Use of computed tomography to define a sacral safe corridor for placement of 2.7mm cortical screws in feline sacroiliac luxation

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Abstract

Objectives This study aimed to define a safe corridor for 2.7mm cortical sacroiliac screw insertion in the dorsal plane (craniocaudal direction) using radiography and computed tomography and in the transverse plane (dorsoventral direction) using computed tomography in feline cadavers. A further aim was to compare the values obtained by computed tomographic images with those previously reported by radiography in the dors transverse plane.

Methods Thirteen pelvises were retrieved from feline cadavers and dissected to expose one of the articular surfaces of the sacrum. A 2.7mm screw was placed in the sacrum to a depth of approximately 1cm in each exposed articular surface. Dorsoventral radiography and computed tomographic scanning of each specimen were performed. Multiplanar reconstructions were performed to allow computed tomographic evaluation in both the dorsal and transverse planes. Calculations were made to find the maximum, minimum and optimum angles for screw placement in craniocaudal (radiography and computed tomography) and dorsoventral (computed tomography) directions when using a 2.7mm cortical screw.

Results Radiographic measurement showed a mean optimum craniocaudal angle of 106° (range 97-112°). The mean minimum angle was 95° (range 87-107°) while the mean maximum angle was 117° (108-124°). Measurement of the dorsal computed tomography scan images showed a mean optimum craniocaudal angle of 101° (range 94-110°). The mean minimum angle was 90° (range 83-99°) while the mean maximum angle was 113° (104-125°). The transverse computed tomography scan images showed a mean dorsoventral minimum angle of 103° (range 95-113°), mean maximum angle was 115° (104-125°) and mean optimum dorsoventral angle of 111° (102-119°).

Conclusions and relevance An optimum craniocaudal angle of 101° is recommended for 2.7mm cortical screw placement in the feline sacral body, with a safety margin between 99 and 104 degrees. No single angle can be recommended in the dorsoventral direction and therefore preoperative measuring on individual patients using computed tomographic images is recommended to establish the ideal individual angle in the transverse plane.

Introduction

A high proportion of feline fractures involve the pelvis or sacrum.[1,2] Sacroiliac fracture-separation is the traumatic detachment of the wing of the ilium from the wing of the sacrum without fracture into either bone, and the term is often used interchangeably with sacroiliac luxation.[3] This is a common component of feline pelvic trauma, with an incidence ranging from 43-60%.[2,4] The most frequent pelvic fracture configuration involving sacroiliac luxation is pelvic floor fracture with unilateral ilial body fracture and contralateral sacroiliac luxation.[2] Cats are more likely to sustain sacroiliac luxation than dogs and frequently these are bilateral.[4] Bilateral sacroiliac luxation has been reported in 27-39% of cases.[2,5] The high incidence of bilateral sacroiliac luxation with no other concurrent pelvic injury in cats has prompted suggestion that the feline sacroiliac joint may be a relatively weak connection between the pelvis and the vertebral column.[6]

It is generally agreed that internal fixation is indicated in patients with sacroiliac luxation if there is a significant reduction of the pelvic canal, a substantial displacement of the iliac wing or if marked pain or neurological deficits are present.[7,8]

In the absence of these clear indications conservative management may be considered an appropriate treatment for cats. However, the evidence for long-term outcome in conservatively managed cats is very limited and it has been shown that a large number of cats will develop degenerative osteoarthritis in the sacroiliac and lumbosacral joints due to altered force transmission and compensatory overload.[9,10]

There are a number of reported methods for surgical stabilisation of sacroiliac luxations, including screw fixation,[5,11,12] transiliac stabilisation with pins, bolts or screws,[13,14,15] sacroiliac pinning with a tension band suture[16] and transiliosacral rods.[17] More recently, a dorsolateral rather than ventrolateral approach has been recommended as a better reduction may be achieved using this approach, possibly due to direct visual assessment of the articular surface.[18] Despite the large number of reported surgical options, placement of a sacroiliac lag screw is one of the most common stabilising methods although it remains a challenging surgery.

Accurate positioning of the screw in the sacral body is essential for a good outcome, while the area for screw placement is small. Implant loosening and subsequent failure of reduction is the most common complication following sacroiliac screw placement and the risk is significantly increased in dogs when the screw is placed outside of the sacral body.[3] It has been reported that the key factor in maintaining sacroiliac fixation in dogs is correct screw positioning within the sacral body.[18] A previous study demonstrated that a minimum screw depth of 60% reduces the chance of screw loosening and therefore is recommended in these cases.[19]

The area available for correct screw placement in cats is on average less than $0.5cm^2$ which is about 25% of the size of the articular surface of the sacral wing.[10] In addition to the risk of loosening, poor positioning of the screw risks damage to adjacent structures. Dorsal exit results in penetration of the vertebral canal and potential damage to the cauda equina while ventral exit risks damage to the median sacral vessels.[20, 21] Cranial exit risks penetrating the lumbosacral disc[10,22] and caudal exit risks damage to the first sacral nerve roots.[19,22] Consequently attempts to define a safe corridor for placement of sacroiliac screws have been made in both cats and dogs. A dorsoventral safe corridor was investigated in cats by Shales and others using radiography.[21] It was concluded that a freehand drill angle of 90^0 to the articular surface in the dorsoventral direction should be recommended using the optimum start point just dorsal to the geometric centre of the articular surface of the sacral wing as previously described.[10] The use of intraoperative radiology has also been recommended as it has been shown to significantly improve the accuracy of both positioning for surgery and of sacroiliac screw placement. However, facilities for portable radiography and/or fluoroscopy are not available to all surgeons. Computed tomography is an imaging modality frequently used in patients with pelvic fractures and it may be expected to offer a more accurate method of defining the safe corridor for placement of sacroiliac screws in cats. To the authors' knowledge no previous studies have documented a craniocaudal safe corridor for lag screw sacroiliac fixation in cats nor has computed tomography been used to establish either a craniocaudal or dorsoventral safe corridor. The aim of our study was to use computed tomographic images to define a safe corridor for sacral screw insertion in craniocaudal and dorsoventral directions, use radiography to define a safe corridor in the craniocaudal direction, and to compare the values obtained by computed tomographic images with those obtained by radiography. Our null hypothesis was that values obtained by both diagnostic imaging modalities would be identical and that screw positioning at 90° to the articular surface in the craniocaudal direction would result in optimal screw positioning.

Materials and Methods

Thirteen feline cadavers of animals which had died for reasons unrelated to this study were collected following ethical approval at the authors' institution. The sacrum and pelvis were retrieved from each cadaver and the bone denuded of soft tissue. One sacroiliac joint was exposed in each pelvis by a cranial ilial ostectomy, excising the ilial wing from approximately 2cm cranial to the acetabulum, exposing the articular surface of the sacrum as would be seen in a clinical case.

An approximately 1cm in depth pilot hole was drilled in each of the exposed articular surfaces with a 2.0mm drill bit using the previously recommended anatomical landmarks for optimal screw placement, with the drill start point 1mm dorsal to the geometric centre of the sacral articular surface.[10,21] A 2.7mm cortical screw was then placed and was maintained for radiographic evaluation and removed for computed tomographic assessment.

Each pelvis was radiographed in a standard dorsoventral view and underwent computed tomographic scanning in a similar position. Computed tomographic images were obtained using a 16-slice scanner (Siemens Somatom Spirit) with 1.3mm slices. Radiography was performed using a single machine (Siemens Multix Top) and processor (AGFA-Gevaert). Images were evaluated on a workstation using DICOM software (Visbion PACS system). Calculations were made as follows by two separate observers:

1. **Radiographic evaluation**:

Radiographic measurements were performed as shown in Figure 1, following guidelines already described in canine sacra.[22] The articular surface of the sacrum was outlined on the side of the screw placement (line D). The cranial and caudal borders of S1 were defined as the most cranial aspect of the vertebral body of S1 as cranial limit (line A) and the line that runs at the level of the cranial border of the cranial dorsal foramen of the sacrum as caudal border (line B), being parallel to line A. Line B was placed in this location as a screw placed more caudally to line B could potentially damage the sacral spinal nerve branches running through the foramen. Another line was marked representing 60% of the sacral body width (line C), being this line parallel to the spinous processes of the sacrum (line S) and perpendicular to lines A and B. Calculations were then made to find the maximum, minimum and optimum angles for screw placement when using a 2.7mm screw. The optimum drilling line (line F) was defined as the line running parallel to the cranial and caudal borders (lines A and B) from the middle of the 2.7mm screw to a depth of 60% into the sacral body (line C). The maximum cranial and caudal drilling lines were defined as those starting at the cranial and caudal aspect of the screw at the level of the articular surface (line D) and extending to the cranial and caudal borders of the sacrum at the level of line C (60% depth of the sacral body). These lines were marked as lines E (maximum cranial drilling line) and line G (maximum caudal drilling line). The maximum, minimum and optimal drilling angles were then calculated from the angle formed between the previously defined E, F and G lines (maximum cranial, optimal and maximum caudal drilling lines) and the articular surface line (line D) as previously reported in dogs.[22] These angles were defined as M (maximum angle), m (minimum angle) and O (optimal angle) as shown in Figure 1.

{Insert Figure 1 and Figure 1 close-up}

Figure 1: Radiographic evaluation of the craniocaudal safe corridor.

Figure 1 close-up: Lines E-G and angles in more detail.

The width of the safe corridor within the sacrum between lines A and B was also measured and recorded in degrees to allow comparison between specimens (Figure 2). This measurement was made at the point of intersection of Line C with Lines E and G. The difference between angles M and m was used to calculate the safe corridor in degrees as described previously.[21]

{Insert Figure 2}

Figure 2: Measurement of the safe corridor on the dorsoventral radiographic view.

2. Computed tomography evaluation:

Multiplanar reconstruction allowed similar measurements to be made on computed tomographic images in the transverse and dorsal planes. All the multiplanar reconstructions were standardised so that one multiplanar reconstruction line was aligned with the S1 spinous process of the sacrum and the other multiplanar reconstruction line was aligned parallel to the ventral aspect of the vertebral canal on the sacral body.

Transverse plane

The slice representing the most appropriate placement site of a sacroiliac screw was selected. This was achieved by scrolling through the images of each specimen in the transverse plane and selecting the image most centred on the optimal drill start point using the predrilled pilot hole as a reference. Measurements were taken from this view (Figure 3). The articular surface of the sacrum was outlined on both sides (line H). The dorsal limit of the sacral corridor was delineated by the ventral floor of the vertebral canal (line I) while the ventral limit was defined by the ventral aspect of the sacral body (line J). A line was marked (line L) to represent 60% of the sacral body width, being parallel with the S1 spinous process (line K). Calculations were then made to find the maximum, minimum and optimum angles for screw placement when using a 2.7mm screw in a similar fashion to those reported previously on radiographic views.[21] The optimum drilling line (line M) was defined as the line running parallel to the dorsal and ventral borders (lines I and J) from the middle of the 2.7mm screw hole to a width of 60% of the sacral body (line L). The maximum dorsal and ventral drilling lines were defined as those starting at the dorsal and ventral aspect of the screw at the level of the articular surface (line H) and extending to the dorsal and ventral borders of the sacral corridor at the level of line L (60% width of the sacral body). These lines were marked as lines P (maximum dorsal drilling line) and line Q (maximum ventral drilling line). The maximum, minimum and optimal drilling angles were then calculated from the angle formed between the previously defined P, Q and M lines (maximum dorsal, ventral and optimum drilling lines) and the articular surface line (line H) as previously reported in cats.[21]

{Insert Figure 3 and Figure 3 close-up}

Figure 3: CT evaluation of the dorsoventral safe corridor in the transverse plane.

Figure 3 close-up: Lines P, M and Q and angles in more detail.

The width of the safe sacral corridor was measured between lines I and J and expressed in degrees as previously described (Figure 4).

{Insert Figure 4}

Figure 4: Measurement of the safe corridor on the transverse CT view.

Dorsal plane

Multiplanar reconstruction was used to select images in the dorsal plane (Figure 5). The most appropriate image was identified by scrolling through the images of each specimen in the dorsal plane and selecting the image most centred on the optimal drill start point using the predrilled pilot hole as a reference. Measurement of the images was then performed as described previously in the radiographic views.

{Insert Figure 5 and Figure 5 close-up}

Figure 5: CT evaluation of the craniocaudal safe corridor in the dorsal plane.

Figure 5 close-up: Lines A, B, E, F, G and angles in more detail.tg

To evaluate the difference between measurements performed on dorsoventral radiographs and those performed using the equivalent dorsal plane computed tomographic image, a Bland-Altman plot was constructed (using Minitab statistical software) for the optimum angles determined by dorsal plane computed tomography and dorsoventral radiography (Figure 6).

{Insert Figure 6}

Figure 6: Bland-Altman plot to evaluate the difference between the optimum angles as measured on dorsoventral radiographs and those performed using the equivalent dorsal plane CT image.

Results

Thirteen sacra of skeletally mature cats were retrieved. No fractures or osteoarthritic change were found on visual examination of any of the specimens, which was then confirmed on the radiographic and computed tomographic images. Results are summarised in Table 1.

	Mean optimum angle (range)	**Mean minimum angle (range)**	**Mean maximum angle (range)**	**Mean width of sacral corridor (range)**
Radiography (dorsoventral view)	106° (97-112°)	95° (87-107°)	117° (108-124°)	32° (28-37°)
CT (dorsal plane)	101° (94-110°)	90° (83-99°)	113° (104-125°)	32° (29-38°)
CT	111°	103°	115° (104-	21° (18-27°)

(transverse plane)	(102-119°)	(95-113°)	125°)	

Table 1: Summary of measurements.

Radiographic evaluation:

Measurements of the dorsoventral radiographs showed a mean optimum craniocaudal angle of 106° (range 97-112°). The mean minimum angle was 95° (range 87-107°) while the mean maximum angle was 117° (108-124°). The mean width of the sacral corridor on dorsoventral radiographs was 32° (range 28-37°).

Computed tomography evaluation:

Measurement on the dorsal computed tomography scan images showed a mean optimum angle of 101° (range 94-110°). The mean minimum angle was 90° (range 83-99°) while the mean maximum angle was 113° (104-125°). The mean width of the sacral corridor on the dorsal computed tomographic view was very similar to the comparable radiographic view at 32° (range 29-38°).

The transverse computed tomography scans images showed a mean optimum angle of insertion of 111° (range 102-119°). The mean minimum angle was 103° (range 95-113°) while the mean maximum angle was 115° (104-125°). The mean width of the sacral corridor was 21° (range 18-27°).

The Bland-Altman plot suggests a bias when comparing equivalent measurements assessed on radiography and CT. On all occasions the CT measurements for the optimum angle were higher than their radiographic equivalent (by an average of 5°) which is clinically significant.

Discussion

We investigated the safe corridor in the feline sacrum for sacroiliac screw insertion, showing that the optimum angle for a lag screw in the craniocaudal direction in our specimens was 101° on computed tomography, and finding differences in the values obtained using radiography and computed tomography. Therefore both of our null hypotheses were rejected.

Stabilisation of a sacroiliac luxation with a lag screw is a common surgical technique, where malpositioning of the screw in the sacral body can lead to loosening of the implant or damage to surrounding structures.[3,10,19-22] Several studies have assessed the anatomy and have recommended angles for safe screw insertion in the canine sacrum. Although a previous study had recommended safe screw placement angles in the dorsoventral direction in feline sacra, to the authors' knowledge there was no previous information on the safe angles in the craniocaudal direction.[21] In addition the equivalent measurements on computed tomography scanning had not been reported. Reported advantages of imaging pelvic fractures using computed tomography over radiography include greater detail of spatial relationship of fracture fragments, lack of superimposition of faecal matter or colonic air and the ability to 3D model the area of interest.[4]

Selection of landmarks for this study followed previous recommendations. The ideal screw-hole position in the sacrum for lag screw fixation has been described as slightly dorsal to the geometric centre of the articular surface of the sacral wing.[10] This same position was also recommended by Shales and colleagues[21] as they found that when the geometric centre was used, there was an increased risk of ventral exit of the screw in the sacrum. Thus this recommended position 1mm dorsal to the geometric centre of the sacral articular surface was used in this study for screw placement.

Previous studies have measured screw placement angles by using lines which started from a point which represented the centre of the screw. This way of measuring the angles does not account for the diameter of the screw and therefore could potentially underestimate the angles obtained. In this report 2.7mm screws were used to measure the different angles of screw positioning, doing the measurements from the edge of the screw so that the diameter of the screw was taken into account. The 2.7mm screw size was selected as this has traditionally been the most commonly used size in the authors' institution. This is due to an expected increased pullout strength and reduced likelihood of loosening.[19] However it could be argued that 2.7mm screws might be oversized for this purpose in some patients, particularly in smaller cats. For example Fischer et al. (2012) used 2.4mm cannulated screws in a cadaveric study[12] while Silveira et al. (2017) described the successful use of a range of cortical screw sizes including 2.0mm, 2.4mm and 2.7mm.[23] Further studies are needed to determine the optimum screw size for sacroiliac luxations in feline patients. Furthermore, the use of different screw sizes will result in different sizes of safe corridors to place a sacroiliac screw. For example, a smaller screw size would allow a larger margin of error and exit from the safe corridor would be less likely. Although needed to be interpreted with caution due to the sample size, results from this study show that in the craniocaudal direction there is an optimal angle of screw placement which would not exit the sacrum cranially or caudally in any specimen when analysing the results obtained on dorsal computed tomography images, but not when analysing the equivalent radiographic dorsoventral views. Within the radiographed group of sacra no maximum drill angle was lower than the optimum angle of 106°. However, when drilling at the optimum angle of 106° there would be a cranial exit of the screw in one sacrum. Results from measurement in the dorsal plane computed tomography cases for this craniocaudal angle were lower than those on the dorsoventral radiographic views, with the optimum drill angle being on average 101°. This angle would be appropriate in all the cases with no risk of cranial or caudal screw exit. The highest value in any specimen within the minimum angle measurement was 99°, while the lowest value in any specimen within the maximum angle measurement was 104°. This indicates that even though the optimal drilling angle was 101° there was a 5° range in which the screw would not exit either the cranial or caudal aspect of the sacrum in any specimen. However, it is not clear if this margin of error is sufficient to allow safe application of this angle to a clinical case. Brioschi et al. (2016) investigated whether a surgeon can drill accurately at a specified angle as well as the influence of various factors on drilling accuracy.[24] Their study showed that greater accuracy was achieved at angles closer to 90°; however, only approximately 85% of participants could drill with a margin of error less than 4° even at this angle. It is possible that use of an angled drill guide would improve accuracy.

When measuring the dorsoventral angle for screw positioning on transverse computed tomographic images the mean optimum angle was calculated at 111°. However, application of this angle to all cases would result in dorsal exit in three specimens and ventral exit in one case. The lowest maximum drill angle was 104°, while the highest minimum angle was 113°. Therefore it is not possible to recommend a single angle which would be ideal for all specimens. A previous study recommended a drilling angle of 90° to the articular surface in the dorsoventral direction.[21] The mean optimum drill angle in that study was 97° compared to our mean optimum drill angle of 111°. In our study there was not a single drilling angle which would remain in the sacral safe corridor in every specimen, and therefore a single optimum angle in the dorsoventral direction has not been recommended. It is likely that these differences between studies are due to different methodologies and/or individual anatomic variation. It is also possible that there is no single optimum angle which applies to all cats in the wider population for either the dorsoventral or craniocaudal direction.

The mean width of the safe corridor in our specimens was 32° in the dorsal plane on CT, 21° in the transverse CT images and 32° on radiography. Therefore the safe corridor width was not affected by imaging modality. While there are no previous studies assessing the width of the safe corridor in the dorsal plane in cats, Shales et al reported a mean safe corridor in feline cadavers in the transverse plane of 20° which is comparable to the width reported in this study.[21]

However, differences were found between the measurements performed on dorsoventral radiographs and those performed using the equivalent dorsal plane computed tomographic image. These differences may have been due to the landmarks chosen and/or the wedge shape of the sacrum. To evaluate these differences, a Bland-Altman plot was constructed for the optimum angles determined by dorsal plane computed tomography and dorsoventral radiography (Figure 6). The Bland-Altman plot suggests a bias when comparing equivalent measurements assessed on radiography and CT. On all occasions the CT measurements for the optimum angle were higher than their radiographic equivalent. In addition the optimum angle when measured on CT is on average 5° greater than the equivalent measurement on radiography (95% confidence intervals). The Bland-Altman plot reveals large limits of agreement with an interval of almost 12°, highlighting a significant discrepancy between the imaging modalities. It has been reported that radiographic measurements are less accurate than measurements performed using computed tomography.[25] For this reason the authors decided to consider only the results on computed tomographic measurements when making clinical recommendations

It should also be emphasised that recommendations in this study are not intended to replace techniques such as intraoperative imaging where they are available as these have been demonstrated to improve the accuracy of implant placement. Tonks et al. (2008) described the benefits of fluoroscopy in allowing both accurate and minimally invasive sacroiliac screw placement, also acknowledging some disadvantages such as additional radiation exposure, equipment cost and maintenance, as well as the learning curve involved in its use.[26] Intraoperative radiography has also been described to improve drilling accuracy in the placement of sacroiliac lag screws in cats.[23]

In summary, an optimum craniocaudal angle of 101° (based on computed tomography) is recommended for screw placement in the feline sacral body, with a safety margin between 99 and 104 degrees. No single angle can be recommended in the dorsoventral direction and therefore preoperative measuring on individual patients using computed tomographic images is recommended to establish the ideal individual dorsoventral angle. To maximise accuracy in all cases of sacroiliac luxation, careful consideration of individual anatomic variation and meticulous preoperative planning and patient positioning are essential. Use of additional aids such as angled drill guides and intraoperative radiology are strongly recommended where available as they will further improve accuracy in implant positioning.

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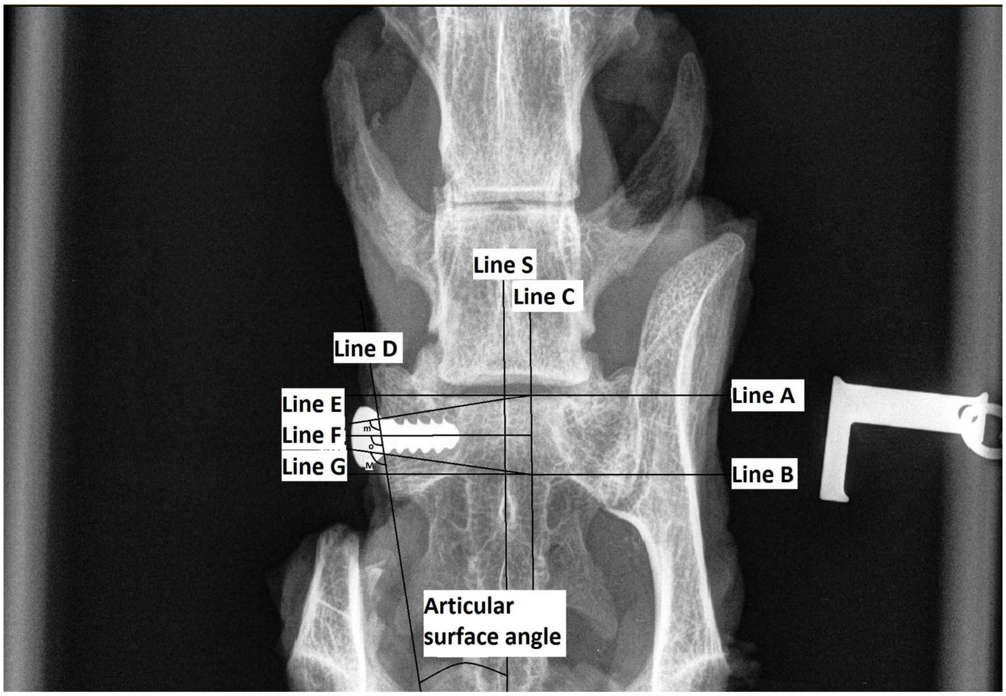

Radiographic evaluation of the craniocaudal safe corridor.

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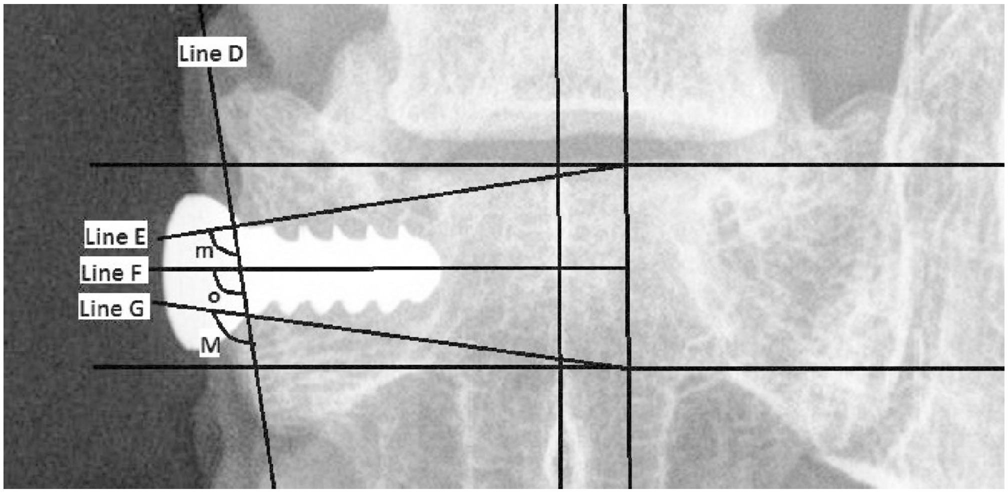

Figure 1 close-up. Radiographic evaluation of the craniocaudal safe corridor (close-up).

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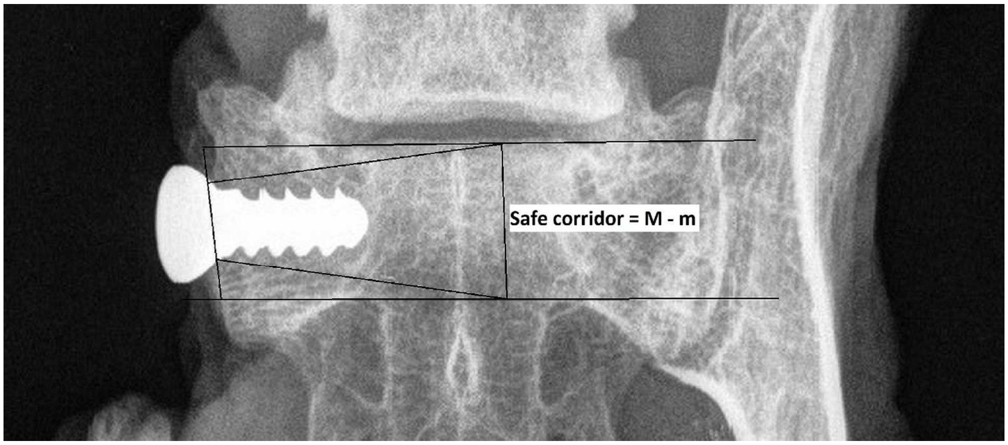

Measurement of the safe corridor on the dorsoventral radiographic view.

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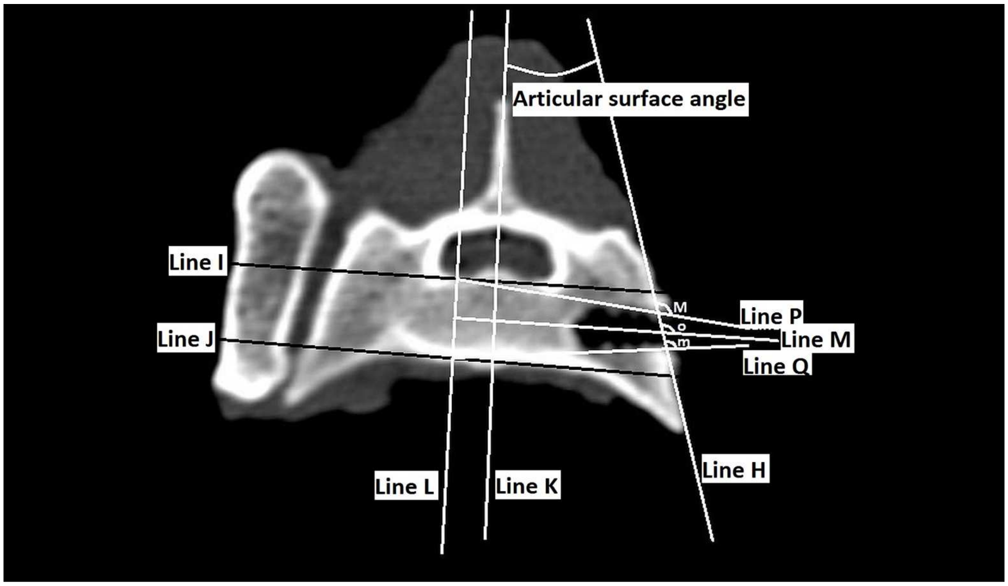

CT evaluation of the dorsoventral safe corridor in the transverse plane.

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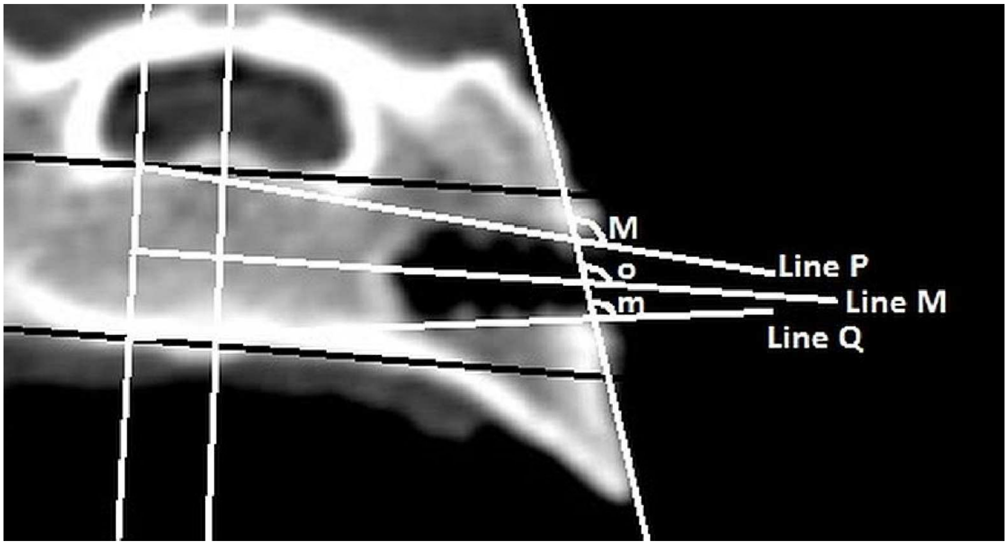
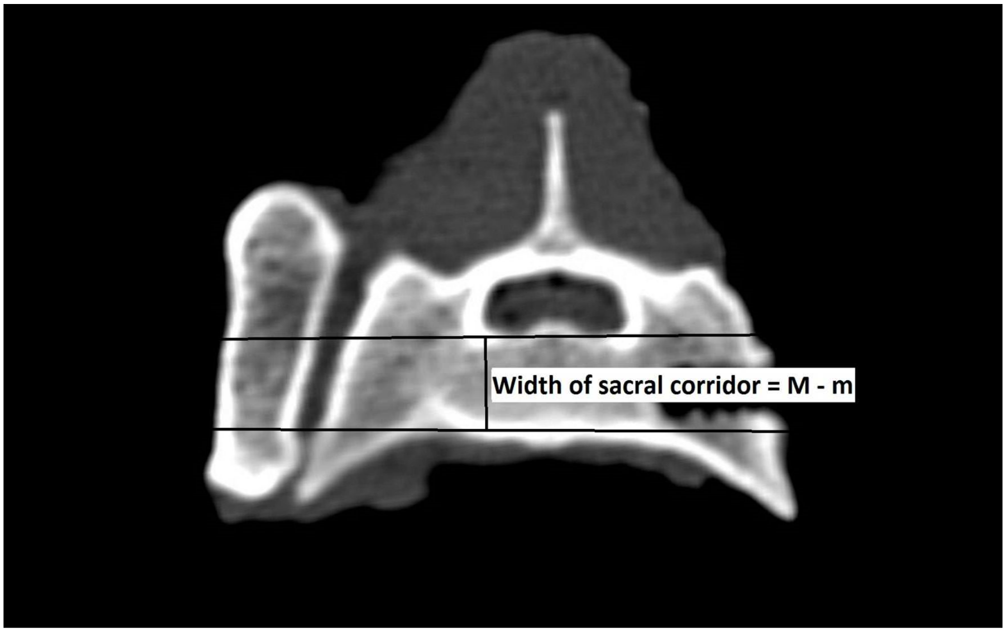


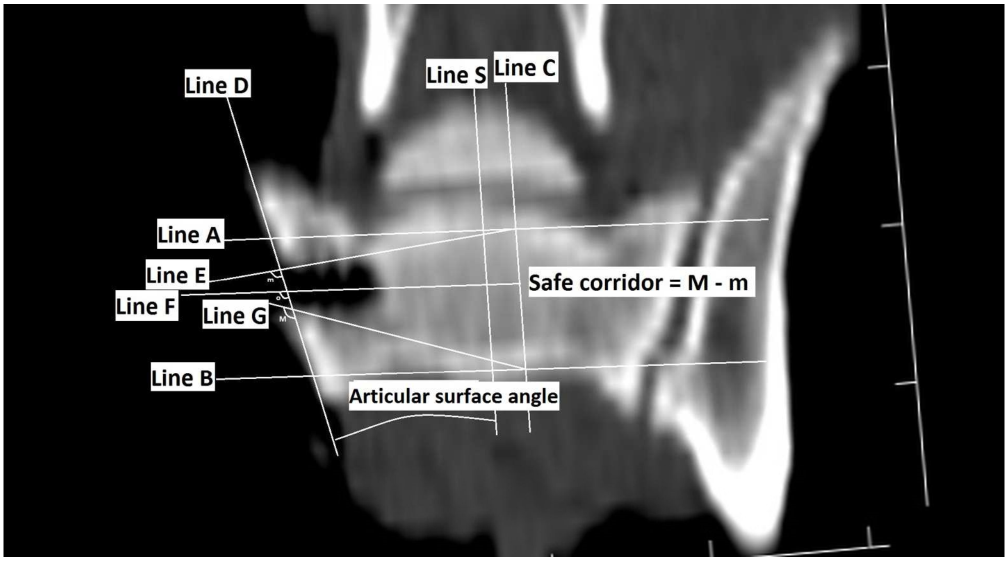
Figure 3 close-up. CT evaluation of the dorsoventral safe corridor in the transverse plane (close-up).

143x77mm (300 x 300 DPI)



Measurement of the safe corridor on the transverse CT view.

149x93mm (300 x 300 DPI)



CT evaluation of the dorsoventral safe corridor in the dorsal plane.

162x89mm (300 x 300 DPI)

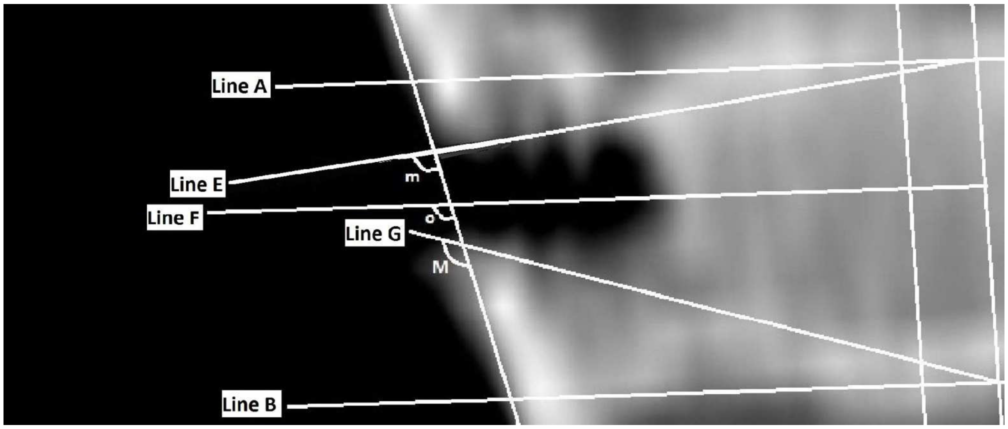


Figure 5 close-up. CT evaluation of the dorsoventral safe corridor in the dorsal plane (close-up).

169x71mm (300 x 300 DPI)

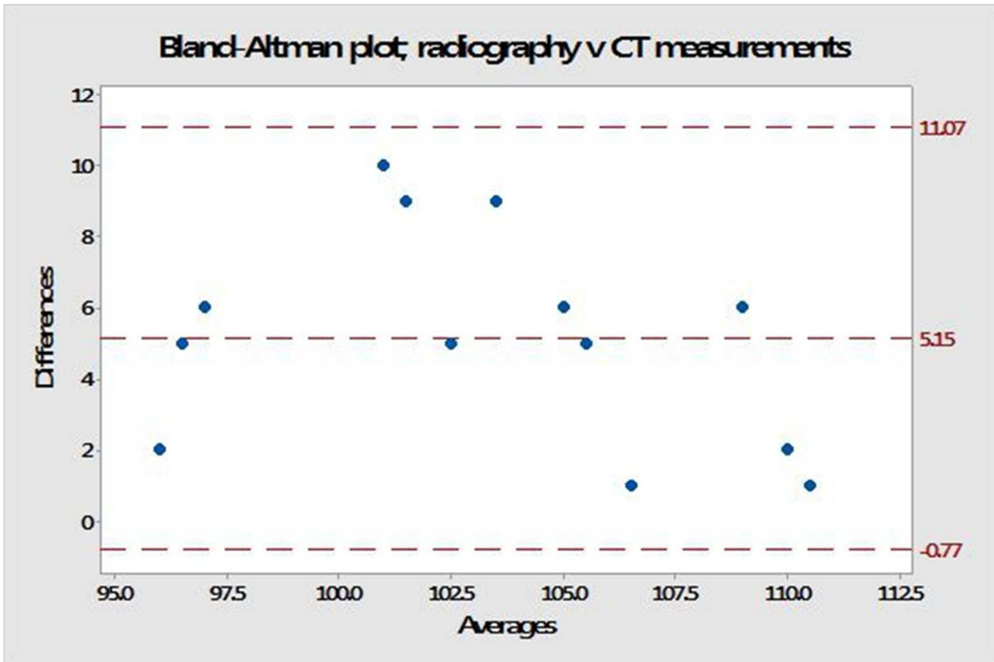


Figure 6: Bland-Altman plot to evaluate the difference between the optimum angles as measured on dorsoventral radiographs and those performed using the equivalent dorsal plane CT image.

152x101mm (96 x 96 DPI)