80545	91.14703	109.107	117.166	100.3088	108.3216	5%	13%	8%	11%	13%	3%	9%	16%	8%	9%	16%	9%	14%	7%	8%			
C30115	181.1051	173.6042	197.4474	148.7007	142.8122	171.5167	134.236	156.1974	184.3844	165.8477	148.7744	171.4029	168.3746	158.9633	189.1389	4%	12%	8%	5%	17%	13%	14%	15%	27%	10%	13%	3%	6%	16%	11%			
C30119	102.8301	95.211	113.716	99.07456	93.29553	104.8654	84.28614	87.65973	99.58879	92.97876	83.82864	100.1693	115.0097	103.9629	113.2711	7%	18%	10%	6%	11%	6%	4%	12%	15%	10%	16%	7%	10%	8%	2%			
C30128	136.4864	129.4606	139.2279	124.3232	111.4078	138.8731	108.2352	105.4608	127.7654	112.701	115.1867	122.251	126.7373	126.5704	123.3986	5%	7%	7%	2%	10%	10%	3%	17%	15%	2%	6%	8%	0%	3%	3%			
C30132	103.4637	104.0208	116.61	103.0403	102.404	113.7901	100.7907	95.49812	106.9792	99.62394	88.9348	93.06962	120.5828	98.82178	104.0536	1%	11%	11%	1%	10%	9%	5%	11%	6%	11%	4%	7%	4%	7%	18%	4%		
C30133	112.0099	120.5563	125.0082	119.109	120.1205	129.6751	106.3414	115.4312	124.9247	110.5005	108.7032	106.1028	117.3883	97.00746	105.4604	7%	4%	10%	1%	7%	8%	8%	8%	15%	2%	2%	4%	7%	6%	17%	8%	10%	
C30140	116.2265	114.6877	123.8365	112.8199	117.3045	123.1956	115.0103	110.4811	118.8294	113.1228	105.1838	121.6215	122.7256	114.3239	116.9806	1%	7%	6%	4%	5%	8%	4%	7%	3%	7%	14%	7%	6%	2%	4%			
C30141	130.8275	123.0449	143.014	112.7433	114.8995	134.1652	129.516	113.8213	129.4679	142.5708	119.6076	132.8944	147.8994	141.3462	144.175	6%	14%	9%	2%	14%	16%	12%	12%	0%	16%	10%	7%	4%	2%	3%			
C30145	121.7335	118.0988	141.0733	114.9201	97.50682	121.4068	110.1085	101.2762	117.5971	122.3637	101.9704	109.8728	136.8252	132.6935	138.1167	3%	16%	14%	15%	20%	5%	8%	14%	6%	17%	7%	10%	7%	4%	1%			
C30146	149.5981	135.517	159.5166	135.7148	125.682	152.576	132.5057	119.5816	138.588	136.5932	119.0437	124.8064	0	0	0	9%	15%	6%	7%	18%	11%	10%	14%	4%	13%	5%	9%						
C30149	119.3686	110.947	120.4475	109.6978	118.8652	122.363	103.9483	104.0932	116.8286	111.4757	103.028	106.4533	117.2306	118.0135	113.655	7%	8%	1%	8%	3%	10%	0%	11%	4%	8%	3%	5%	1%	4%	3%			
C30150	119.9407	102.3633	126.2227	115.5915	100.341	123.8512	111.3261	105.1226	121.2182	124.5608	113.9473	126.5714	150.775	127.9499	132.6783	15%	19%	5%	13%	19%	7%	6%	13%	2%	9%	10%	2%	15%	4%	12%			

Appendix 30: Researcher 4s raw data gathered from visual analysis

Image No.	GRADE
CS0002	0
CS0003	0
CS0004	0
CS0006	0
CS0007	0
CS0011	0
CS0012	0
CS0014	0
CS0015	0
CS0020	0
CS0024	0
CS0034	0
CS0035	0
CS0040	0
CS0044	0
CS0045	W1
CS0047	0
CS0048	0
CS0051	0
CS0052	0
CS0053	0
CS0054	0
CS0060	0
CS0064	0
CS0065	0
CS0074	0
CS0079	W1
CS0081	0
CS0087	0
CS0088	0
CS0090	0
CS0092	0
CS0098	0
CS0099	0
CS0105	0
CS0114	0
CS0115	0
CS0119	C1
CS0128	0
CS0132	0
CS0133	0
CS0140	0
CS0141	0
CS0145	0
CS0146	0
CS0149	0
CS0150	0

Appendix 31: Raw data sorted into new format to allow intercomparison

Researcher 1s data in new format

ID	Age	Gender	C3	C4	C5	C6	C7
CS0002	46	M	1		5		
CS0003	50	F					
CS0004	25	F	1	1	2	2	
CS0006	19	F		1		1	1
CS0007	48	M					
CS0011	32	M			5		
CS0012	20	F					
CS0014	23	M		1			
CS0015	37	M		1	2		
CS0020	29	M	2	2		1	
CS0024	44	M	1				
CS0034	42	F		4	5	4	
CS0035	46	F					
CS0040	34	M	1	1	1	1	
CS0044	22	M			1		
CS0045	39	M		2	2		
CS0047	45	M	1		1	4	2
CS0048	40	F	1	1		1	
CS0051	45	F	1			1	
CS0052	43	F					
CS0053	49	M			1	1	
CS0054	30	F				1	
CS0060	30	M					
CS0064	50	M	2	5	2		1
CS0065	48	F	2	2	1	1	2
CS0074	44	M	2	1		2	
CS0079	44	F			5		4
CS0081	25	M			1	1	
CS0087	31	M					
CS0088	18	F			5		
CS0090	44	F		4		1	1
CS0092	24	M	1	1	2	1	
CS0098	41	F			1	2	1
CS0099	41	F	1			1	
CS0105	42	M	1				
CS0114	25	M		1	2	1	
CS0115	45	M		4	5	1	2
CS0119	39	F				1	
CS0128	48	F	1	2			
CS0132	40	M		1	4	2	
CS0133	32	M			5	2	2
CS0140	36	M					1
CS0141	41	F	1	2			
CS0145	43	F	1	1	2		1
CS0146	50	M			2		
CS0149	50	M		5	1		
CS0150	28	F	2	2	2	1	

Researcher 3s data in new format

ID	Age	Gender	C3	C4	C5	C6	C7
CS0002	46	M			5		
CS0003	50	F					
CS0004	25	F		1	1	1	
CS0006	19	F	1	1			
CS0007	48	M	1				
CS0011	32	M			5		
CS0012	20	F					
CS0014	23	M					
CS0015	37	M			1		
CS0020	29	M					
CS0024	44	M	4				
CS0034	42	F		4	4		
CS0035	46	F					
CS0040	34	M					
CS0044	22	M					
CS0045	39	M			1		
CS0047	45	M					
CS0048	40	F					
CS0051	45	F					
CS0052	43	F					
CS0053	49	M					
CS0054	30	F					
CS0060	30	M					
CS0064	50	M		1			
CS0065	48	F	1	2		2	
CS0074	44	M	1				
CS0079	44	F			5		
CS0081	25	M					
CS0087	31	M					
CS0088	18	F					
CS0090	44	F					
CS0092	24	M					
CS0098	41	F					
CS0099	41	F					
CS0105	42	M					
CS0114	25	M					
CS0115	45	M			5		
CS0119	39	F					
CS0128	48	F					
CS0132	40	M					
CS0133	32	M					
CS0140	36	M					
CS0141	41	F					
CS0145	43	F					
CS0146	50	M					
CS0149	50	M					
CS0150	28	F					

Researcher 4s data in new format

ID	Age	Gender	C3	C4	C5	C6	C7
CS0002	46	M					
CS0003	50	F					
CS0004	25	F					
CS0006	19	F					
CS0007	48	M					
CS0011	32	M					
CS0012	20	F					
CS0014	23	M					
CS0015	37	M					
CS0020	29	M					
CS0024	44	M					
CS0034	42	F					
CS0035	46	F					
CS0040	34	M					
CS0044	22	M					
CS0045	39	M		4			
CS0047	45	M					
CS0048	40	F					
CS0051	45	F					
CS0052	43	F					
CS0053	49	M					
CS0054	30	F					
CS0060	30	M					
CS0064	50	M					
CS0065	48	F					
CS0074	44	M					
CS0079	44	F			7		
CS0081	25	M					
CS0087	31	M					
CS0088	18	F					
CS0090	44	F					
CS0092	24	M					
CS0098	41	F					
CS0099	41	F					
CS0105	42	M					
CS0114	25	M					
CS0115	45	M					
CS0119	39	F				7	
CS0128	48	F					
CS0132	40	M					
CS0133	32	M					
CS0140	36	M					
CS0141	41	F					
CS0145	43	F					
CS0146	50	M					
CS0149	50	M					
CS0150	28	F					

Researcher 1s data in new format (no change due this data being created in the new format from the beginning)

ID	Age	Gender	C3	C4	C5	C6	C7
CS0002	46	M		7	7	2	
CS0003	50	F	1	2			
CS0004	25	F	1	2	5	2	
CS0006	19	F	2	4		1	
CS0007	48	M					
CS0011	32	M		4			
CS0012	20	F					
CS0014	23	M					
CS0015	37	M			2		
CS0020	29	M		1			
CS0024	44	M					
CS0034	42	F		5	6		
CS0035	46	F					
CS0040	34	M	1			1	
CS0044	22	M				2	
CS0045	39	M		2	2		
CS0047	45	M					
CS0048	40	F					
CS0051	45	F	1			2	
CS0052	43	F	1		2	8	
CS0053	49	M	4			6	
CS0054	30	F		1	1		
CS0060	30	M					
CS0064	50	M	1	5	4		
CS0065	48	F	1	1	1		1
CS0074	44	M	2	1	1	1	
CS0079	44	F	1		6		
CS0081	25	M	1		1		
CS0087	31	M					
CS0088	18	F					
CS0090	44	F		4	5	2	
CS0092	24	M	1		2		
CS0098	41	F			2		
CS0099	41	F			1	1	
CS0105	42	M		2			
CS0114	25	M					
CS0115	45	M		2	6		
CS0119	39	F				4	
CS0128	48	F					
CS0132	40	M		2	5	5	
CS0133	32	M			7		
CS0140	36	M					
CS0141	41	F	1	1	1	1	
CS0145	43	F		5	5		1
CS0146	50	M	1		1		
CS0149	50	M		7	7		
CS0150	28	F	2	2	2	1	

Appendix 32: Kappa score calculation

```
. kap var1 var2

                Expected
Agreement       Agreement      Kappa    Std. Err.       Z    Prob>Z
------------------------------------------------------------------
   58.72%         43.35%     0.2714       0.0400     6.79    0.0000

. kap var1 var2

                Expected
Agreement       Agreement      Kappa    Std. Err.       Z    Prob>Z
------------------------------------------------------------------
   80.43%         72.93%     0.2768       0.0508     5.44    0.0000
```

Appendix 33: Coefficient of variance calculation from vertebral body segmentation (interoperator)

In mm	Image No	81	87	88	90	92	94	98	105	114	115
AO	Mean	0.47816147	0.491435	0.474485	0.580289	0.565528	0.513871	0.579461	0.604028	0.377013	0.386726
CW	Mean	0.361485	0.36275	0.428968	0.390171	0.534129	0.333311	0.504056	0.497808	0.296943	0.307324
JR	Mean	0.36726283	0.392888	0.404829	0.496408	0.553133	0.363463	0.509798	0.509769	0.318003	0.329068
MG	Mean	0.39716595	0.36645	0.480527	0.446807	0.675664	0.417948	0.537589	0.549214	0.359514	0.30984
VW	Mean	0.36531201	0.428752	0.798614	0.503907	1.055086	0.519358	0.548044	0.917077	0.418934	0.396732
					Average difference of a vertebral body segmentation						0.476102
	Variance	0.00242205	0.002848	0.025694	0.005002	0.047783	0.007235	0.000936	0.030126	0.002332	0.001831
mean of variance			0.012621								
rmssd (sq root of mean of variance)			0.112342								
mean of means			0.476102								
rmscv (coefficient of variance)			23.5963								

Coefficient of variance calculation from average vertebral body size (interoperator)

Average vertebra size in mm										
Image No	**81**	**87**	**88**	**90**	**92**	**94**	**98**	**105**	**114**	**115**
AO	65.482856	80.65626	66.4629	67.70525	79.13901	62.59571	78.69222	78.13219	70.0437	82.85672
CW	67.802791	80.48523	68.91942	71.06299	83.39253	65.12343	81.5301	76.95436	71.66377	82.26105
JR	66.7879	80.13203	68.22055	71.44998	81.98555	65.95249	80.61649	76.99532	71.43473	83.19153
MG	68.224563	81.38066	67.85332	71.36066	82.902	65.91107	81.8515	76.65063	72.48187	83.0804
VW	65.324223	77.46132	65.00393	69.3723	79.87882	63.7318	77.81684	73.76987	68.45666	80.85258
					Average size of a vertebral body across all images					74.02188
Variance	1.7298437	2.257997	2.437102	2.640678	3.494341	2.143328	3.143584	2.648026	2.509897	0.925029
mean of variance		2.392983								
rmssd (sq root of mean of variance)		1.546927								
mean of means		74.02188								
rmscv (coefficient of variance)		2.089824								

Appendix 34: Coefficient of variance calculation from vertebral body segmentation (intraoperator)

In mm	Image No	81	87	88	90	92	94	98	105	114	115
1	Mean	0.24151	0.261947	0.245796	0.31788	0.418994	0.290302	0.34884	0.287208	0.215074	0.256091
2	Mean	0.233807	0.272315	0.219573	0.281825	0.394875	0.269122	0.331861	0.288548	0.208421	0.294976
3	Mean	0.181795	0.284384	0.214901	0.300553	0.404146	0.233896	0.395094	0.259028	0.243316	0.275661
4	Mean	0.231602	0.247857	0.264226	0.283954	0.550358	0.265997	0.502285	0.27647	0.237144	0.360933
5	Mean	0.25285	0.287193	0.230112	0.288781	0.405556	0.307083	0.353777	0.296958	0.229159	0.310192
6	Mean	0.233859	0.328348	0.234668	0.259759	0.454149	0.247083	0.354677	0.267405	0.241275	0.299332
7	Mean	0.266586	0.313419	0.222203	0.281302	0.427778	0.235198	0.383695	0.350008	0.18879	0.289284
8	Mean	0.285183	0.263443	0.225347	0.296068	0.431586	0.326114	0.508283	0.396774	0.26571	0.316872
9	Mean	0.257799	0.252345	0.19417	0.292801	0.378792	0.303428	0.416726	0.310935	0.239162	0.261808
10	Mean	0.235005	0.426962	0.244637	0.305192	0.387844	0.272187	0.345516	0.296707	0.202837	0.3025
Variance		0.00075	0.002852	0.000373	0.00025	0.002432	0.000985	0.004092	0.001723	0.000528	0.000903
mean of variance		0.001489									
rmssd (sq root of mean of variance)		0.038584									
mean of means		0.297758									
rmscv (coefficient of variance)		12.95831									

Coefficient of variance calculation from average vertebral body size (intraoperator)

Average size mm										
Image No	81	87	88	90	92	94	98	105	114	115
1	69.29152	82.22076	69.3044	72.96428	83.08348	66.95717	82.05399	76.82788	72.4508	84.77064
2	69.09081	81.97466	68.55184	72.90158	83.82791	65.54811	80.83709	78.1482	71.79986	84.43531
3	67.98314	82.5302	68.95013	73.35973	83.33207	67.08662	82.3548	77.37251	73.19857	84.62132
4	67.96197	82.05727	68.74474	73.0102	84.75116	65.92456	81.10057	77.38776	71.78603	84.2593
5	68.85346	82.81742	69.00134	72.85663	85.53508	66.36273	81.06799	77.3571	72.16272	83.88786
6	68.12021	83.32187	69.31549	72.60186	86.26797	66.40865	81.18253	76.8904	72.71177	84.06257
7	67.65338	82.47059	68.85119	72.71389	85.13065	66.6142	81.33421	78.04544	72.38941	82.99988
8	67.21033	81.67423	68.74422	72.52115	84.45776	65.4179	80.74577	76.96863	71.61262	83.833
9	68.27212	82.71305	68.78133	72.95461	84.17229	66.86119	82.31912	77.53719	72.14933	84.11379
10	68.22456	81.38066	67.85332	71.36066	82.902	65.91107	81.8515	76.65063	72.48187	83.0804
Variance	0.418035	0.329986	0.172132	0.284552	1.211767	0.346094	0.368058	0.251812	0.229169	0.348829
mean of variance				0.396044						
rmssd (sq root of mean of variance)				0.62932						
mean of means				75.78558						
rmscv (coefficient of variance)				0.830395						

Appendix 34: Coefficient of variance calculation from vertebral body segmentation (intraoperator)

In mm	Image No	81	87	88	90	92	94	98	105	114	115
1	Mean	0.24151	0.261947	0.245796	0.31788	0.418994	0.290302	0.34884	0.287208	0.215074	0.256091
2	Mean	0.233807	0.272315	0.219573	0.281825	0.394875	0.269122	0.331861	0.288548	0.208421	0.294976
3	Mean	0.181795	0.284384	0.214901	0.300553	0.404146	0.233896	0.395094	0.259028	0.243316	0.275661
4	Mean	0.231602	0.247857	0.264226	0.283954	0.550358	0.265997	0.502285	0.27647	0.237144	0.360933
5	Mean	0.25285	0.287193	0.230112	0.288781	0.405556	0.307083	0.353777	0.296958	0.229159	0.310192
6	Mean	0.233859	0.328348	0.234668	0.259759	0.454149	0.247083	0.354677	0.267405	0.241275	0.299332
7	Mean	0.266586	0.313419	0.222203	0.281302	0.427778	0.235198	0.383695	0.350008	0.18879	0.289284
8	Mean	0.285183	0.263443	0.225347	0.296068	0.431586	0.326114	0.508283	0.396774	0.26571	0.316872
9	Mean	0.257799	0.252345	0.19417	0.292801	0.378792	0.303428	0.416726	0.310935	0.239162	0.261808
10	Mean	0.235005	0.426962	0.244637	0.305192	0.387844	0.272187	0.345516	0.296707	0.202837	0.3025
Variance		0.00075	0.002852	0.000373	0.00025	0.002432	0.000985	0.004092	0.001723	0.000528	0.000903
mean of variance		0.001489									
rmssd (sq root of mean of variance)		0.038584									
mean of means		0.297758									
rmscv (coefficient of variance)		12.95831									

Coefficient of variance calculation from average vertebral body size (intraoperator)

Average size mm										
Image No	81	87	88	90	92	94	98	105	114	115
1	69.29152	82.22076	69.3044	72.96428	83.08348	66.95717	82.05399	76.82788	72.4508	84.77064
2	69.09081	81.97466	68.55184	72.90158	83.82791	65.54811	80.83709	78.1482	71.79986	84.43531
3	67.98314	82.5302	68.95013	73.35973	83.33207	67.08662	82.3548	77.37251	73.19857	84.62132
4	67.96197	82.05727	68.74474	73.0102	84.75116	65.92456	81.10057	77.38776	71.78603	84.2593
5	68.85346	82.81742	69.00134	72.85663	85.53508	66.36273	81.06799	77.3571	72.16272	83.88786
6	68.12021	83.32187	69.31549	72.60186	86.26797	66.40865	81.18253	76.8904	72.71177	84.06257
7	67.65338	82.47059	68.85119	72.71389	85.13065	66.6142	81.33421	78.04544	72.38941	82.99988
8	67.21033	81.67423	68.74422	72.52115	84.45776	65.4179	80.74577	76.96863	71.61262	83.833
9	68.27212	82.71305	68.78133	72.95461	84.17229	66.86119	82.31912	77.53719	72.14933	84.11379
10	68.22456	81.38066	67.85332	71.36066	82.902	65.91107	81.8515	76.65063	72.48187	83.0804
Variance	0.418035	0.329986	0.172132	0.284552	1.211767	0.346094	0.368058	0.251812	0.229169	0.348829
mean of variance				0.396044						
rmssd (sq root of mean of variance)				0.62932						
mean of means				75.78558						
rmscv (coefficient of variance)				0.830395						

REFERENCES

1. McGraw-Hill. Concise dictionary of modern medicine. Cervical spine injury. 2002. [cited 6 November 2015]. Available from: http://medical-dictionary.thefreedictionary.com/cervical+spine+injury.

2. Looby S, Flanders A. Spine trauma. Radiologic Clinics of North America. 2011;49(1):129-63.

3. Rojas CA, Vermess D, et al. normal thickness and appearance of the prevertebral soft tissues on multidetector CT. American Journal of Neuroradiology. 2009;30(1):136-41.

4. Marcon RM, Cristante AF, et al. Fractures of the cervical spine. Clinics. 2013;68(11):1455-61.

5. South western ambulance service nhs foundation trust. Spinal care and immobilisation. 2014 .[cited 6 November 2015]. Available from: http://www.swast.nhs.uk/Downloads/Clinical%20Guidelines%20SWASFT%20staff/CG31_spinalcare.pdf

6. Grossheim LF, Polglaze S, et al. Cervical spine injury: an evidence-based evaluation of the patient with blunt cervical trauma. Emergency Medicine Practice. 2009;11(4).

7. Platzer P, Hauswirth N, et al. Delayed or missed diagnosis of cervical spine injuries. The Journal of Trauma. 2006;61(1):150-5.

8. National osteoporosis foundation. What is osteoporosis? [cited 7 November 2015]. Available from: http://nof.org/articles/7

9. Foster MR. C1 fractures.[cited 6 November 2015]. Available from: http://emedicine.medscape.com/article/1263453-overview#a7.

10. Leonard JR, Jaffe DM, et al. Cervical spine injury patterns in children. Pediatrics. 2014;133(5):e1179-88.

11. Blackmore CC, Emerson SS, et al. Cervical spine imaging in patients with trauma: Determination of fracture risk to optimize use. Radiology. 1999;211(3):759-65.

12. Panjabi M, Dvorak J, et al. Flexion, extension, and lateral bending of the upper cervical spine in response to alar ligament transections. Journal of Spinal Disorders. 1991;4(2):157-67.

13. Foo D, Rossier AB. Anterior spinal artery syndrome and its natural history. Paraplegia.1983;21 (1): 1-10.

14. Robertson PA, Ryan MD. Neurological deterioration after reduction of cervical subluxation. Mechanical compression by disc tissue. Journal Bone and Joint Surgery.1992;74(2):4.

15. Morris GT, McCoy E. Clearing the cervical spine in unconscious polytrauma victims, balancing risks and effective screening. Anaesthesia. 2004;59:464-82.

16. Davis JW, Phreaner DL, et al. The etiology of missed cervical spine injuries. The Journal of Trauma. 1993;34(3):342-6.

17. Apparelyzed spinal cord injury peer support. Spinal cord injury statistics. 2014. [cited 6 November 2015]. Available from: http://www.apparelyzed.com/statistics.html.

18. National spinal cord injury statistical center. Spinal cord injury facts and figures at a glance, 2012. Birmingham: University of Alabama at Birmingham. [cited 6 November 2015]. Available from: https://www.nscisc.uab.edu/PublicDocuments/fact_figures_docs/Facts%202012%20Feb%20Final.pdf

19. National institute for health and care excellence. Head injury. triage, assessment, investigation and early management of head injury in children, young people and adults. In: National institute for health and care excellence. 2014:180.

20.Her majesty's government. Strength and opportunity 2011, The landscape of the medical technology, medical biotechnology, industrial biotechnology and pharmaceutical sectors in the UK. In: Department of business Utai, Department of Health. 2011.

21.Gunn C. Bones and Joints; A guide for students. 5th edition: Churchill Livingstone Elsevier; 2007.

22.Ullrich P. Cervical discs. 2009. [cited 6 November 2015]. Available from: http://www.spine-health.com/conditions/spine-anatomy/cervical-discs.

23.789 productions inc. Anatomy of the cervical spine. [cited 6 November 2015]. Available from: https://www.elance.com/samples/logo-start-up-company-illustrator-logo-graphics/85801675/.

24.Medical dictionary for the health professions and nursing. Semispinalis cervicis muscle: Elsevier Inc. 2012. [cited 6 November 2015]. Available from: http://medical-dictionary.thefreedictionary.com/semispinalis+cervicis+muscle.

25.Miller-Keane. Encyclopedia and dictionary of medicine nursing, and allied health. Pedicle: Elsevier inc. 2003. [cited 6 November 2015]. Available from: http://medical-dictionary.thefreedictionary.com/pedicle.

26.Pal GP, Routal RV. The role of the vertebral laminae in the stability of the cervical spine. Journal of Anatomy. 1996;188(Pt 2):485-9.

27.Drugs information online dadri, Medical dictionary,. Definition of C4 (cervical vertebra). [cited 6 November 2015]. Available from: http://dxline.org/medic/term/c4-cervical-vertebra/

28.Tomp AW. Upper cervical chiropractic. [cited 6 November 2015]. Available from: http://uppercervicalchiropracticorangecounty.com/#.

29.McMinn RHM. Lasts anatomy regional and applied. Churchill livingstone. 2003. ISBN:B0084AQDG8.

30.Butler P, Mitchell WM, et al. Applied radiological anatomy. Cambridge University Press. 1999. ISBN:0521481104.

31.Nunn H. The Cervical spine. [cited 6 November 2015]. Available from: http://www.imageinterpretation.co.uk/cervical.php

32.Torretti JA, Sengupta DK. Cervical spine trauma. Indian Journal of Orthopaedics. 2007;41(4):255-67

33.Giugno G. Anterior subluxation of C4 on C5, with other imaging demonstrating unilateral locked left facet and perched right facet at C4-C5. 2009. [cited 2015 6 November]. Available from: http://neuroradiologyonthenet.blogspot.co.uk/2009/06/anterior-subluxation-of-c4-on-c5-with.html.

34.EB Medicine. Cervical spine injury an evidence-based evaluation of the patient with blunt cervical trauma. [cited 6 November 2015]. Available from: http://www.ebmedicine.net/topics.php?paction=showTopicSeg&topic_id=189&seg_id=3911.

35.McConnell J, Eyres R, et al. Interpreting trauma radiographs: Blackwell publishing; 2005: 286

36.Kim KS, Chen HH, et al. Flexion teardrop fracture of the cervical spine: radiographic characteristics. American Journal of Roentgenology. 1989;152 (2): 319-26.

37.Ahn J-S. Lower cervical spine injury. Journal of the Korean Fracture Society. 2011;24(1):100-13.

38 Davenport M. Cervical spine fracture. 2015. [cited 7 November 2015]. Available from: http://emedicine.medscape.com/article/824380-overview#a8.

39.Jefferson G. Fracture of the atlas vertebra. Report of four cases, and a review of those previously recorded. British journal of surgery. 1919;7(27):407-22.

40.Lee C, Woodring JH. Unstable jefferson variant atlas fractures: an unrecognized cervical injury. American Journal of Neuroradiology. 1991;12(6):1105-10.

41.Dixon A. Jefferson fracture. Trauma radiology course. [cited 7 November 2015]. Available from: http://radiopaedia.org/cases/jefferson-fracture

42.Anderson LD, D'Alonzo RT. Fractures of the odontoid process of the axis. The Journal of Bone and Joint Surgery; American Volume. 1974;56(8):1663-74.

43.Knipe H, Gaillard F, et al. Atlanto-occipital dissociation injuries. [cited 7 November 2015]. Available from: http://radiopaedia.org/articles/atlanto-occipital-dissociation-injuries.

44.Zivot U, Di Maio VJM. Motor vehicle-pedestrian accidents in adults: Relationship between impact speed, injuries, and distance thrown. American Journal of Forensic Medicine and Pathology. 1993;14(3):185-6.

45.Miller-Keane Encyclopedia and dictionary of medicine nursing and allied health,. Subluxation: Elsevier inc. 2003. [cited 6 November 2015]. Available from: http://medical-dictionary.thefreedictionary.com/subluxation.

46.Woodring JH, Lee C. Limitations of cervical radiography in the evaluation of acute cervical trauma. The Journal of Trauma. 1993;34(1):32-9.

47.Naeem Z, Bennion C. Choosing the best modality. Imaging and Therapy Practice. 2016:5-9.

48.Bailitz J, Starr F, et al. CT should replace three-view radiographs as the initial screening test in patients at high, moderate, and low risk for blunt cervical spine injury: a prospective comparison. The Journal of Trauma. 2009;66(6):1605-9.

49.Holmes JF, Akkinepalli R. Computed tomography versus plain radiography to screen for cervical spine injury: a meta-analysis. The Journal of Trauma: Injury, Infection, and Critical Care. 2005;58(5):902-5.

50.Kokabi N, Raper DM, et al. Application of imaging guidelines in patients with suspected cervical spine trauma: retrospective analysis and literature review. Emergency Radiology. 2011;18(1):31-8.

51.Teasdale G. The glasgow structured approach to assessment of the glasgow coma scale. 2014. [cited 6 November 2015]. Available from: http://www.glasgowcomascale.org/.

52.Stiell IG, Wells GA, et al. The canadian c-spine rule for radiography in alert and stable trauma patients. Journal of the American Medical Association. 2001; 286(15):1841-8.

53.Ackland H, Cameron P. Cervical spine assessment following trauma. Australian Family Physician. 2012;41:196-201.

54.National institute for health and care. Investigation for injuries to the cervical spine in patients with head injury. [cited 6 November 2015]

55.Hoffman JR, Schriger DL, et al. Low-risk criteria for cervical-spine radiography in blunt trauma: a prospective study. Annals of Emergency Medicine. 1992;21(12):1454-60.

56.Hoffman JR, Mower WR, et al. Validity of a set of clinical criteria to rule out injury to the cervical spine in patients with blunt trauma. New England Journal of Medicine. 2000;343(2):94-9.

57.Hoffman JR, Wolfson AB, et al. Selective cervical spine radiography in blunt trauma: methodology of the national emergency x-radiography utilization study (nexus). Annals of Emergency Medicine. 1998;32(4):461-9.

58.Stiell IG, Clement CM, et al. The Canadian c-spine rule versus the nexus low-risk criteria in patients with trauma. The New England Journal of Medicine. 2003;349(26):2510-8.

59.National institute for health and care excellence. algorithm 1: selection of adults for CT head scan. [cited 6 November 2015]

60.Goldberg AL, Kershah SM. Advances in Imaging of vertebral and spinal cord injury. The Journal of Spinal Cord Medicine. 2010;33(2):105-16.

61.Graber MA, Kathol M. Cervical spine radiographs in the trauma patient. American Family Physician. 1999;59(2):331-42.

62.Richardson M, L. Radiographic anatomy of the skeleton, cervical spine -- lateral view, unlabelled. 1997. [cited 6 November 2015]. Available from: http://uwmsk.org/RadAnat/CSpineLateral.html.

63.Ahmad N. Radiographic positioning techniques for the cervical spine. 2003. [cited 6 November 2015]. Available from: http://www.auntminnie.com/index.aspx?sec=ser&sub=def&pag=dis&ItemID=57734.

64.Whteley AS, Jefferson G, et al. Clark's postioning in radiography. Thireteenth edition. CRC Press. 2015

65.Sloan C, Holmes K, et al. Clark's pocket handbook for radiographers. London: Hodder Arnold; 2010.

66. Sandstrom S Akerman RT, et. The WHO manual of diagnostic imaging, radiographicuq and projections. International Society of Radiology. 2003 [cited 18 November 2016]. Available from: http://apps.who.int/medicinedocs/documents/s15634e/s15634e.pdf

67.Challans A. cervical spine radiographic anatomy. 2011. [cited 6 November 2015]. Available from: http://www.wikiradiography.net/page/Cervical+Spine+Radiographic+Anatomy

68.Ahmad A. X-ray positioning manual. 2008. [cited 18 November 2016]. Available from: http://cdn.auntminnie.com/user/documents/content_documents/X-Ray_Patient_Positioning_Manual_080402.pdf

69. Denis F. The three column spine and its significance in the classification of acute thoracolumbar spinal injuries. Spine.1983;8(8): 817-31.

70.Denis F. Spinal instability as defined by the three-column spine concept in acute spinal trauma. Clinical orthopaedics and related research. 1983 :65-76. [cited 6 November 2015]. Available from: http://medicine.missouri.edu/ortho/docs/spine/Denis%201983.pdf

71.Davies J, B., Khanna K, et al. The paediatric plain cervical-spine film – got it cracked? . European Congress of Radiology. 2014.

72.Parizel PM, van der Zijden T, et al. Trauma of the spine and spinal cord: imaging strategies. European Spine Journal. 2010;19(Suppl 1):8-17.

73.Vollmer DG, Gegg C. Classification and acute management of thoracolumbar fractures. Neurosurgery clinics of North America. 1997;8(4):499-507.

74.Dvorak, J. Cervical fractures [cited 11 November 2016]. Available from: http://f-marc.com/footballdiploma/lessons/cervical-cervical-fractures/

75.Trauma.org. The lateral cervical spine x-ray. [cited 6 November 2015]. Available from: http://www.trauma.org/archive/spine/lateral-cspine.html.

76.Raby N, Berman L, et al. Accident and emergency radiology: a survival guide. Second ed. China: Elsevier saunders; 2005: 342

77.Erickson B, J., Bartholmai B. Computer-aided detection and diagnosis at the start of the third millennium. Journal of Digital Imaging. 2002;15(2):59-68.

78.Castellino RA. Computer aided detection (CAD): an overview. Cancer imaging : the official publication of the International Cancer Imaging Society. 2005;5:17-9.

79.Baert AL, Reiser MF. et al. Digital mammography. Berlin: Springer-Verlag; 2010:128

80.Lodwick GS, Haun CL, et al. Computer diagnosis of primary bone tumors. Radiology. 1963;80(2):273-5.

81.Meyers PH, Nice CM, Jr. et al. Automated computer analysis of radiographic images. Radiology. 1964;83:1029-34.

82.Winsberg F, Elkin M, et al. Detection of radiographic abnormalities in mammograms by means of optical scanning and computer analysis. Radiology. 1967;89(2):211-5.

83.Kruger RP, Townes JR, et al. Automated radiographic diagnosis via feature extraction and classification of cardiac size and shape descriptors. Institute of Electrical and Electronics Engineers Transactions on Bio-medical Engineering. 1972;19(3):174-86.

84.Kruger RP, Thompson WB, et al. Computer diagnosis of pneumoconiosis. systems, man and cybernetics, Institute of Electrical and Electronics Engineers Transactions on Bio-medical Engineering. 1974;SMC-4(1):40-9.

85.Toriwaki J, Suenaga Y, et al. Pattern recognition of chest x-ray images. Computer Graphics and Image Processing. 1973;2:252-71.

86.Doi K. Computer-aided diagnosis in medical imaging: historical review, current status and future potential. Computerized medical imaging and graphics.Tthe Official Journal of the Computerized Medical Imaging Society. 2007;31(4-):198-211.

87.Halpern EJ, Halpern DJ. Diagnosis of coronary stenosis with ct angiography comparison of automated computer diagnosis with expert readings. Academic Radiology. 2011;18(3):324-33.

88.Doi K. Overview on research and development of computer-aided diagnostic schemes. Seminars in ultrasound, CT and MRI. 2004;25(5):404-10.

89.Foran DJ, Chen W, et al. Automated image interpretation and computer-assisted diagnostics. Analytical Cellular Pathology. 2011;34(6):279-300.

90.Grados F, Fechtenbaum J, et al. Radiographic methods for evaluating osteoporotic vertebral fractures. Joint Bone Spine. Elsevier. 2009;76(3):241-7.

91.Chan HP, Doi K, et al. Improvement in radiologists' detection of clustered microcalcifications on mammograms. The potential of computer-aided diagnosis. Investigative Radiology. 1990;25(10):1102-10.

92.Freer TW, Ulissey MJ. Screening mammography with computer-aided detection: prospective study of 12,860 patients in a community breast center. Radiology. 2001;220(3):781-6.

93.Cupples TE, Cunningham JE, et al. Impact of computer-aided detection in a regional screening mammography program. American Journal of Roentgenology. 2005;185(4):944-50.

94.Morton MJ, Whaley DH, et al. Screening mammograms: interpretation with computer-aided detection--prospective evaluation. Radiology. 2006;239(2):375-83.

95.Beigelman-Aubry C, Raffy P, et al. Computer-aided detection of solid lung nodules on follow-up mdct screening: evaluation of detection, tracking, and reading time. American Journal of Roentgenology. 2007;189(4):948-55.

96.Petrick N, Haider M, et al. Ct colonography with computer-aided detection as a second reader: observer performance study. Radiology. 2008;246(1):148-56.

97.Wang S, Burtt K, et al. Computer aided-diagnosis of prostate cancer on multiparametric mri: A technical review of current research. Biomed Research International. 2014;2014:789561.

98.Rief M, Kranz A, et al. Computer-aided ct coronary artery stenosis detection: comparison with human reading and quantitative coronary angiography. The iIternational Journal of Cardiovascular Imaging. 2014;30(8):1621-7.

99.Sadik M, Suurkula M, et al. Improved classifications of planar whole-body bone scans using a computer-assisted diagnosis system: a multicenter, multiple-reader, multiple-case study. Journal of nuclear medicine : official publication, Society of Nuclear Medicine. 2009;50(3):368-75.

100. O'Connor SD, Yao J, et al. Lytic metastases in thoracolumbar spine: computer-aided detection at ct—preliminary study. Radiology. 2007;242(3):811-6.

101. Wiese T, Burns J, et al. editors. Computer-aided detection of sclerotic bone metastases in the spine using watershed algorithm and support vector machines. Biomedical Imaging: From nano to macro, 2011 Institute of electrical and electronics engineers international conference on; March 30 2011 -April 2 2011.

102. Cole EB, Zhang Z, et al. Impact of computer-aided detection systems on radiologist accuracy with digital mammography. American Journal of Roentgenology. 2014;203(4):909-16.

103. Philpotts LE. Can computer-aided detection be detrimental to mammographic interpretation? Radiology. 2009;253(1):17-22.

104. Bjarnason K, Hassager C, et al. Anteroposterior and lateral spinal dxa for the assessment of vertebral body strength: comparison with hip and forearm measurement. Osteoporosis International. 1996;6(1):37-42.

105. Liberman UA, Weiss SR, et al. Effect of oral alendronate on bone mineral density and the incidence of fractures in postmenopausal osteoporosis. The Alendronate Phase III Osteoporosis Treatment Study Group. The New England Journal of Medicine. 1995;333(22):1437-43.

106. Black DM, Cummings SR, et al. Randomised trial of effect of alendronate on risk of fracture in women with existing vertebral fractures. Fracture intervention trial research group. Lancet (London, England). 1996;348(9041):1535-41.

107. Ettinger B, Black DM, et al. Reduction of vertebral fracture risk in postmenopausal women with osteoporosis treated with raloxifene: results from a 3-year randomized clinical trial. multiple outcomes of raloxifene evaluation (more) Investigators. The Journal of the American Medical Association. 1999;282(7):637-45.

108. Waris JH, Sirola JP, et al. Mikkeli osteoporosis index identifies fracture risk factors and osteoporosis and intervention thressholds parallel with FRAX. Journal of Osteoporosis. 2011;2011(2):732560.

109. Genant HK, Wu CY, et al. Vertebral fracture assessment using a semiquantitative technique. Journal of bone and mineral research : the official Journal of the American Society for Bone and Mineral Research. 1993;8(9):1137-48.

110.Guglielmi G, Diacinti D, et al. Vertebral morphometry: current methods and recent advances. European Radiology. 2008;18(7):1484-96.

111.Lenchik L, Rogers LF, et al. Diagnosis of osteoporotic vertebral fractures: importance of recognition and description by radiologists. American Journal of Roentgenology. 2004;183(4):949-58.

112.Wu CY, Li J, et al. Comparison of semiquantitative and quantitative techniques for the assessment of prevalent and incident vertebral fractures. Osteoporosis International. 1995;5(5):354-70.

113.Kim YM, Demissie S, et al. Intra-and inter-reader reliability of semi-automated quantitative morphometry measurements and vertebral fracture assessment using lateral scout views from computed tomography. Osteoporosis International. 2011;22(10).

114.Kasai S, Li F, et al. Usefulness of computer-aided diagnosis schemes for vertebral fractures and lung nodules on chest radiographs. American Journal of Roentgenology. 2008;191(1):260-5.

115.Ehsanbakhsh A, R., Akhbari H, et al. The prevalence of undetected vertebral fracture in patients with back pain by dual-energy x-ray absorptiometry (dxa) of the lateral thoracic and lumbar spine. Asian Spine Journal. 2011;5(3):139-45.

116.Guglielmi G, Palmieri F, et al. Assessment of osteoporotic vertebral fractures using specialized workflow software for 6-point morphometry. European Journal of Radiology. 2009;70(1):142-8.

117.Complete medical services. Ge lunar prodigy v hologic discovery bone densitometer. 2013. [cited 7 November 2015]. Available from: http://completemedicalservices.com/ge-lunar-prodigy-v-hologic-discovery-bone-densitometer/.

118.Binkley N, Krueger D, et al. Lateral vertebral assessment: a valuable technique to detect clinically significant vertebral fractures. Osteoporosis International. 2005;16(12):1513-8.

119.Genant HK, Jergas M, et al. Comparison of semiquantitative visual and quantitative morphometric assessment of prevalent and incident vertebral fractures in osteoporosis The Study of Osteoporotic Fractures Research Group. Journal of bone and mineral research : the official Journal of the American Society for Bone and Mineral Research. 1996;11(7):984-96.

120. Benjelloun M, Mahmoudi S, et al. A framework of vertebra segmentation using the active shape model-based approach. International Journal of Biomedical Imaging. 2011;2011.

121. Freelon D. ReCal Oir: ordinal, interval, and ratio intercoder reliability as a web service. International Journal of Internet Science. 2013;8(1):10-6.

122. Eorthopod. Cervical spine anatomy. [cited 6 November 2015]. Available from: http://www.eorthopod.com/cervical-spine-anatomy/topic/94

123. Allisy-Roberts P, Williams J. Farr's physics for medical imaging. W.B. Saunders Company. 2007. ISBN:0702028444.

124. Flanders A. Spine - thoracolumbar injury. 2009. [cited 6 November 2015]. Available from: http://www.radiologyassistant.nl/en/p4906c8352d8d2/spine-thoracolumbar-injury.html.

125. Viera AJ, Garrett JM. Understanding interobserver agreement: the kappa statistic. Family Medicine. 2005;37(5):360-3.

126. Panda A., Das CJ, et al. Imaging of vertebral fractures. Indian Journal of Endocrinology and Metabolism 2014;18(3):295-303.

127. Schwartz E, Steinberg D. Detection of vertebral fractures. Current Osteoporos Reports. 2005;3(4):126-35.

128. Tofer D, Finzel S, et al. Segmentation and quantification of bone erosions in high-resolution peripheral quantitative computed tomography datasets of the metacarpophalangeal joints of patients with rheumatoid arthritis. Rheumatology 2014;53(1):65-71

129. Inc, P. E. Cervical vertebrae. 2006. [cited 7 May 2016]. Available from: http://www.kean.edu/~jfasick/docs/Fall%20Semester%20Lectures%20Chapt.%201-15%20%20'07/Chapter%207C.pdf.

130. Krupinski EA, Berbaum KS, et al. Long radiology workdays reduce detection and accommodation accuracy. Journal of the American College of Radiology. 2010;7(9):698-704.

131. Lee C S, Nagy PG, et al. Cognitive and system factors contributing to diagnostic errors in radiology. American Journal of Roentgenology. 2013; 201(3):611-617.

132. Lecron F, Benjelloun M, et al. Cervical spine mobility analysis on radiographs: a fully automatic approach. Computerised Medical Imaging and Graphics. 2012;36(8):634-42

133. Larhmam A, Benjelloun M, et al. Vertebra identification using template matching modelmp and k-means clustering. International Journal of Computer Assisted Radiology and Surgery. 2012;9(2):177-87

134. Burns JE, Yao J, et al. Automated detection of sclerotic metastases in the thoracolumbar spine at CT. Radiology. 2013; 268(1):69-78.

135. Burns JE, Wiese T, et al. Computer-aided detection of sclerotic spine lesions on CT. Skeletal Radiology 2011;40 (4):513.

136. Kasai, S, Feng L, et al. Usefulness of computer-aided diagnosis schemes for vertebral fractures and lung nodules on chest radiographs. American Journal of Roentgenology. 2008;191(1):260-265.

137. Wickstrom G, Bendix T. The "hawthorne effect"--what did the original hawthorne studies actually show. Scandinavian Journal of Work Environment Health 2000;26(4):363-367.

138. Investopedia. Analysis paralysis. [cited 29 April 2016]. Available from: http://www.investopedia.com/terms/a/analysisparalysis.asp.

139. Narang B, Phillips M, et al. Semi-automatic delineation of the spino-laminar junction curve on lateral x-ray radiographs of the cervical spine. Society of Photo-optical Instrumentation Engineers. 2015. [cited 6 November 2015]. Available from: http://www.staff.city.ac.uk/~sbbh653/publications/SpinoLaminarJunctionSPIE2015.pdf

140. Jebri B, Phillips M, et al. Detection of degenerative change in lateral projection cervical spine x-ray images. Society of Photo-optical Instrumentation Engineers. 2015. [cited 6 November 2015]. Available from: http://www.staff.city.ac.uk/~sbbh653/publications/DegenerativeChangeSPIE2015.pdf

141. National institute for health and care excellence. Spinal injury:assessment and initial management (NG41). 2016.