The Effect of Orthodontic Treatment on Traumatised Teeth: A Systematic Review and Vignette Study

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Abstract

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Traumatic dental injuries (TDI) are oral conditions which are often overlooked, despite their relatively high prevalence and its significant impact on the individual and their family. Most dental injuries tend to frequently occur within the 8-9 year old age group with the upper maxillary incisors being the most affected teeth. The consequences of TDI is dependent on the severity of the injury with pulp necrosis, pulp canal obliteration, root fracture, root resorption and loss of the tooth being the most commonly reported sequalae. There is a link between malocclusion and incidence of TDI with increased overjet and incompetent lips being significant factors leaving the upper incisors unprotected to dental injuries. Literature has shown that 20% of children had sustained trauma by the time they graduated from school and as many as 1 in 10 patients referred to an orthodontists had a history of dental trauma prior to active orthodontic treatment. Orthodontics therapy has been suggested as a preventative measure in correcting unfavourable malocclusions and potentially avoiding TDI's. The drawback to orthodontics is that it shares many of the complications reported in traumatic dental injuries, mainly pulp necrosis, pulp canal obliteration and root resorption. It is unknown whether these risks become amplified when traumatised teeth are orthodontically treated. To date, this is poorly understood in literature.

Aim

The aims of this project were two fold. The first was to determine if orthodontic treatment of teeth with a history of dental trauma increases the risk of pulp necrosis, root resorption, pulp obliteration and root fracture. The second was to evaluate whether orthodontists

considered the endodontic implications associated with the orthodontic treatment of teeth with a history of dental trauma.

Methods

The systematic review was conducted to answer the first aim according to internationally recognised PRISMA methodology. A specific question was constructed according to PICO principles. Electronic databases were searched (MEDLINE, EMBASE, Web of Science, the Cochrane Library) from 1970 to 2019. Different combinations of keywords were used for searching e.g., 'Orthodontics', 'tooth movement', 'dental pulp', 'dental trauma', 'pulp necrosis', 'root resorption', 'pulp obliteration' and 'root fracture'. Inclusion criteria included clinical studies (any design) of people (aged >7 years) who had undergone orthodontic treatment using any orthodontic appliance with a history of dental trauma prior to or during orthodontic treatment. Literature reviews, case reports, animal studies, commentaries and letters to editors were excluded.

For the second study, a mixed methods vignette survey was designed, piloted and distributed to UK registered specialist orthodontists electronically over a 4 month period from May–Sept 2019 using social media forums and emails. GDPs, orthodontic trainees and incomplete surveys were excluded from the study. The survey was split into three parts. Part one explored the orthodontist's professional background, part two examined orthodontists experiences and training in dental trauma and part three consisted of three vignette clinical scenarios with open and closed questions to explore the orthodontist's understanding of endodontic risk with the provision of orthodontic treatment of three cases, which were a mid-root fracture, pulp canal obliteration and an immature non vital central incisor.

Results

Searches retrieved 5382 citations. After screening titles and abstracts only, 29 potentially eligible papers were identified; six retrospective cohort studies were retained after the inclusion criteria were applied. Included studies were assessed as having a low risk of bias (using the Newcastle-Ottawa Scale). Evidence from narrative synthesis (participants, n= 1897; incisors, n=3659) suggests a positive correlation exists between orthodontic treatment and an increase in pulp necrosis, pulp obliteration and root resorption in teeth with a history of dental trauma versus non-traumatised teeth. This risk is increased with more severe periodontally injured teeth. There were no published results regarding root fractures.

With regards to the vignette survey, 76 orthodontists responded from the UK. Following quantative analysis of the data and thematic analysis of the transcripts, the following was identified; with regards to diagnosing dental trauma, 46% of orthodontists utilised an OPT and 53% did not carry out pre-treatment sensibility tests in the assessment of patients with a history of dental trauma. 46% of orthodontists felt they had insufficient training in dental trauma and 42% lacked confidence in the management of teeth with a history of dental trauma. In addition, 32% of clinician's felt there is lack of guidance in the orthodontic treatment of traumatised teeth and pulpal Sequalae. Qualitative themes identified were: Non-standardised pre- treatment examination, dental trauma experience, dental trauma training and lack of evidence based guidance on the orthodontic treatment of traumatised teeth.

Conclusion

The systematic review showed that there is insufficient scientific evidence regarding orthodontic treatment of traumatised teeth. However, a history of dental trauma may be considered a risk factor for loss of pulp vitality and increased pulp canal obliteration. Orthodontists should therefore be aware of these risks. The pulpal condition should be

monitored frequently by intraoral radiographs and sensibility testing throughout orthodontic treatment and during the retention period. With regards to the vignette survey, orthodontists are not following a standardised protocol in their examination of teeth with a history of trauma prior to orthodontic treatment. There is a need within orthodontics, to create a standardised protocol to assess teeth with a history of dental trauma. In addition, there is a need for orthodontists to gain greater training in the management of patients with dental trauma.

Acknowledgement

‘In the name of Allah, the Most Gracious, the Most Merciful’

I would like to thank God for all the guidance, health, wealth and blessing bestowed upon me within the last three years and allowing me to complete one of my greatest clinical and academic achievements, which I hope, will help many others in the future years to come.

To my family, particularly my parents, my brother Khalid and sister Dania, thank you for your love, support and unwavering belief in me and for continually pushing me to achieve greater things. Words alone can never repay what you have done for me. Without you I would not be the person I am today. Therefore, it is with infinite gratitude that I dedicate this work to my beloved parents.

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‘We work best when we are at the edge of our abilities and a little bit outside of our comfort zone’

For every beginning there is an end

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Thesis Structure

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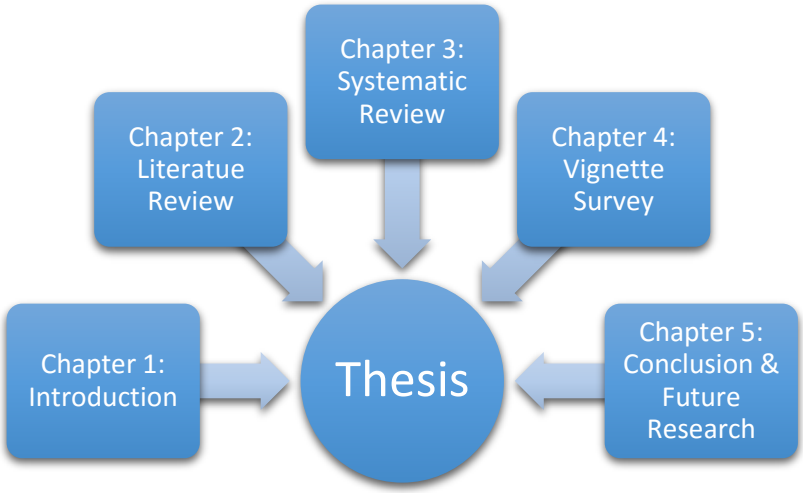
Chapter 2 Literature Review: This chapter outlines the current literature surrounding dental trauma and their classifications, orthodontic treatment and its mechanism of action, as well as, the common complications shared between orthodontic therapy and traumatic dental injuries.

Chapter 3 Systematic Review: This chapter will discuss the methodology, results, conclusion and discussion of the systematic review which will examine the effect of orthodontic treatment on traumatised teeth.

Chapter 4 Vignette Survey: This chapter will outline the definition of vignette surveys as well as the methodology, pilot, design of the vignette survey. It will then discuss the thematic analysis of the results and the themes that have emerged from the study, the conclusions of the vignette scenarios and discussion of the findings.

Chapter 5 Conclusion and Future Research: This chapter will have an overarching conclusion based on both study findings and future research projects in this subject area.



Chapter One: Introduction

Traumatic dental injuries are a preventable oral condition which is often overlooked, despite its relatively high prevalence and its significant impact on the individual, their family and society. The worldwide incidence of traumatic dental injuries in pre-school children to their primary teeth is 33% and 25% of school children and 30% of adults have suffered dental trauma to their permanent teeth (Glendor 2008; Daly B 2013; Sheiham and Watt 2000).

The findings from the UK child Health Survey 2013 showed that the prevalence of dental trauma to permanent incisors of children in all age groups was 9.1%, the rate was double in boys compared to girls. The prevalence varied significantly across different age groups with the lowest prevalence in 8-year olds (5.4%), in 12-year-old and 15-year olds it was 12.4% and 9.4% respectively (Blokland et al. 2016; Lader D and J 2005).

The oral cavity makes up less than 1 % of total body area, however, a population-based study in Sweden showed it accounted for almost 5% of all injuries in all ages. Worldwide, the proportion of maxillofacial injuries, as accounted by A&E admissions varies from 9% - 33% with indirect oral cavity injury (Nair and Paul 1986; Hayter, Ward, and Smith 1991).

The prevalence of traumatic dental injuries in the mixed and permanent dentition, they are frequently seen in the 8-9-year-old age bracket and most of these injuries involve the upper maxillary incisor teeth (Blokland et al. 2016). Patients with an increased positive overjet, are at increased risk (Bauss, Rohling, and Schwestka-Polly 2004). One study showed that an increase of overjet from 0-3mm – 3-6mm increased the likelihood of TDI by two folds and if the overjet extended over 6mm this increased to three folds (Marcenes et al. 1999; Burden 1995). One other notable factor of significance is insufficient lip closure, which often leave the upper incisor teeth unprotected from injury.

Ironically, these characteristics are frequent findings in many patients with an orthodontic treatment need. O'Brien stated that 20% of children had trauma to their permanent teeth

by the time they graduated from school (O'Brien 1994). This lends itself to some studies which have suggested that 1 in 10 patients referred for orthodontic treatment have had previous dental trauma prior to active orthodontic treatment, with infraction, enamel and enamel – dentine fractures present in 80% of cases (Bauss, Rohling, and Schwestka-Polly 2004).

When analysing the literature on orthodontic treatment of traumatised teeth is it clear that it is sparse and comprises of anecdotal evidence and retrospective papers with small sample size involving a heterogeneous collection of dental injuries, meaning definitive conclusions are hard to draw. Moreover, very little is known about the effect of orthodontic movement on traumatised teeth.

1.1 Research Aims and Objectives

Aim

The aim of this thesis is to examine the effect of orthodontic treatment on traumatised teeth.

Objectives

- Evaluate the effect of orthodontic treatment on traumatised teeth.
- Evaluate orthodontist's perspective on the treatment planning of traumatised teeth requiring orthodontic treatment.
- Evaluate orthodontists perceived difficulties in the orthodontic treatment of traumatised teeth, their pre-orthodontic treatment planning of dental trauma and limitations in dental trauma teaching, experience in dental trauma and exposure of dental trauma.
- To gain an insight of orthodontists referral pattern of difficult trauma cases and knowledge or lack of current guidelines.

Chapter Two: Literature Review

2. 1 Type of Dental Injuries

To begin with, we will explore the current knowledge on dental trauma which will look at crown fractures, root fractures and periodontal ligament injuries (luxation injuries).

2.1.1 Crown Fractures

Crown fractures can be classified into:

A. Enamel infraction
B. Enamel fracture
C. Uncomplicated Enamel- dentine fracture
D. Complicated Enamel- dentine fracture (involving the pulp)

In the permanent dentition, crown fractures account to 26% - 76% of dental injuries. The most common cause of crown fractures to the permanent dentition is falls, sporting accidents, automobile accidents and objects striking the teeth (Andreasen 1970a).

2.1.2 Enamel Infraction

These are common injuries that are often overlooked and their occurrence has been quoted in literature to range from 10.5% and 12.5% respectively (Güngör 2014; Ravin 1981). In anterior and posterior teeth they appear as craze lines within enamel substance without loss of tooth structure which does not extend to the enamel-dentine junction with no associated symptoms or pain. Enamel infraction is caused by direct trauma to the tooth enamel occurring more often on the labial surface of maxillary incisor teeth. The fracture lines can be located horizontally, vertically or divergent (Sutton 1961).

In posterior teeth enamel infractions may be associated with the dentine and cementum which are linked to the 'Cracked tooth syndrome'. Sensibility testing should be frequently carried out to detect possible pulpal involvement (Rivera and Walton 2015).

2.1.3 Enamel and Enamel – Dentine Fractures

Enamel fracture is seen mostly on the corners of the tooth. In very rare cases the entire enamel can fracture off the labial surface. Enamel- dentine fractures can be subcategorised into uncomplicated and complicated fractures. Uncomplicated enamel dentine fractures do not involve the pulp of the tooth, whereas, complicated fractures expose the underlying dental pulp (Gutz 1971). Enamel fractures are the most common type of fracture reported within dental literature with an incidence of 82% in the primary dentition (Güngör 2014; Oliveira et al. 2007; Hasan, Qudeimat, and Andersson 2010). Uncomplicated enamel – dentine fractures on the other hand are the most commonly reported trauma in the permanent dentition with a prevalence rate ranging from 2.5% to 32.6% (Hasan, Qudeimat, and Andersson 2010; Güngör 2014; Oliveira et al. 2007) and 2.4% to 33% in the primary dentition (Güngör 2014; Wilson et al. 1997; Gong et al. 2011).

Enamel and uncomplicated enamel- dentine fractures occur more often than complicated enamel – dentine fractures in both the primary and permanent dentition (Ravn 1974). They are usually associated with a single tooth more commonly the maxillary central incisor. Furthermore, these types of fractures, although not frequently, maybe associated with a combined subluxation, extrusion and intrusion luxation injuries. This presentation of concomitant injury is of prognostic importance (Andreasen 1970a).

A Complicated Enamel – Dentine fracture usually presents with an exposed pulp with haemorrhaging from the exposed pulp. Pulp polyp or proliferation of the pulpal tissue may present clinically if the injury had occurred in a young tooth with a delay of treatment for a few days or even weeks (Zadik, Chosack, and Eidelman 1979).

2.1.4 Crown- Root fractures

Crown- root fractures are fractures which involve the enamel, dentine and cementum, they can be sub categorised as complicated involving the pulp or uncomplicated without pulpal

involvement. They comprise 5% of all traumatic injuries in adults and 2% in children. (Andreasen 1970a).

In the anterior region, crown root fractures occur because of direct trauma (Bennett 1963), unlike posterior teeth where the fracture may occur indirectly, affecting a cusp with the termination of the fracture being subgingival without pulpal involvement (Needleman and Wolfman 1976). Crown-root fractures can also result from iatrogenic causes, such as pressure with down packing in root canal obturation, cementation of posts, fractured posts or poorly designed restorations (Rivera and Walton 2015).

Clinically, displacement of the fracture is minimal and are often overlooked in clinical examinations as they seldom give any symptoms. Radiographically, they are often not seen on the radiograph as the fracture line will be perpendicular to the radiographic beam (Rivera and Walton 2015).

2.1.5 Root Fractures

Root fracture is defined as a fracture involving the dentine, cementum and pulp, which are relatively uncommon and make up 0.5 -7% of all dento-alveolar traumas (Andreasen 1970a). The mechanism of fracture is caused by frontal impact creating compression zones labial and lingual resulting in shear stress zones within the tooth dictating the plane of fracture. In the permanent dentition, the maxillary central incisors are the most affected and are most common in the 11-20 years old age group (Andreasen and Hjorting-Hansen 1967). The clinical findings reveal a slightly extruded tooth with the site of the fracture determining the degree of mobility. It is usually difficult to distinguish clinically whether the mobility is due to a mobile fracture or a luxation injury(Jacobsen 1976).

Radiographic examination is crucial in demonstrating the root fracture since the fracture line is most often oblique and at a favourable angle to be detected radiographically. Root fractures will normally be visible if the central beam is aimed 15-20 degrees off the fracture

plane (Bender and Freedland 1983). Two periapical radiographs at 15 degrees from each other can also sometimes detect the fracture. In many occasions, the fracture line may not be detected immediately and may be revealed at future appointments due to haemorrhage or granulation (Andreasen 1989).

Studies have shown that root fractured occurred mostly in the apical and middle third and less likely in the coronal third (Zachrisson and Jacobsen 1975). Other studies however, have demonstrated that middle third fractures were the most common of all root fractures whilst coronal and apical third fractures occurred with equal frequency (Andreasen 1989).

The healing event after root fracture is initiated from pulpal or periodontal ligament (PDL) tissue or both. This process occurs independently from each other. With regards to pulpal healing, two healing sequelae may occur. If the pulp is intact, odontoblast progenitor cells will form a dentine bridge which unites the coronal and apical segments as soon as two weeks after the initial injury (Andreasen et al. 2007). Callus formation derived from cementum and initiated by PDL will then cover the fracture site, this will be seen radiographically three months after the injury and may take years before its completed (Andreasen, Andreasen, and Bayer 1989).

If the pulp is severed or stretched at the fracture level, revascularisation will take place at the coronal aspect of the pulp. If bacteria are absent, this process results in pulp canal obliteration of the coronal segment with PDL derived cells dominating root healing. If bacteria is present in the coronal segment of the pulp, then granulation tissue formation will ensue (Jin, Thomas, and Chen 1996).

Due to the traumatic nature of the injury, an inflammatory response is triggered releasing a series of osteoclast- activating factors which in turn may lead to root resorption. These processes are usually detected 12 months after the initial injury (Andreasen 1988).

Factors which had the greatest influence on healing were age, stage of root development, mobility of the coronal fragments, restorations present and marginal periodontitis. A long-term study showed that in 94 cases of coronal root fracture, 44% were lost in comparison to 8% in middle root fractures (Cvek, Mejare, and Andreasen 2002).

Forceful application of a splint had a negative impact on healing, with a rigid splint giving the poorest outcome (Andreasen, Andreasen, and Bayer 1989). The length of splinting did not have an implication on healing with four weeks of splinting seen as an acceptable period (Andreasen et al. 2004). Delay in treatment time by a few days did not impact negatively on the outcome either (Andreasen et al. 2004). Antibiotic therapy did not help improve healing in cases of root fracture (Andreasen 1989; Andreasen et al. 2004). However, two large clinical studies have shown that the predictors of healing was proportionate to the type and severity of injury, the anatomy of the pulp (size and vascularity) and optimal repositioning/ use of flexible splint . All of which has been found to favour healing (Cvek, Mejare, and Andreasen 2002; Cvek, Andreasen, and Borum 2001). Only one clinical study has looked into these factors showing a good long-term survival of 83% at 10 years and pulp necrosis in 20-40% which was age dependant (Welbury et al. 2002).

Root resorption as described previously is a complication of root fractures and is found in approximately 60% of cases on permeant incisors. They are usually detected 12 months after the injury (Darcey and Qualtrough 2016).

2.1.6 Luxation Injuries

Luxation injuries are periodontal ligament injuries which depending on the direction of the impact force may result in a variety of luxation injuries. Five different forms of luxation injuries are recognised and these are:

1. Concussion Injury: The account to 23% of all dental injuries and is the most common dental injury (Borum and Andreasen 2001). This is an injury to the tooth supporting structure

without mobility or displacement of the tooth but with discomfort on percussion (Andreasen et al. 2007).

2. Subluxation Injuries: This form of injury, accounts for 21% of all traumatic injuries (Borum and Andreasen 2001). This involves injury to the tooth supporting structure with abnormal mobility but without radiographic or clinical displacement of the tooth (Andreasen et al. 2007). In concussion and subluxation injuries, there is a generalised feature of oedema, bleeding and laceration of the PDL. The pulps neurovascular supply may or may not be intact. One hour after injury, the PDL changes showed signs of bleeding and haemorrhage, torn, compressed or stretched PDL fibres with cell destruction and oedema. (Miyashin, Kato, and Takagi 1991).

3. Extrusive Luxation: The frequency of extrusive luxation injuries has been shown to be 7% of traumatic injuries (Borum and Andreasen 2001). This is partial avulsion of the tooth within its supporting socket without leaving the socket. Radiographically there is widening of the PDL space. Histologically, there is complete rupture of the PDL fibres and rupture of the neuro-vascular supply to the pulp. Within 2 weeks newly formed collagen is seen laid down and within 3 weeks normal PDL appears on the root surface (Mandel and Viidik 1989).

4. Lateral Luxation: Lateral luxation injuries comprises 11% of all dental injuries (Borum and Andreasen 2001). Lateral displacement of the tooth within the socket accompanied by possible communication or fracture of the alveolar socket. Radiographically, based on the beam direction, there may or may not be widening of the PDL space. This type of injury is a complex injury involving the rupture and compression of the PDL, the pulp neurovascular supply is cut off with fracture of the alveolar socket (Andreasen and Andreasen 1985).

5. Intrusive Luxation: This form of injury comprises 0.3 – 1.9% of all dental injuries (Andreasen and Ravn 1972). This involves displacement of the tooth deeper into the alveolar bone socket. This may be accompanied by fracture of the alveolar bone. Radiographically,

this may appear as a loss of PDL space. In animal studies, there appears to be crushing periodontal injuries to the PDL and alveolar socket with rupture of the pulp neurovascular supply. Furthermore, after three months some teeth showed evidence of ankylosis whereas others showed surface resorption. Some did show normal PDL (Andreasen 1970b; Miyashin, Kato, and Takagi 1991; Turley, Joiner, and Hellstrom 1984; Cunha et al. 1995).

Luxation injuries account for 15% - 61% of dento-alveolar traumas in adult teeth. In the primary and permanent dentition, luxation injuries primarily involve the maxillary central incisors and rarely the mandibular incisor teeth and with an increase in age the pattern of injury changes (Ravn 1974; Andreasen 1970a; Andreasen 1970b). In the primary dentition, there is a marked increase in intrusion and extrusion luxation, this finding may be related to the high resilience of alveolar bone at this age. Whereas, in the adult population, intrusive luxation injuries are relatively low in incidence and presents more in younger adults (Andreasen 1970b). In luxation injuries, two or three teeth are involved with concomitant crown or root fractures.

2.1.7 Avulsion

Tooth avulsion implies the total displacement of the tooth from its socket. It is an infrequent complication following trauma and its incidence is reported at 0.5 – 3% of all traumatic injuries to permanent teeth (Ravn 1974). The main causes of avulsion are sporting injuries and fights (Andreasen 1970a).

The maxillary incisors are the most commonly affected teeth, most often it affects a single tooth and avulsion of multiple teeth can be encounter following severe injury. Other injuries occurring at the same time as avulsions are damage to the alveolar bone as well as laceration to the lip. Radiographs are seldom required unless there is damage to the alveolar bone or incomplete fracture of the tooth with possible remnants of root present within the socket (Andreasen et al. 1995).

Avulsion causes extensive damage to the PDL and pulpal tissue. The blood and nerve supply at the apex is severed and the periodontal ligament is torn from its attachment to the bone at the interface with an exposed root surface of the tooth present. The prognosis of an avulsed tooth is determined by two factors; the stage of root formation and extra-oral dry time (Andreasen et al. 1995).

2.2 Prevalence, Incidence and Aetiology of Traumatic Dental Injuries

The prevalence of TDI worldwide is high. A large survey carried out in the USA with an age group of 5-60-year olds, showed approximately 25% of adults had evidence of a TDI (Kaste et al. 1996). Another study in the UK showed that 1 in 5 children had suffered injury to their permanent maxillary incisors before leaving school (O'Brien 1994). Very few studies assessed the incidence of TDI, the findings of a prospective study in Copenhagen, Denmark which examined all dental injuries from the age of 0 – 14 years old, showed that 30% of children in the study had sustained an injury to their primary dentition and 22% to their permanent dentition (Andreasen and Ravn 1972). Another prospective study on an Australian population showed an incidence of 20 cases of TDI per 1000 children ages 6-12 years old (Stockwell 1988). One other prospective study in Sweden showed that the mean incident of TDI in boys was 1.6 and girls 1.0 per 100 children per year between the 0-19-year-old bracket (Glendor 1996).

The aetiology and exact process in which mechanical energy leads to dental trauma is still, to most part, unknown and not backed by any experimental evidence. It has been shown that most dental injuries affect the anterior teeth with the maxillary incisors being a prime candidate, whereas, mandibular central incisors and maxillary lateral incisors involved less frequently. This pattern of injury is also similar in the primary dentition (Ellis and Davey 1970). Furthermore, dental injuries more often only affect a single tooth with injuries

associated with sports, whilst multiple dental injuries occurred in road traffic accidents and interpersonal violence especially in teenagers (Andreasen 1970a).

Literature has shown that the most common types of dental injury to permanent teeth is enamel fracture followed by enamel- dentine fracture (Belcheva et al. 2008). In many cross-sectional studies, soft tissue lesions were not studied or assessed. Furthermore, TDI affects children and adults unequally. Some individuals may not be affected or may have one episode of trauma, whilst others may suffer from repeated episodes of TDI (Hamilton, Hill, and Holloway 1997). There seems to be no gender differences with repeated trauma to happening to the same teeth (Onetto, Flores, and Garbarino 1994). The frequency of repeated TDI ranges from 4- 49%, whilst repeated injury to the same teeth were reported in the 8-45% range. The risk of sustaining a second dental trauma was found to be eight times for patients who had sustained their first episode of trauma at 9 years of age compared to 12-year olds (Andreasen 1970a).

Generally, boys have almost twice the TDI risk as girls to their permanent dentition, this may be related to the fact they may be more involved in sports and contact games compared to girls. Recent studies however, show a reduction in this difference, which may reflect a change in in society with sports being accesses by girls as well as boys (Andreasen 1970a).

2.4 Complications of Traumatic Dental Injuries

2.4.1 Crown Discolouration

Post traumatic colour change to the crown is a documented phenomenon whereby the crown may change colour from pink, blue to grey and would be clinically distinguishable (Arwill, Henschen, and Sundwall-Hagland 1967). One explanation for this phenomenon is that if the injury was not of high intensity to rupture the arteries passing through the foramen, it could sever or rupture the thin vein walls causing bleeding and haemorrhaging into the canal which diffuses through the hard tissues of the coronal segment. One other

suggestion could be ischemia from broken down capillaries due to the rupture of the arteries at the apical foramen and the erythrocyte escaping into the pulpal tissues. (Stanley et al. 1978).

If the injury has displaced the tooth, in such injuries as intrusive or extrusive luxation, the apical vessels are severed instantly with no haemorrhaging of blood in to the apical tissue, therefore no immediate discolouration (Cooke 1951). However, in moderate injury, where there hasn't been total disruption of blood vessels then ischaemia will ensure with increased vascular permeability (Converse and Rapaport 1956; Andreasen et al. 2007).

In more recently clinical studies, the coronal grey discolouration in some cases was described as a temporary discolouration following luxation injuries in mature permanent incisors. The normalization could be associated with the loss and restoration of pulpal sensibility as well as the appearance and disappearance of apical radiolucency's and pulp canal obliteration. It has been suggested that in the absence of infection, these events lead to the healing of the pulp. In the presence of infection however, the infection may lead to the permanent discolouration of the injured avascular pulp due to the autolysis of the necrotic pulp and the by-products seeping into the dentine tubules (Andreasen 1986; Andreasen 1989).

2.4.2 Transient Apical Breakdown (TAB)

Transient Apical Breakdown is a temporary radiographic change to the apex at the region of the apical foramen which has been shown to be a complication following luxation injuries (Andreasen 1986). This phenomenon happens as a result to the displacement of the root after a luxation injury and the total or partial severing of the vascularity at the apical foramen leading to ischaemic changes to the pulp. This leads to the activation of the osteoclast activating factors as a wound healing response. This process causes an increase to the PDL space or widening of the apical foramen diameter which may accommodate vascular ingrowth into the pulp root canal system. Once remodelling phase has been achieved the

resorption phase resolves. Radiographically, this would present as a normal root canal system and PDL structure (Andreasen 1986).

2.4.3 Pulp Canal Obliteration (PCO)

The process of pulpal revascularisation following tooth luxation can result in 'Pulp Canal Obliteration' or 'Calcific Metamorphosis (CM). PCO occurs as a complication of dental trauma and most commonly on the anterior teeth of young adults. The degree of canal obliteration seems to be associated with the severity of luxation injury. The exact mechanism of pulp canal obliteration is still unknown, however, it may be described as a response to severe injury to the neurovascular supply of the pulp which, after healing leads to accelerated dentin deposition and yellow discolouration clinically (McCabe and Dummer 2012).

Several studies have investigated PCO and its relation to dental trauma. Holcomb & Gregory, 1967 evaluated 882 servicemen who had experienced dental trauma to their anterior teeth over a four year period, from which only 34 men had shown partial or total PCO on 41 anterior teeth (4% incidence rate). Of the 41 teeth with PCO only three teeth (7%) developed periapical radiolucency on radiographic reviews (Holcomb and Gregory 1967).

Another study by Andreasen, 1970, assessed 108 patients with 189 luxated permanent anterior teeth, the study showed PCO in 42 teeth (225) over a mean observation period of 3.4 years. Robertson et al, 1996, also examined 82 cases of traumatised anterior incisor teeth with PCO exhibiting various severities of luxation injuries (concussion, subluxation, extrusion, lateral luxation and intrusion luxation) over a 7 – 22-year period (mean of 16 years). Pulp necrosis occurred in seven teeth (9%) with the incidence of pulp necrosis on pulp canal obliterated teeth increasing over time (Robertson et al. 1996).

The severity of PCO is related to the severity of the injury. It appears to be more common in severely mobile or displaced teeth and is rarely seen with no tooth displacement as there is no injury to the pulp neurovascular supply. The frequency of PCO is directly determined by

the type and severity of the injury as well as the stage of root development (De Cleen 2002). Andreasen et al, 1987 showed that PCO occurred in 3% of concussion injuries with an immature root and 7% in mature roots. The same study revealed slightly higher figures in teeth that had subluxation injuries, with PCO in 11% of teeth with immature roots and 8% in completely formed roots. Furthermore, the study showed the greater the severity of injury the greater the frequency of PCO (Andreasen and Pedersen 1985).

After luxation injuries, the affected tooth, does not always react positively to sensibility tests (Andreasen 1970b). The response to thermal and electric pulp testing has been reported to be reduced or absent (Holcomb and Gregory 1967), however, it can be reversible and can take several weeks before sensibility tests show a positive result (De Cleen 2002). If PCO is present however, some studies have shown unreliability with sensibility tests (De Cleen 2002; Holcomb and Gregory 1967; Oginni, Adekoya-Sofowora, and Kolawole 2009) with a decrease in response as PCO becomes more pronounced (Oginni, Adekoya-Sofowora, and Kolawole 2009; Schindler and Gullickson 1988).

With regards to the difference in sensibility tests between partial and complete PCO, there seems to be a significant difference, with greater sensibility recorded in partial PCO cases (Oginni, Adekoya-Sofowora, and Kolawole 2009). It is important to be cautious of a negative response to sensibility tests as it may not always imply pulp necrosis (Oginni, Adekoya-Sofowora, and Kolawole 2009; Holcomb and Gregory 1967). With some studies outlining no differences to sensibility testing up to five years after the injury (Andreasen et al. 2007).

Radiographically, the canals are reduced in size at the coronal pulp chamber with gradual narrowing of the canal space throughout the root canal system with partial or complete canal obliteration. Pulp canal obliteration has been shown to appear as soon as 3-12 months after injury with 2 forms of obliteration known in literature. ‘Partial Pulp Canal Obliteration’ whereby coronally the canal is sclerosed, but the apical root is narrowed but is seen

radiographically, whereas, 'complete pulp canal obliteration' the coronal pulp chamber and the root canal are not visible (Andreasen et al. 2007; Oginni, Adekoya-Sofowora, and Kolawole 2009; McCabe and Dummer 2012). Teeth that have undergone PCO are generally asymptomatic (Robertson et al. 1996; Oginni, Adekoya-Sofowora, and Kolawole 2009). They are found incidentally an a clinical radiographic examinations with patients not recollecting any history of trauma that may have contributed to the clinical findings (Oginni, Adekoya-Sofowora, and Kolawole 2009).

2.4.4 Pulp Necrosis

Throughout a follow up period the tooth may suffer from complications such as pulp necrosis, crown discolouration, pulp obliteration, transient apical breakdown, root resorption and loss of marginal bone support (Dumsha 1995).

Pulp necrosis following dental luxation injury in the permanent dentition ranged from 15% - 59% (Andreasen 1970b). It has been acknowledged that two main factors contribute significantly to the development of pulp necrosis, namely the type of luxation injury and the stage of root development (Andreasen and Pedersen 1985).

When closely examining the type of injury a greater number of pulp necrosis was witnessed in intrusion luxation and avulsion followed by lateral and extrusive luxation. Pulp necrosis was least frequency evident amongst concussion and subluxation injuries (Trope 2002; Skiellkr 1960).

Subsequently, when examining the stage of root development, teeth with mature closed apices were more likely to suffer pulp necrosis in comparison to teeth with open apices as teeth with open apices are more likely to achieve revascularization (Andreasen 1970b). Diagnosis of pulp necrosis following luxation injury can be more challenging due to the radiographic interpretation of the extent of damage to the periodontal structure and its surroundings. Thus, pulp necrosis can be diagnosed within the first 6 months of a concussion

and subluxation injury and up to 2 years following an intrusion, extrusion and lateral luxation injury, this could be due to difficulties in radiographic diagnosis of the extent of damage to the PDL (Andreasen and Pedersen 1985).

Clinically, pulp necrosis in permanent teeth presents with a spontaneous throbbing pain or tenderness to percussion signifying inflammation of an infected pulp in the PDL. In histological studies, tenderness on percussion was in fact the only sign which significantly related to pulp necrosis following a luxation injury. Conversely, the majority of luxation and root fracture injuries are asymptomatic with diagnosis based heavily on the clinical and radiographic signs (Bergenholtz 1974). A 'Grey' discoloured crown with or without a periapical lesion radiographically can sometimes be observed as soon as 2-3 weeks after trauma. If there is no periapical involvement, then it can be assumed a sterile necrosis may be taking place. A periapical radiograph with periapical rarefaction almost always represents signs of pulpal inflammation and infection dominated by anaerobic micro-organisms (Cvek, Nord, and Hollender 1976).

Sensibility testing is therefore required as an adjunct to determine pulp necrosis, however, the finding of sensibility tests can be difficult to interpret and potentially misleading. There is a general agreement from previous studies that sensibility testing or colour change alone is not an indication to diagnose pulp necrosis and that the formation of a periapical lesion is considered the only sign of pulp necrosis. A change of sensibility testing from positive to negative should suspect a strong link to pulp necrosis (Skiellkr 1960; Magnusson and Holm 1969; Alghaithy and Qualtrough 2017).

2.4.5 Root Resorption

Pathophysiology of Root Resorption

Root resorption is a recognised phenomenon following trauma. The pathophysiology of root resorption has been linked to the osteoclastic bone cell which are found on Howships

lacunae or crypts located on hard tissue surfaces, and are distinguished from other cells as they have ruffled margins which come in contact with bone or dentine which seals the surface area with integrins (Patel and Pitt Ford 2007).

Osteoclasts are the main cells which cause resorption which can break down bone, cartilage and dentine. The stimulation which triggers resorption is yet unknown, there are multiple theories that describe this interaction but are yet to be proven. It is said that factor K-B Ligand (Osteoclast differentiation factor (ODF), osteoprotegrin ligand (OPGL) and receptor activator of nuclear factor K-B ligand (RANKL) are known to create osteoclast formation. The release of these factors, which are found on the cell surfaces of monocytes and macrophages stimulate both cells to merge to become osteoclasts (Yasuda et al. 1998).

Resorption within the dental confines is essential for repair as well as the process of exfoliation of the primary dentition. Throughout normal physiology, there is an equilibrium between osteoclast activators and inhibition. However, when there is damage to tissue, pro-inflammatory markers such as cytokines are produced to help in the repair process and this process will include osteoclasts. With regards to dental hard tissue repair the RANKL system is integral to this process and if a tooth has extensive damage complete resorption may occur (Lossdörfer, Götz, and Jäger 2002).

Barriers to Root Resorption

It is important to note that resorptive lesions are rare with biological mechanisms present to prevent root resorption of teeth. These barriers include: a vital periodontal ligament, a healthy cementum layer and pre-dentine layer (Trope 2002).

- Vital Periodontal ligament

It has been shown through research that a vital periodontal ligament layer undergoes less resorption than those suffering from necrotised periodontium. The degree of the resorptive

defect correlates with the size of the necrotic periodontal membrane. It has been shown that the PDL can produce RANKL and areas larger than 1.5mm may not heal as well and may be more prone to resorption. Furthermore, it is hypothesised that an area with periodontal tissue necrosis and damaged cementum may undergo greater damage(Trope 2002) .

- Healthy intact cementum

An area of highly mineralised and intact cementum offers resistance to resorption. This is because cementum is more resistant to resorption than dentine and is formed from a layer of cementoblasts with an outer layer of cementoid. This layer, which is non-mineralised may be the barrier that prevents resorption. Furthermore, cementum may lack the protein which is found in bone to activate osteoclasts and may contain inhibitory factors for osteoclastic processes. Moreover, cementum plays a role in the prevention of bacterial spread from the dentine to the periodontal ligament which inhibits the initiation of the inflammatory response and osteoclastic activity. It is therefore understood, that there must be significant damage to the cementum to cause resorption (Andreasen 1981b, 1981a).

- Pre-dentine layer

It has been hypothesised that the resistance to internal resorption is predominantly linked to the presence of the non-collagenous layer found in pre-dentine. Therefore, pre-dentine within the root canal system is likened to cementum on the external surface of the root in its inhibitory role of resorption and its processes (Wedenberg and Lindskog 1987).

Classification of Root Resorption

Root resorption can be simple be classified as external or internal root resorption. External root resorption describing resorption that occurs on the external surface of the root and internal resorption whereby the lesion is sustained to the dentine of the root canal or pulp chamber. Classification have been designed to describe the site and size of the lesion, whilst

others have classified the resorptive process based on the aetiology of the resorptive process (Darcey and Qualtrough 2013). The most widely used and acknowledged classification is Andreasens classification which breaks down resorption into (Andreasen 1970b):

External Resorption

- External surface resorption
- External inflammatory resorption
- External replacement resorption
- External cervical root resorption

Internal Resorption

- Internal surface resorption
- Internal Inflammatory resorption
- Internal replacement resorption

External Surface Resorption (ESR)

This form of resorption occurs on the surface of the root and surrounding periodontium. It is a localised and self-limiting process whereby the osteoclasts have a limited activity of up to 2-3 weeks followed by cemental and periodontal ligament healing. If there is no further stimulation, then healing will take place uneventfully. If the resorptive lesion extended to cementum only, then full healing will take place. If the lesion involved the dentine layer, then new cementum will be formed, and the root contour may present radiographically as partially restored. This form of resorption as discussed previously is very common and grossly under reported (Andreasen 1981a; Trope 2002).

External Inflammatory Resorption (EIR)

This form of resorption occurs on the surface of the root and a frequent complication following luxation and avulsion injuries. The prevalence of EIR in luxation injuries ranges between 5 – 18% and affects 30% of replanted teeth following avulsion injuries. It is a progressive condition which can advance at a rapid rate to the extent that a whole root surface can resorb within months if left untreated. It can also affect teeth with chronic periapical periodontitis (Andreasen et al. 2007).

In external inflammatory resorption, damage and stripping of the cementum layer and the breach of its integrity is the predisposing factor for all forms of external inflammatory resorption. This results in the underlying dentine layer to be exposed to osteoclastic activity. The severity of which depends on the severity of the injury, the stage of root development and the pulpal status. If the damage is sufficient enough to cause an aggressive osteoclastic activity to pursue on exposed dentine tubules, then a communication may form between the pulp space and the resorptive defect (Andreasen 1985).

Diagnosis of EIR is dependent on radiographic examination. Radiographically the surface of the root may appear rugged, concave or radiolucent. There is complete loss of the lamina dura on the area of root resorption. This can be seen as early as 3 – 4 weeks after the injury to the tooth and always initiated within 1 year after the injury. EIR can have a rapid and aggressive progression with the entire loss of the root possible within 3 months of its onset (Darcey and Qualtrough 2013).

With regards to the relationship between trauma and EIR, it is well documents that trauma, orthodontics and chronic endodontic infections may results in the developments of EIR. With regards to trauma, Soares et al, 2015 examined the frequency of root resorption following trauma sustained to permanent teeth. The study found that EIR was more likely to occur the greater the severity of the periodontal ligament injury sustained. Intrusive luxation and

avulsion had the greatest cause of EIR at an odds ratio of 3.7 and 2.8 respectively, followed by lateral luxation and extrusive luxation (Soares et al. 2015).

External Replacement Resorption (Ankylosis)

In this process the root is replaced with bone, this process is also called ankylosis. The aetiology of this is still poorly understood however it can be related to the absence of vital PDL covering the root surface. In this process the bony develops within the PDL space and fuses to the root forming a union with the tooth. It can be demonstrated as early as 2 weeks following trauma (Hammarstrom, Blomlof, and Lindskog 1989).

Two forms of ankylosis may take place, either 'progressive replacement resorption' which gradually over time will resorb the entire root surface, or 'transient replacement resorption' in which an ankylosed region may later disappear over many years, however, very little is known about their prevalence within literature. (Hammarstrom, Blomlof, and Lindskog 1989; Trope 2002).

Progressive replacement resorption tends to occur when the whole PDL has been removed prior to replantation of the tooth and the damaged PDL is replaced by adjacent bone marrow cells within the socket. Transient replacement resorption is possibly related to an area of minor damage which has undergone replacement resorption to only be replaced with vital periodontal ligament over time (Hammarström et al. 1986).

Radiographically ankylosis will show areas of missing PDL replaced with alveolar bone. It has been shown that ankylosis can be seen as soon as 2 months after re-implantation, however, the average is over 6-12 months. Clinically however, ankylosis will show an immobile tooth with infra-position in children. The percussion pitch is high compared to adjacent teeth. The rate of ERR varies between age groups and growth rate of the patients. In children aged 7 –

16 years of age the tooth may be lost within 3 – 7 years after the onset of ankylosis, whereas, in adults it can survive 20 years before its loss (Darcey and Qualtrough 2013; Trope 2002).

External Cervical Resorption

This is one form of external resorption which presents immediately below the epithelial attachment of the tooth at the cervical region affecting the mineralised cementum, dentine and predentine in its advanced forms(Darcey and Qualtrough 2013).

The aetiology of cervical root resorption is unknown; however, according to Heithersay et al, 1999. Orthodontics and trauma were the two most common predisposing factors in the development of external cervical resorption. Of the 222 patients and 257 teeth diagnosed with ECR in Heithersays study, 21.2% of patients developed this after orthodontic therapy and 14% following trauma, however, the type of trauma was not described (Heithersay 1999).

Internal Inflammatory Resorption (IIR)

Internal inflammatory resorption to take place there must be damage to the odontoblast and pre-dentine layer of the root canal wall resulting in the exposure of the underlying dentin to odontoclasts (Patel et al. 2010).

The exact cause which triggers this reaction is unknown, however, various aetiological factors have been proposed for the loss of the pre-dentine including trauma, caries, periodontal disease, calcium hydroxide procedures, and excess heat within the pulp canal on vital teeth during restorative treatment, orthodontic treatment, cracks and idiopathic changes within the pulpal tissue. The cause and severity of trauma and its correlation to IRR is unknown (Patel et al. 2010).

Radiographically, IIR can occur at any location within the root system and a well-defined radiolucent outline and symmetry. Sometimes the lesion may present with a sinus. If that's

the case a PA with GP will help locate the source of the sinus and may show a perforation due to the extent of the resorption. (Patel et al. 2010).

The management of such lesions depends on the extent of hard tissue destruction, this will also affect the prognosis of treatment. CBCT may be required to examine the size and extent of the lesion as well as perforation of the root canal system. If the tooth is deemed salvageable then RCT is initiated with the aim of reducing the bacterial count and stimulus (Patel et al. 2010).

Internal Replacement Root Resorption

This presents itself with a more irregular enlargement of the canal space leading to pulp canal obliteration with a mixture of radiolucent and radiopaque appearance radiographically reflecting metaplastic changes. There is uncertainty to why this may occur, one hypothesis is the pulp stem cells are producing osteoid material as a reparative process to trauma or inflammation. A second cause maybe that the cells are not pulpal in origin and may have originates from the periapical tissue and migrated into the pulp space from the microvascular capillary network (Wedenberg 1987; Darcey and Qualtrough 2016). Again, like IRR, internal replacement root resorption is rare and the cause, severity of trauma and its correlation to internal replacement root resorption is to date unknown.

2.5 Orthodontic treatment and its mechanism of action

To gain an understanding of the orthodontic – trauma interplay, we first need to acknowledge the literature surrounding orthodontic tooth movement and its related complications.

Orthodontics, is a specialist branch within dentistry which examines, diagnoses and treats malocclusions. This treatment is based on the theory, that if prolonged pressure is applied to the tooth, then the tooth will move due to remodelling due to selective removal of bone

in the ‘pressure area’ and addition of new bone in the ‘tension areas’ leading to successful tooth movement through bone. This process is cell mediated, the conversion of orthodontic forces into biological activity is poorly understood with four proposed theories for mechanical tooth movement. The pressure – tension theory, the bone bending theory, the piezoelectric theory and hydrodynamic theory.

2.6 Theories of orthodontic tooth movements

2.6.1 Pressure – Tension Theory

The classic histological studies conducted by Sandstedt, 1904, Oppenheim 1911 and Schwartz 1932, led to the pressure – tension theory which hypothesised that alteration to the blood flow within the periodontal ligament by sustained pressure that leads the tooth into shifting its position within the PDL space, this compresses the ligament is pressure areas and stretches the PDL in the opposing side. In the compressed region blood flow is decreased and increased in the areas under tension. When this force is applied on the tooth, bone is laid down in the tension side of the PDL and resorbs on the pressure side. This leads to the cells of the PDL to react because their cytoskeleton has been deformed and the cells resorbed at the side of the bone immediately adjacent to the necrotic PDL area is removed all together. This is known as undermining resorption. (Schwarz 1932; Reitan 1970; Oppenheim 2007).

The hypothesis suggested that when mechanical loads are applied on the PDL, the PDL acted like a visco-elastic gel which flowed when steady forces were subjected on the tooth. This mechanical force which acted on the tooth seems to originally be attributed to three distinct interacting fluid systems, these are the vascular system, the cells and fibres within the PDL and the interstitial fluid. (Oppenheim 2007).

2.6.2 Bone Bending Theory

Some researchers who studied the pressure – tension theory, outlined conceptual flaws in this motion. They explained that the periodontal ligament is a continuous hydrostatic system whereby forces applied to the PDL will transmit an equal force to all the regions of the tooth.

This led to the 'bone bending theory' which was first suggested by Farrar in 1888 and later confirmed through rat studies by Baumrind and in human studies by Grimm et al. They hypothesised that when an orthodontic force is applied on a tooth. The forces are delivered to all the tissues near the application force. These forces bend bone, tooth and the solid structures within the PDL. They explained that bone was found to be more elastic and bends more readily when forces are applied to it. (Baumrind 1969; Grimm 1972).

This results in bone turnover and renewal of the cellular and inorganic fractions. Whilst the bone is placed in a deformed position, the bone turnover is said to be accelerated. The authors further stated that the re-organised bone not only occurs at the lamina dura of the alveolar bone, but also on the surface of the trabaculum of the alveolar bone. The forces that are applied to the tooth are dissipated to the bone leading to the formation of stress lines. This stimulus alters the biological response perpendicular to the created stress lines. This in turn, modifies the shape and organisation of the bone to counteract the exogenous forces acting on it. (Grimm 1972; Baumrind 1969).

2.6.3 'Piezo-electric Theory'

Although the bone bending theory had merit, it contradicted the view of orthopaedic principles which stated that 'any mechanical compression stimulates bone formation and tension stimulates resorption'. This led to the 'piezo-electric theory' which was proposed by Bassett and Becker 1962, they stated that when bone is bent due to the application of applied mechanical forces, the stressed tissue generates an electric potential. These

potentials may charge macromolecules that interact with specific sites on the cell membrane or mobilise the diffusion of ions across cell membranes.

These studies demonstrated that areas of electro- positivity favoured osteoblastic activity and areas of electro-negativity favoured osteoclastic activity. Davidovitch et al proposed that a relationship exists between mechanical and electric potential within the bone. The bending of bone therefore causes 2 classes of stress generated effects. They further experimented with exogenous supply of electric current in conjunction with orthodontic forces which showed enhanced cellular activity within the PDL and alveolar bone resulting in rapid tooth movements. Proffitt et al, 1999 described this theory as having 2 characteristics, firstly, the forces have a fast decay rate, meaning, the force is initiated when it is applied and equally disappears when the force is maintained. Secondly, they produce equal signals when the applied forces are released. (Proffit, Fields, and Sarver 2013; Pollack, Salzstein, and Pienkowski 1984; Davidovitch et al. 1980).

Whilst all four theories have merit, the 'pressure- tension theory' is the most accepted within orthodontic literature and is the most widely researched form of tooth movement.

2.7 Complications of Orthodontic treatment

2.7.1 Orthodontics and Pulp Necrosis

The effect of orthodontic treatment on the dental pulp has been an issue of interest to orthodontists for several decades as orthodontic forces causes changes to the periodontium and the pulp (Hamilton and Gutmann 1999; Javed et al. 2015). In fact, some researchers have even termed orthodontic movement 'controlled trauma' (Popp, Årtun, and Linge 1992) Several studies have evaluated the effect of orthodontic forces on the dental pulp, however, the reported results in current published literature are inconclusive and inconsistent and this is mostly down to the varying differences in study methods and methodological limitations (Leavitt et al. 2002). Some have shown short term effects due to alteration in pulpal tissue

respiration (Unsterseher et al. 1987; Nixon et al. 1993). Whilst some studies have shown long term consequences such as pulpal necrosis (Hamersky, Weimer, and Taintor 1980; Spector, Rothenhaus, and Herman 1974).

Rapid tooth movement has the potential to cause pulpal damage due to changes to the blood vessels in the apical periodontium. These changes may have a direct effect on the metabolic rate of the pulpal tissue, more so on the odontoblasts in fully formed teeth. There seems to be a suggestion that the greater the orthodontic force the greater the possible rate of pulpal damage. Certain orthodontic movements were also implicated with increased risk of pulpal damage such as labio-lingual expansion, tipping movements, bodily movements and intrusive forces.

When examining the correlation of apical size and pulpal respiration with regards to orthodontic movement, studies showed that teeth with open apices performed better than teeth with small and fully formed roots. Further studies have found that age and apical firmament size correlated with the return of normal respiratory rate. Age had a negative impact whilst apical foramen size had a positive impact on pulp respiratory rate (Hamilton and Gutmann 1999).

One systematic review looked at orthodontic forces and its effect on pulpal tissue within humans, the results demonstrated that orthodontic forces evoke a biological pulpal response. However, the included studies were of low quality with limited information with a lack of high quality evidence to conclusively determine the effect of orthodontic forces on the dental pulp as well as contradictory scientific results to support the notion that orthodontic forces reduce pulpal blood flow (von Böhl et al. 2012).

2.7.2 Orthodontics and pulp canal obliteration

If pulpal vasculature is altered due to orthodontic forces, this could lead to changes pulpal metabolism leading to pulp canal obliteration due to increased deposition of reparative

dentine in the coronal and radicular portions of the pulp. This incidental finding however, doesn't seem to be of clinical significance. (Delivanis and Sauer 1982).

2.7.3 Orthodontics and Root Resorption

One of the detrimental effects of orthodontic movement is a well-researched but still unknown phenomenon of orthodontic induced inflammatory root resorption (OIIRR). Its prevalence has been reported to be between 1.1% and 100% (Mayoral 1982). Despite the plethora of research into this topic, most publications have tried to understand the phenomenon of root resorption and have found it increasingly difficult to find solutions in its prevention. (Reitan 1970).

The subject of OIIRR has many related studies and review articles, to analyse the information with regards to this outcome, OIIRR can be sub grouped into its causes, which are two broad categories of:

1. Patient related factors

A. Genetic
B. Immunology
C. Systemic factors
D. Chronological age
E. Dental age
F. Gender
G. Presence of RR prior to orthodontic treatment
H. Habits
I. Trauma
J. Tooth structure and root formation
K. Individual tooth susceptibility

2. Treatment related factors

This can be split into two groups:

A. Orthodontic treatment related factors

a) Force magnitude

b) Duration of applied forces

c) Type of tooth movement

d) Treatment methods

B. Non- orthodontic related factors

a) Endodontically treated teeth

Genetic: Genetics may have an underlying cause for those who may or may not develop OIIRR. A study by Harris et al 1997, concluded that irrespective of the nature of the malocclusion, treatment plan, appliance used and the orthodontics techniques, some patients are resistant to apical resorption due to that individuals genotype, whilst other patients may be at susceptible to severe resorption (Harris, Kineret, and Tolley 1997)**.**

Orthodontic literature continues to debate the role of genetic markers as well as the different biological agents to their role in OIIRR. The evidence is not yet conclusive and future research may demystify their role in OIIRR. (Sameshima and Sinclair 2001) Studies examining familial connection confirmed strong familial connection between orthodontic treatment and OIIRR, if the patient undergoing orthodontic treatment has had a sibling who had orthodontic treatment, post treatment radiographs and signs of OIRR can give an indication of the patient's likelihood of developing OIIRR (Harris, Kineret, and Tolley 1997)**.** Sameshima and Sinclair reported that white and Hispanic patients are more vulnerable to OIIRR than Asian patients. (Sameshima and Sinclair 2001).

Immune system: The role of immunology with OIIRR is poorly researched compared to studies examining the effect of genetics on OIIRR. It was hypothesised in the past, that's

OIIRR may be associated with the immune response to dentine matrix proteins. However, this is inconclusive.(Al-Qawasmi et al. 2003).

Systematic factors: The patient's systemic factors and its interplay with OIIRR is focused on two main streams. One is the patients systematic state at the time of orthodontics, the other is the influence of external factors such as drugs, hormones, supplements and other therapeutic procedures including surgery. Allergy including asthma however, has been extensively researched within orthodontic literature and has been shown to be a risk factor for increased root resorption (Owman-Moll and Kurol 2000; Nishioka et al. 2006).

Chronologic Age: Studies that examined chronological age and root resorption found no significant correlation between the age of the patient and incidence of root resorption. (Ren et al. 2008; Jiang, McDonald, and Fu 2010).

Dental age: Consensus within orthodontic literature that there is a positive correlation between age and root resorption, moreover there is an advantage in orthodontically moving teeth with incomplete root formation in the prevention of shortened roots. Hendrix et al, showed that teeth with incomplete root formation prior to orthodontic movement continued to develop during orthodontic treatment, however, the roots tended not to reach their expected length potential. (Owman-Moll and Kurol 2000).

A second study by Mavragani et al, looked the orthodontic treatment of teeth with incomplete root formation, his study concluded that the roots continued to develop during orthodontic treatment and reached normal root lengths. The study also found that incompletely formed teeth reached a greater length than those who had fully formed prior orthodontic treatment. (Mavragani et al. 2002).

Gender: All studies into the association between sex and root resorption showed no difference in the incidence or severity between males and female subjects. (Sameshima and Sinclair 2001).

Presence of root resorption prior and during orthodontic treatment: There are studies showing a positive correlation between the severity of root resorption prior orthodontic treatment and after orthodontic treatment, this was shown by Jiang et al's work which evaluated panoramic radiographs of anterior teeth.(Jiang, McDonald, and Fu 2010).

Another study which confirmed these findings were the studies conducted by Artun et al, this study evaluated periapical radiographs of maxillary central and lateral incisors. It concluded that patients who showed signs of root resorption at the first 6 months of active orthodontic treatment were more likely to experience root resorption at the following 6 months of treatment. A further study also by Artun et al, showed that subjects who had root resorption at the end of their treatment was highly related to the root resorption seen at the first 6 and 12 months of treatment. (Artun et al. 2005).

Habits: Previously published literature on the effect of habits on root resorption and orthodontic treatment which examined finger sucking, tongue thrust, and nail biting showed statistical correlation between orthodontics and root resorption. (Odenrick and Brattstrom 1983)**.** However, newer studies have dispelled any association between habits and parafunction to root resorption prior or following orthodontic treatment. (Makedonas et al. 2012; Owman-Moll and Kurol 2000).

Tooth structure and root formation: The effect of orthodontic movement on teeth with varying root forms is still inconclusive within orthodontic literature. Mavragani et al looked at mild dental invagination, whilst Van Parys et al examined pipette shaped roots and Lund et al studied root length prior to orthodontic movements, all 3 studies did not show a positive correlation with root resorption.(Mavragani et al. 2002; Van Parys et al. 2012)**.**

Individual tooth susceptibility: All teeth are susceptible to root resorption by the inflammation created from orthodontic movement. Several studies however, indicate that some teeth are more prone to root resorption than others. A study that used panoramic radiographs to assess resorption pre- and post-treatment showed more resorption being reported on maxillary incisors and premolars. (Apajalahti and Peltola 2007).

Force Magnitude: Orthodontic tooth movements cannot occur without the application of forces on the teeth, this force is sometimes blamed for the cause of root resorption. Several research studies conducted in Sydney, Australia by Darendeliler using microcomputed tomography, scanning electron microscopes and laser microscopes to examine the effect of forces on root resorption found that the volume of resorption defects on particular areas of the roots in human premolars and rat's molars was directly correlated to the magnitude of force exerted on the teeth during intrusion, extrusion, rotational, tipping and bodily movements. These studies concluded that when extreme forces were applied on rat molar, root resorption increased but the amount of tooth movement decreased. (Darendeliler et al. 2004).

Duration of orthodontic forces: It has been shown in clinical and histological studies that the long-term exposure of roots to orthodontic forces may lead to greater root resorption, this may be due to prolonged periods of inflammation or changes in environment around the roots of the teeth and genetic expression in every individual. (Sameshima and Sinclair 2001).

Type of orthodontic movement: The most vulnerable tooth movement to teeth is intrusive forces. One study found that applying a continuous intrusive force of 100cN on human maxillary first premolars for 8 weeks produced four times more root resorption than a similar extrusive force. Other clinical studies found that orthodontic movements coupled with intrusive forces showed greater detriment to the root than non-intrusive forces. (Chiqueto, Martins, and Janson 2008; Han et al. 2005)**.**

Methods of treatment: There is evidence in orthodontic literature to suggest root resorption occurring in all forms and methods of treatment including removable appliances. When examining the effect of extraction versus non-extraction, the extraction groups had a significantly higher rate of severe root resorption than non-extraction groups. This may be due to the greater distance of root movement during orthodontic treatment. (Huang et al. 2010)**.**

Furthermore, super-elastic heat activated arch wire was found to significantly increase the risk of root resorption compared to conventional stainless-steel arch wire. During the levelling stage of orthodontic treatment Alzahawi 2014, with intermittent forces causing less resorption than continuous forces. (Alzahawi et al. 2014)**.**

However, Wieland et al, 2003 had an opposing view and explained that the type of wire used can influence OIRR. Stainless Steel produce a rapidly declining force when activated unlike NiTi wires which are super-elastic and deliver a constant force over a long period of time which resulted in a significantly greater resorptive damage. (Weiland 2003).

Endodontically treated teeth: Within current literature there is little evidence regarding the orthodontic treatment of endodontically treated teeth with most recommendations opinion rather than evidence based (Brezniak and Wasserstein 2002; Beck et al. 2013). Available studies have shown that root treated teeth can be moved in a similar fashion to vital teeth as long as they are not ankylosed (Spurrier et al. 1990; Mirabella and Artun 1995). Provided the periodontal ligament is healthy in the endodontically treated teeth, then normal forces can be applied to them as vital teeth (Spurrier et al. 1990).

With regards to root resorption, it has been reported that root treated teeth maybe more resistant to root resorption compared to vital teeth (Spurrier et al. 1990). Recent studies which examined periapical or panoramic radiographs have concluded that root treated teeth show no significant difference in the degree of root resorption compared to vital pulps.

(Llamas-Carreras et al. 2010). It has been suggested that this may be due to the hardness and density of dentine being greater and thus more resistant to the resorptive process (Brezniak and Wasserstein 1993). Another theory is the lack of neuropeptide release from pulpal tissue which results in an inflammatory process which contributes to the resorptive process (Bender, Byers, and Mori 1997).

2.8 Role of Orthodontics in Dental Trauma

The role of orthodontics with respects to dental trauma can be divided into two main domains, the role of orthodontics in the prevention of dental trauma and the role of orthodontics in the treatment management of dental trauma.

2.8.1 Prevention of dental trauma

The role of orthodontics within dental trauma has been intertwined for many decades. Since the mid- 1940's there has been a believed association between class 2 malocclusion and increased incidence of dental trauma. Studies within the years to follow have continually published literature that supports increased trauma in patients with increased overjet especially to the maxillary anterior teeth and inadequate lip coverage. Forsberg and Tedestam study reported predisposing factors that related to traumatic injuries to the permanent teeth. Their study showed that a class 2 division 1 angles relationship, a 4mm+ overjet, short upper lip, incompetent lips and mouth breathing were all factors that increased the susceptibility of dental trauma to the permanent dentition. (Forsberg and Tedestam 1993).

These results have also been supported by a retrospective study which examined the dental records of 1367 consecutive patients needing orthodontic treatment within a private practice setting. The study examine data relating to trauma to the permanent incisal teeth. The results of the study showed that 10% of patients had suffered dental trauma prior to orthodontic treatment and this was prevalent more so in the 11-15 year age group which

corresponds to the late mixed dentition stage of dental development. The maxillary central incisors were the most affected (79.6%) with uncomplicated enamel – dentin fractures (42.7%) and enamel fractures (33.8%) the most common type of trauma recorded. In addition, patients with inadequate lip coverage or increased overjet had a significantly higher risk of sustaining dental trauma, which corresponds to previously reported literature. (Bauss, Rohling, and Schwestka-Polly 2004).

On the basis of many years of research supporting the notion that increased overjet and inadequate lip coverage as a risk factors for increased trauma to the maxillary anterior teeth, it would be logical to either protect these teeth with the use of mouth guards or preventatively move the teeth with orthodontic appliances. (Forsberg and Tedestam 1993).

Two studies examined early orthodontic treatment to aide prevention of traumatic dental injuries to the maxillary anterior teeth. The perspective randomised clinical trials were carried out at the University of North Carolina and University of Florida respectively. Both studies had a patient pool with a mean age of 9 years and above with class 2 malocclusion and a minimum overjet of 5-7mm. These selected patients had a pre-study dental trauma prevalence of 29% and 25% respectively with an intra-study trauma prevalence of 23% and 28%. It was argued that some patients were more prone to trauma than the general population and clearly in both studies the participants were more susceptible to multiple trauma events. The studies concluded that given the cost, the duration of treatment and lack of definitive randomised clinical data, there appears little evidence to recommend routine orthodontic treatment for increased overjet in the prevention of dental trauma. (Koroluk, Tulloch, and Phillips 2003; Chen et al. 2011).

2.8.2 The implications of orthodontic treatment on traumatised teeth

Prior to the commencement of orthodontic treatment of traumatised teeth, a thorough treatment plan must be carried out which will involve the detailed evaluation and prognosis

of the injured tooth and the treatment of the malocclusion. This treatment plan involves the careful co-ordination of clinical and radiographic findings as well as any perceived complications that may surface as a by-product of the orthodontic movement of the traumatised teeth (Andreasen et al. 2007).

When analysing the literature on orthodontic treatment of traumatised teeth, which will be discussed in greater depth in chapter 3, the studies are sparse and comprise of anecdotal evidence and retrospective papers with small sample sizes involving a heterogeneous collection of dental injuries, meaning definitive conclusions are hard to draw. Moreover, very little is known about the effect of orthodontic movement on traumatised teeth due to the difficulties in conducting clinical trials in this field of dentistry especially on paediatric patients. This is reflected in literature by the lack of current evidence. Kindelan et al 2008, to date is the only published review which discusses dental trauma and its influence on orthodontic management. This published work is perceived by many orthodontists as the current best evidence within orthodontics. (Kindelan et al. 2008).

The void in literature was the main focal point in the formulation and undertaking of a systematic review to determine the effect of orthodontic treatment on traumatised teeth as well as examining orthodontists perception of orthodontic management of traumatised teeth through vignette surveys, in doing so gauging the specialists opinion on this topic and their current understanding and limitations in the orthodontic treatment planning of traumatic teeth.

Chapter Three: The effect of orthodontic treatment on traumatised teeth: A systematic review

3.1 Introduction

3.1.1 The effect of orthodontic treatment on traumatised teeth: The current literature

In the current orthodontic literature there is very little evidence underpinning the prognosis of orthodontically treated teeth with dental trauma. During orthodontic treatment of traumatised teeth, special care must be taken to avoid excessive forces and pressure on these teeth to reduce the risk of root resorption. An examination of the root anatomy is important as blunted, pipette shaped and bent apices are more likely to undergo root resorption. Furthermore, orthodontic movements into the labial or lingual cortical bone can cause excessive root resorption. In addition, it is important to avoid heavy orthodontic forces and prolonged duration and intensity of orthodontic forces, both are regarded as important factors in the development of root resorption (Mavragani et al. 2002; Makedonas et al. 2012).

3.1.2 Orthodontic treatment and pulp necrosis

A systematic review in which the authors not only examined the biological effect of orthodontic forces on the dental pulp but also included the effect of dental trauma on pulpal tissue as part of their inclusion criteria. Their review showed orthodontic forces temporarily reduce pulpal blood flow as well as altered the osteoblastic effect on the dental pulp without inducing pulpal necrosis. The study authors concluded that there was insufficient scientific evidence correlating the effect of orthodontic forces on pulpal tissue, however, a history of dental trauma maybe considered a risk factor for pulpal necrosis during orthodontic treatment (Javed et al. 2015).

3.1.3 Orthodontic treatment and pulp canal obliteration (PCO)

The effect of orthodontic forces and pulp canal obliteration is poorly addressed in literature. There is evidence to suggest that orthodontically treated teeth tend to show PCO many years after the treatment is completed. Popp et al 1992, radiographically evaluated and examined the volume of the pulp in orthodontically treated and untreated teeth and found a reduction in pulpal canal volume in both groups (Popp, Årtun, and Linge 1992).

However, Venkatesh et al 2014, examined the volumetric changes in the dental pulp after orthodontic treatment determined by cone beam computed tomography (CBCT) imaging, this study included 87 patients who were split into an experimental group and a control group. The experimental group included 48 patients who had orthodontic treatment for mild to moderate crowding of the anterior teeth. The control group of 38 patients did not have orthodontic treatment. The experimental group had a CBCT of the six maxillary anterior teeth at the start (T0) and completion of orthodontic treatment (T1) whereas the control group had CBCT of the upper maxillary teeth and 17-18 months thereafter to match the orthodontic treatment time of the experimental arm. The results showed a statistically significant difference in pulp volume in both groups but more so in the orthodontically treated group (Venkatesh, Ajmera, and Ganeshkar 2014).

3.1.4 Orthodontic treatment of traumatised teeth and root resorption

The effect of orthodontic forces on root resorption is well documented in orthodontic literature (Reitan 1970; Reitan ; Sameshima and Sinclair 2001; Jiang, McDonald, and Fu 2010). Furthermore, there are some studies that have explored the effect of orthodontic treatment on groups with traumatised teeth and whether this affects root resorption more so than the non-trauma groups, however, the research is limited in scope (Brin et al. 1991; Linge and Linge 1991).

Malmgren et al 1982, in a study based at the Eastman Institute in Stockholm, looked into the extent of root resorption before and after active orthodontic treatment on 27 paediatric patients with 55 traumatised teeth and 60 non traumatised teeth. The teeth at the time of injury were examined and diagnosed by paediatric specialists. The type of injuries recorded were crown fractures in 18 teeth and periodontal injuries in 37 teeth (concussion, subluxation or luxation injuries). The roots were radiographically assessed before and after orthodontic treatment. After active orthodontic treatment 49% of the traumatised teeth showed signs of irregular root form, 325 had minor root resorption, 15% moderate root resorption and 4% severe resorption. Teeth that had undergone luxation injuries were more prone to resorption but the difference between different injuries was no significant. Overall, the study showed that the extent of root resorption in traumatised vs non-traumatised teeth was the same (Malmgren et al. 1982).

Linge and Linge 1991, showed that traumatic teeth had 1.07mm root resorption in comparison to 0.64mm in uninjured teeth (Linge and Linge 1991). Furthermore, Brin et al 1991. Looked at the effect of traumatised teeth against orthodontic forces. Moderate root resorption was present in 27% on teeth with previous trauma in comparison to 7.8% in the orthodontic only group and 6.7% in the trauma only group without any orthodontic treatment (Brin et al. 1991).

It is common practice within orthodontics to evaluate the risk of root resorption after the initial 6 months of treatment. If there are signs of resorption, a 3 month break from treatment may prevent severe root resorption at treatment completion. The clinical sequel to severe root resorption is the major concern to trauma and orthodontic treatment. A study conducted by Levander and Malmgren 1988, showed that incisors with a total root length less than 9mm had increased mobility and shifted the resistance more coronally, thus forces will have a greater impact on a tooth with a shortened root length especially when the crown

to root ratio is less than 1:1. This finding coupled with the loss of alveolar bone with age implies that the stability of teeth with resorption will decrease with time. Therefore, teeth with resorption will need to monitor for their long-term prognosis over time especially in the case of severe root resorption on teeth with a root length of less than 9mm (Levander and Malmgren 1988).

3.1.5 Orthodontic treatment of fractured roots

With regards to root fractures, their orthodontic management depends on the type of healing and location of the fracture. Roots with a fracture site that has healed with calcific tissue (dentin and cementum) can be moved orthodontically without separation of the fragments as the fracture has been consolidated by a hard tissue callus. However, healing with connective tissue cannot be orthodontically moved as there is a risk of separation of the fragments of root, therefore, with this form of healing, orthodontic management is based on the location of the fracture. If the fracture is apical third, then the tooth has enough periodontal support to allow tooth movement. Teeth with a mid-root fracture are more hazardous to move as there is a risk of separation and further resorption of the coronal segment of the tooth (Zachrisson and Jacobsen 1975).

3.2 Current Guidelines

Kindelan and Day 2008 published a two-part paper in the Journal of Orthodontics which aimed to aide orthodontists in their decision making when treating teeth with varying degrees of dental trauma. This Kindelan and Day paper is regarded by many orthodontists as the ‘go to guide’ when trying to treatment plan and formulate a decision on traumatised teeth requiring orthodontic intervention. The paper stated, on page 68 of the Journal of Orthodontics:

'Unfortunately, most of the dental literature surrounding the subject of dental trauma and orthodontic treatment comprises anecdotal case reports and retrospective review articles incorporating small patient numbers' (Kindelan et al. 2008).

3.3 Why carry out a systematic review?

The Cochrane handbook for systematic reviews defines a systematic review as 'a collation of all empirical evidence that fits pre-specified eligibility criteria in order to answer a specific research question'(Cochrane Community 9 July 2017). It uses explicit, systematic methods that are selected with a view to minimising bias and providing reliable findings from which conclusions can be drawn and decisions made' (Antman et al. 1992).

Systematic reviews can help map out uncertainty within research to identify areas of weakness within literature or areas of medical practice that needs further investigation. Conversely, they can highlight areas of knowledge which we believe we know much about but in reality, have very little convincing evidence to support our beliefs. Therefore, the role of systematic reviews cannot be underestimated and are of crucial importance in evidence based dentistry especially the implementation of the knowledge generated from systematic reviews into current practice. In addition, systematic reviews are positioned at the top of the 'hierarchy of evidence' and follow a transparent, explicit and reproducible protocol enabling us to carefully examine the available published literature and guiding current evidence based practice (Uman 2011; Moher et al. 2015; Moher et al. 2009).

3.4 Systematic review question

This systematic review will look at the current literature to determine whether orthodontically treated traumatised teeth have an increased incidence of pulp necrosis, root resorption, (PCO) and root fractures.

3.5 Systematic review methodology

3.5.1 Information sources and searches

A systematic search of electronic databases was carried out with the help of an information specialist. The appropriate syntax for each database was used. Relevant keywords were used to search for relevant published literature. Searches were conducted in MEDLINE (OvidSP), EMBASE (OvidSP), Web of Science (Thompson Reuters), Cochrane Database of Systematic Reviews (Wiley) and the Cochrane Central Register of Controlled Trials (CENTRAL) from 1980 – 27th July 2017. The end of July 2017 was the cut-off point as the electronic searches were carried out on that date. The search was conducted from 1970 onwards as hand searches from the years previous to this did not have any papers of relevance to this study. A second updated search was also conducted from July 2017 – July 2019 that did not identify any new studies for inclusion within the systematic review.

The individual customised search strategies for each database are attached in *Chapter Five*: Conclusions and Future Research

5.1 Overall Conclusions

The aim of this study project was to examine the current literature surrounding the effect of orthodontic treatment on traumatised teeth and its endodontic implications. This was carried out by analysing the current literature through a carefully constructed question and pre-planned inclusion and exclusion criteria which answered this question through a systematic review. The results of which incentivised the utilisation and design of a web based vignette study to understand orthodontist's perspective of dental trauma and how this may affect their orthodontic management of these cases, by exploring their background, teaching experience, trauma experience and how they may tackle three vignette, true to life scenarios through open and close ended questions and analysing their written responses to formulate themes to gain a primary understanding of their experiences, limitations and difficulties with

such cases. The conclusions of the studies were discussed in-depth in both chapters 3 and 4 respectively, the main conclusions were as follows:

1. Literature regarding the effect of orthodontic treatment on traumatised teeth is scarce within current known literature with a lack of robust published scientific evidence.
2. A history of dental trauma maybe considered a risk factor for potential loss of vitality and pulp canal obliteration during or after orthodontic treatment.
3. The evidence surrounding the risk of root resorption from the accumulative sequalae of orthodontic treatment and dental trauma is inconclusive, however, there seems to be no greater risk of root resorption in both hard and periodontal tissue injuries.
4. Orthodontists should be aware of this risk and the pulpal condition of the traumatised teeth should be monitored frequently throughout the orthodontic treatment and retention period.
5. The lack of evidence based knowledge surrounding this subject matter has contributed to a lack of guidance within the orthodontic field in the treatment management of traumatised teeth within an orthodontic environment leading to ambiguity in treatment planning as well as:-

- Increased referrals to paediatric, orthodontic and endodontic specialists with a knock on effect leading to greater waiting times, greater patient and parent inconvenience, the need to travel greater distances for treatment provision at increased financial and time cost to parents and guardians, as well as, an increased demand for specialist services at a time of fiscal constraints within the NHS coupled.
- Confusion amongst orthodontists with regards to waiting times for various injuries prior to orthodontic treatment.
- Lack of trauma experience within their orthodontic specialist training and postgraduate orthodontic trauma refreshment CPD courses.

- Reliance on general dental practitioners in the trauma management and review of cases, who themselves may possibly feel uneasy and lack confidence, training and experience in dealing with trauma. Thus leading to trauma mismanagement, misdiagnosis and planning leading to reduced outcomes.
- From a public viewpoint, the above named factors may help government bodies, educational institutes, health authorities and commissioners to explore these deficiencies, given that the NHS financially provides funding for orthodontic provision to children of certain age groups and complexity within the UK. The high prevalence of dental trauma which, in many circumstances is linked to malocclusion, may prompt commissioners to evolve specialist training programmes, undergraduate dental programmes and postgraduate CPD programmes to improve teaching of dental trauma, as well as, preventative programmes that educate clinicians to spot patients which maybe more prevalent to trauma within a population base and thus reducing long term cost of care provision.

5.2 Clinical Implication

The systematic review and the qualitative study, raised the following points:

- Lack of literature and robust clinical guidelines

The systematic review as well as the literature review both shed light on the limited knowledge that surrounds the topic of orthodontics treatment and its interplay with trauma. The current evidence is made of literature reviews and opinion pieces which are backed by low grade evidence. This very evidence is outdated, whereby the orthodontic treatment carried out utilised outdated techniques which are now out of touch with modern orthodontic principles. Furthermore, the sample sizes in many of the studies were far too small to be able to get meaningful outcomes. All the studies examined are retrospective in

nature and the patients included in the studies had sustained a variety of dental traumas, which may have been inaccurately recorded with possible misdiagnosis and reliance of patient's recollection of their trauma, all these factors add great bias in the studies. In addition, within the same studies various orthodontic treatments, forces, durations and treatment modalities were adopted. These additional factors coupled with the uncertain trauma diagnosis creates multifactorial data, the outcome of which cannot be relied on in day to day clinical use.

The lack of current literature is reflected in the current guidelines which does not cover all pulpal complications, some notable examples is pulp canal obliteration and orthodontic treatment of immature apices with or without an apical plug. The monitoring times are based on trauma and perceived complications to the pulp and not the accumulative effect of trauma and orthodontic movement. This ambiguity in literature means that treatment plans are based on anecdotal or clinicians own experiences rather than evidence based approaches. This approach may leave clinicians and patients vulnerable to unknown clinical implications of treatment, as well as, changes in treatment plans and additional treatment for unexpected complications such as root canal treatment or tooth loss.

It is worth noting that the current guidelines are over 10 years ago and although this is outdated there is no emergence of new evidence to merit re-writing it. Much of the guidelines written are based according to the findings of Andreasen and his colleagues (Andreasen et al. 2007). This evidence did not examine the effect of orthodontic treatment on these traumatised teeth, therefore, the guidelines are based on weak evidence that doesn't factor orthodontic intervention, that said this is the best evidence at present and the original attempt to write these guidelines has to be applauded.

- Implication on clinicians and patient care

The study has highlighted inadequacies within current orthodontic specialist training. Many specialists as well as consultants lacked confidence, experience and training in dental trauma. This has a negative impact on patient clinical care on various levels. Looking at the current orthodontic specialist training curriculum, the training of orthodontists is under 'Module 31 – Orthodontics and Restorative dentistry'. Many orthodontists, I suspect, would have had insufficient training in trauma from undergraduate level and this lack of confidence, experience has continued throughout their clinical journey as general dental practitioners and throughout specialist training. The fall out effect of this could be specialist's lack of experience to diagnose various forms of dental trauma, may not have the diagnostic knowledge to treatment plan trauma cases through the correct use of sensibility testing and radiographic imaging and thus lack of overall management of traumatic dental injuries. The need for orthodontic management further adds to this lack of experience, meaning many specialists would rather refer these cases for a second opinion and in some cases not treat such cases at all.

These all have implications on patient care, namely, knowing when to treat versus how long to monitor the tooth/ teeth prior to any orthodontic movement, knowing how to consent patients who have had trauma and needing orthodontic care, knowing the complications their orthodontic treatment will have on the prognosis of the tooth. This lack of training translates into potential failure of orthodontic treatment or increased risk of complications, frustrated patients, lack of trust in orthodontic provision and the dental profession.

A notable trend in dentistry is the rise of orthodontic treatment in adult patients using 'Short term' orthodontic devices. The lack of orthodontic knowledge in this field may have a knock on effect on adult patients as well as GDPs confidence in orthodontists, who may ask for a second opinion or advice before carrying out similar treatment in primary care settings.

One measurement that can help reduce some of this confusion and ambiguity is to create dedicated trauma clinics for orthodontists within their specialist training. This can be in the form of shadowing or the treatment of cases seen in paediatrics or restorative clinics. A dedicated trauma clinic may give orthodontists greater first-hand experience with trauma, its diagnosis and treatment planning and dealing with complications that may result from this. This experience can be strengthened by studying dental trauma and the literature surrounding trauma in more depth and not only looking at its implications to orthodontic therapy but knowing the implications of trauma in general would give greater foundations going forward. This can all be integrated into a modernised curriculum for orthodontic specialist training which meets the demands of the patients of today. For qualified clinicians, CPD events updating orthodontists on trauma, its complications and implications to orthodontic provision may help reduce some of the anxiety surrounding this subject manner.

Another implication to patients, as seen in the studies, is a lack of dedicated trauma centres, this like many other services in the NHS are based on the postcode lottery. A lack of services means reliance on general practitioners and other specialists to manage dental trauma. These clinicians, like orthodontists may share a similar lack of confidence to deal with trauma and its sequalae. The rise of litigation within the dental industry has meant that many clinicians, with the lack of confidence, competence and training in dental trauma, alongside lack of local services, refer patients to consultants in secondary and tertiary care setting. This will overburden an already stretched, underfunded and understaffed NHS service. The outcome of which is longer waiting lists, disgruntled patients and parents and possibly detrimental effect on teeth which have had dental trauma, which could have been treated sooner with better or more predictable outcomes. Further to that, endodontists are not seen by many orthodontists as a first call of referral following trauma. Endodontists, are on the whole, the most well trained clinicians when dealing with pulpal disease and its complications, they need to be more involved in dental trauma and its treatment, either

through trauma clinics or 'Managing Clinical Networks (MCNs) set up by local NHS trusts. These networks will allow dentists, orthodontists and endodontists to liaise with one another and be able to follow up patients within primary care setting, thus reducing the stress on secondary and tertiary care, as well as, reducing waiting lists and allowing patients to see the right clinicians at the right stages of treatment.

5.3 Future research

In order to investigate the clinical significance of orthodontic therapy on traumatised teeth, further research is required to evaluate the true extent and effect of orthodontics, with it variability in treatment, on teeth with a history of dental trauma and the array of injuries and complications within a clinical setting, as well as, long term outcomes for the tooth and the individual it affects.

Current literature on the effect of orthodontic treatment on traumatised teeth is extremely limited. Most studies on this subject are record linked and retrospective in nature. Moreover, these studies are based on small sample sizes involving a wide presentation of dental trauma, on a wide spectrum of dental age groups and malocclusions. Furthermore, the orthodontic treatment varies across studies and usually carried out by one examiner in a private practice setting rather than a multicentre setting. This leads to possible misdiagnosis, mistreatment, subjectivity on differing views on the management of dental trauma within various settings and various countries and their help belief on the best way to manage and stabilise trauma as well as, the orthodontic treatment of the teeth in the future. All of this may result to a lack of definitive conclusions to be drawn. In addition, it is very difficult, if not impossible to conduct future studies involving dental trauma subjects due to the sensitive nature of the injury and age groups of paediatric patients, thus ethical approval within these parameters may never been granted and the cultivation of which is reflected in literature by the lack of current evidence based approach to this matter. Kindelan et al 2008, to date is the only

published review which discusses dental trauma and its influence on orthodontic management. This published work is perceived by many orthodontists as the best evidence within orthodontics (Kindelan et al. 2008).

Future research is required to study the effect of orthodontic treatment on traumatised teeth, one suggestion could come from the development of the 'Core Outcome Sets (COS)' for traumatic dental injuries in children and adults as set out by the International Association of Dental Traumatology (IADT)(Day 4 July 2014). The aim of the COS is to define what outcomes are collected, how they are measured and at what time intervals with patients who have suffered from dental trauma. COS will help collate data for evidence based comparisons of dental trauma treatment and interventions, which at present is challenging due to the diversity of outcomes reported in clinical studies based on a variety of different interventions and treatment modalities. Furthermore, many clinical studies favour the publications of interventions with a positive outcomes which adds bias in outcome reporting (Williamson et al. 2012; Sinha, Smyth, and Williamson 2011).

To address many of the current challenges in clinical traumatology research COS can be utilised to an agreed standardised collection of outcomes. This would allow researchers and clinicians to compare similar outcomes of various interventions over a larger population sample to compare effectiveness of interventions and promote changes in guidelines in the treatment of dental trauma and orthodontic treatment of traumatised teeth (Sinha, Smyth, and Williamson 2011; Williamson et al. 2012).

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The results of the searches were exported to an EndNote library (version X7) and de-duplicated.

3.5.2 Study selection

The PICO (Participants, Interventions, Comparators and Outcomes) headings describe the inclusion and exclusion criteria used to identify studies relevant to the review.

(P) Participants: patients aged 7 years and older with a history of dental trauma prior to orthodontic treatment or trauma during orthodontic treatment.

(I) Types of interventions: orthodontic treatment on teeth with a history of dental trauma.

(C) Comparators: in studies where there is a comparator

- patients aged 7 years and older with a history of dental trauma without orthodontic treatment.
- patients aged 7 years and older with no history of dental trauma or orthodontic treatment.
- patients aged 7 years and older undergoing orthodontic treatment without previous dental trauma.

(O) Outcome: risk of

- pulp non-vitality.
- pulp canal obliteration (PCO).
- root resorption.
- root fracture.

Exclusion criteria (**Error! Reference source not found.**)

- Animal studies.
- Letter to editor.
- Commentaries.
- Case reports.
- Teeth with anomalies in size, structure or shape.
- Orthodontic treatment of endodontically treated teeth.
- Non-English language publications.

Records identified by the search strategy were assessed for inclusion in two stages. First, two reviewer Ammar Al Hourani (AAH) and Afzal Haque (AH) independently screened all the titles and abstracts of the papers listed in the EndNote library. All publications considered to be potentially relevant to the review were obtained as full-text papers. The same reviewers then independently applied the inclusion and exclusion criteria set out above to the full-text papers.

3.5.3 Data extraction

Specific data were extracted from the studies meeting the inclusion criteria and recorded in tables. Data extracted included information relevant to:

I. **Study characteristics:** country of the study, when the study was conducted, where the study was conducted, study design, follow-up period and source of funding.

II. **Participants characteristics:** allocated treatment group, percentage of males, number of traumatised incisors, type of injuries, mean age at time of trauma (years), age at start of orthodontic treatment (years), mean age at end of orthodontic treatment (years), mean age at re-examination (years).

III. **Intervention and comparator characteristics**: intervention, comparators, orthodontic appliances, orthodontic forces (g), duration of intervention (months), total orthodontic treatment time (months), retention period (years).

IV. **Outcomes:** percentage of pulp necrosis, diagnosis of pulp necrosis, percentage of pulp necrosis in central versus lateral incisors, pulp necrosis and intervention period, percentage pulp obliteration, percentage root resorption, comparison of hard tissue and periodontal tissue injury and its resultant outcome on pulp vitality, pulp canal obliteration and root resorption as per the intervention and comparator groups.

V. **Definitions and measurement of outcomes:** definition of pulp necrosis, pulp obliteration, Malmgrens classification of root resorption. Measurement of outcomes of pulp necrosis, pulp obliteration (Jacobson and Kerekes classification).

VI. **Inclusion criteria:** inclusion criteria as stipulated in each study.

VII. **Authors conclusions:** summary of authors' findings.

Data extraction tables were designed and then piloted and refined using data from two of the included studies. Two reviewer (AAH and AH) then extracted information from all the studies that met the inclusion criteria. The review supervisors (AB and JG) independently checked the extracted data and any disagreements were resolved through discussion.

3.5.4 Quality assessment of individual studies

The methodological quality of the individual studies was assessed using the Newcastle – Ottawa Scale (NOS) (Wells et al. 2011). The NOS is a quality assessment tool designed for use with non-randomised control studies. It comprises eight numbered items from three categories linked to: selection of the study groups, the comparability of the groups and the outcome of the studies. One star is awarded per item except for 'comparability' which can be awarded up to two stars. In total, nine stars can be awarded per study. According to the

NOS scoring guidelines, stars are allocated if a study is deemed to have a low risk of bias (Wells GA 2012).

Quality assessment of the individual studies was carried out by two reviewer (AAH and AH) using the NOS templates for non-randomised studies provided by the Ottawa Hospitals website. The results were collated in a customised quality assessment checklist table which were initially piloted and then later refined. The quality assessment data were independently reviewed by the review supervisors (AB and JG) and disagreements were resolved through discussion.

3.5.5 Data synthesis

The results of the quality assessment exercise and data extraction are summarised in structured tables and are discussed narratively. Due to the heterogeneity of the data in the included studies, meta-analysis of the study results was not possible.

The process of study selection is shown in **Error! Reference source not found.**. A total of 5382 non-duplicated references were identified by the search strategy and were subsequently screened for inclusion in the systematic review. From the 5382 papers, 5353 studies were excluded as they did not evaluate the association of orthodontic tooth movements on teeth with dental trauma. The remaining 29 full-text papers were obtained to enable application of the inclusion/ exclusion criteria. A total of six publications met the inclusion criteria. 23 full-text papers were excluded for the following reasons: animal study (n=1), case reports (n=8), literature review (n=9) and research which did not examine the effect of orthodontic treatment on traumatised teeth (n=5). Abbreviations are summarised in Figure 3.2

Figure 3.1: Preferred Reporting Items in Systematic Reviews (PRISMA)

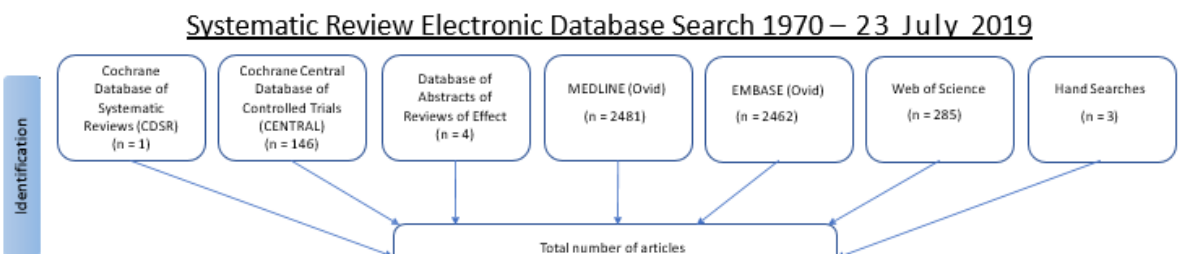

Figure 3. 2: Abbreviations

Abbreviation	Explanation
RCT	Root canal treatment
Enamel #	Enamel fracture
Enamel-dentine #	Enamel and dentine fracture
Tx	Treatment
Ortho	Orthodontics
OT/ TO	Orthodontic treatment on teeth with dental trauma
O	Orthodontic treatment on teeth with no history of dental trauma
T	Teeth with dental trauma
Tx	Treatment
TDI	Traumatic Dental Injuries
C	Control
IOPA	Intra-oral periapical radiograph
Class 2 Div 1	Class 2 division 1 incisal relationship
RR	Root resorption
PA	Periapical
PCO	Pulp canal obliteration
PO	Pulp obliteration

SS	Statistically Significant

Details of the studies that did not fulfil the inclusion criteria are presented in Appendix 6.

Of the included studies, six were published in peer reviewed journals (Brin et al. 1991; Malmgren et al. 1982; Bauss et al. 2008; Bauss et al. 2010; Bauss et al. 2008 (a); Bauss et al. 2009). All six studies were designed as retrospective cohort studies with the following comparison groups:

- Three studies had comparisons between orthodontic treatment of traumatised teeth (OT or TO), teeth with trauma and no orthodontic treatment (T) and an orthodontic treatment group with no history of trauma (O) (Bauss et al. 2010; Bauss et al. 2008 (a); Bauss et al. 2009).
- Two studies had comparisons between orthodontic treatment of traumatised teeth (OT/ TO) and a control group (C) (Bauss et al. 2008; Malmgren et al. 1982).
- One study had four comparison groups, an orthodontic treatment of traumatised teeth (OT) teeth with trauma and no orthodontic treatment (T), an orthodontic treatment group with no history of trauma (O) and a control group (C) (Brin et al. 1991).

The inclusion & exclusion criteria described in the six included studies are presented in Appendix 7.

The definitions & measurements of outcomes described in the six studies are shown in Appendix 8.

3.6.2 Quality assessment of included studies

The methodological quality of the included trials was assessed using the NOS checklist for non-randomised studies. All studies included in the systematic review were non-randomised studies. The results of the quality assessment exercise are presented in Table 3.1.

Overall, the methodological quality of five studies indicated a low risk of bias (Malmgren et al. 1982; Bauss et al. 2008; Bauss et al. 2010; Bauss et al. 2008 (a); Bauss et al. 2009). One study had medium risk of bias (Brin et al. 1991). All six studies had an intervention cohort which were 'representative of the population of interest; however, all six studies failed to describe the origin of the non-intervention cohort groups. The clinical details for all six studies were ascertained from secure dental records. It was clear from the descriptions presented in all six studies that the outcomes of interest were not present at the start of the study.

In terms of comparability of the cohorts described within the studies, five studies analysed their study control groups and were awarded two out of a possible two stars (Malmgren et al. 1982; Bauss et al. 2008; Bauss et al. 2010; Bauss et al. 2008 (a); Bauss et al. 2009). However, one study failed to describe its control groups and no stars were awarded for that study (Brin et al. 1991).

In relation to the assessment of outcomes, all six studies record-linked their results and had a medium duration of follow up of over 6 months. Furthermore, all six studies had complete follow up of cohorts and the authors were able to account for all participants at the end of the study.

Table 3. 1: Quality Assessment – Newcastle-Ottawa scale

Studies						
Quality assessment criteria	Bauss (a) 2008 (Bauss et al. 2008 (a))	Bauss (b) 2008 (Bauss et al. 2008)	Bauss 2009 (Bauss et al. 2009)	Bauss 2010 (Bauss et al. 2010)	Brin 1991 (Brin et al. 1991)	Malmgren 1982 (Malmgren et al. 1982)
Selection						
S1. Representativeness of intervention cohort?	*	*	*	*	*	*

S2. Selection of the non-intervention cohort?	-	-	-	-	-	-
S3. Ascertainment of intervention?	*	*	*	*	*	*
S4. Demonstration that outcome of interest was not present at start of study?	*	*	*	*	*	*
Comparability						
C1. Study controls for age/sex?	*	*	*	*	-	*
C2. Study controls for at least 3 additional risk factors?	*	*	*	*	*	*
Outcome						
O1. Assessment of outcome?	*	*	*	*	*	*
O2. Was follow long enough for outcome to occur?	*	*	*	*	*	*
O3. Adequacy of follow-up of cohorts?	*	*	*	*	*	*
Overall quality score (Maximum of 9 stars)	8	8	8	8	7	8

C (Control), Class 2 Div 1, (Class 2 division 1 incisal relationship), Enamel # (Enamel fracture), Enamel-dentine # (Enamel and dentine fracture), IOPA (Intra-oral periapical radiograph), O (Orthodontic treatment on teeth with no history of dental trauma), Ortho (Orthodontics), OT/ TO (Orthodontic treatment on teeth with dental trauma), Ortho tx (orthodontic treatment), PA (periapical), PO (Pulp obliteration), PCO (pulp canal obliteration), RCT (root canal treatment), RR (root resorption), SS (statistically significant), T (trauma without orthodontic treatment), Tx (treatment), TDI (traumatic dental injuries)

3.6.3 Characteristics of the included studies

The study characteristics are summarised in Table 3.2. The six included studies took place in three different European countries; four studies were carried out in Germany (Bauss et al. 2008; Bauss et al. 2010; Bauss et al. 2008 (a); Bauss et al. 2009) and published in the 2000s (2008, 2008, 2009, 2010 respectively), with one study in Sweden published in 1982 (Malmgren et al. 1982) and one study in Israel published in 1991 (Brin et al. 1991).

All six studies were retrospective studies and the investigators examined patient dental records. In three studies, the dental records were examined over a 14-year period (Bauss et al. 2008; Bauss et al. 2008 (a); Bauss et al. 2010), whilst in one study patient records were examined over 17 years (Bauss et al. 2009), in another study there was a 10-year follow-up period (Malmgren et al. 1982) and in one study, the authors did not report the duration of the intervention (Brin et al. 1991).

The setting in which the research took place also varied across the studies. Four studies were conducted in a private dental clinic (Bauss et al. 2008; Bauss et al. 2010; Bauss et al. 2008 (a); Bauss et al. 2009), whereas one study was conducted in several university departments (paediatric and orthodontic department) as well as in public and private practice (Brin et al. 1991). One study was conducted in a university setting only (Malmgren et al. 1982).

In five studies, the intervention and control groups were clinically followed up for a minimum of 9 months after treatment (which ranged from 9 months to 5.5 years) (Bauss et al. 2008; Bauss et al. 2010; Bauss et al. 2008 (a); Bauss et al. 2009; Brin et al. 1991). This enabled the researchers to examine the intervention (OT/ TO) and control groups (T, O, C) for a period after the completion of treatment or the effect of the trauma on the involved incisors. This follow up can help determine if pulp non-vitality, pulp obliteration and root resorption occurred during treatment or as a delayed complication in months or years after the

intervention. One study had no post-treatment follow up period recorded (Malmgren et al. 1982).

With regards to research funding, five studies did not state a source of research funding (Malmgren et al. 1982; Bauss et al. 2008; Bauss et al. 2010; Bauss et al. 2008 (a); Bauss et al. 2009); one study reported funding support from a university (Brin et al. 1991).

3.6.4 Participant characteristics

Participant characteristics are described **Error! Reference source not found.**.

The six included studies incorporated a total population of approximately 1897 treated patients with cohorts ranging from 26 to 200 patients involving 3659 maxillary permanent incisors (ranging from 54 to 800 maxillary incisors). Only maxillary incisors were included in the six studies. Three studies had an intervention with two comparative arms (Bauss et al. 2008 (a); Bauss et al. 2009; Bauss et al. 2010), whilst two studies had an intervention and one control group (Bauss et al. 2008; Malmgren et al. 1982) and one study had an intervention and three comparative groups (Brin et al. 1991).

Five of the included studies enrolled more male participants (> 55%) than females (Malmgren et al. 1982; Bauss et al. 2008; Bauss et al. 2010; Bauss et al. 2008 (a); Bauss et al. 2009), whilst one study did not record the male: female ratio of the participants (Brin et al. 1991). None of the studies reported the ethnicity of the participants. All six studies provided a breakdown of the number of incisors that had incurred hard tissue and periodontal tissue injuries. Four studies described their hard and periodontal tissue injuries using the following categories: enamel fracture, enamel-dentine fracture or uncomplicated crown fracture, subluxation, lateral luxation, extrusion luxation and intrusive luxation (Bauss et al. 2008; Bauss et al. 2010; Bauss et al. 2008 (a); Bauss et al. 2009). One study categorised tissue injuries as: injuries to crown only, injuries to attached apparatus and unknown injury (Brin et al. 1991). One study

categorised its injuries as uncomplicated crown fractures, complicated crown fractures, concussion, subluxation and luxation (Malmgren et al. 1982). None of the studies examined tooth avulsion or root fractures.

In five studies, injuries occurred after the mean age of 9 years old (range 9.3 to 12.7 years) (Bauss et al. 2008; Bauss et al. 2010; Bauss et al. 2008 (a); Bauss et al. 2009; Brin et al. 1991), in one study the age of trauma ranged from years 7 to 15 (Malmgren et al. 1982). Only one study reported the age of the patient at the start of treatment (Brin et al. 1991). Three studies reported the age of the patient after the completion of orthodontic treatment (Bauss et al. 2008; Bauss et al. 2010; Bauss et al. 2008 (a)). One study reported the time of the trauma during orthodontic treatment, this study split the time of the incident into two subcategories: orthodontic treatment time before trauma (the number of months during treatment before trauma took place, which averaged 13.9 months) and treatment time after trauma (average 12.7 months) (Bauss et al. 2009). Four studies included the mean age of patients at the time of trauma re-examination ranging from 12 to 14.8 years of age (Bauss et al. 2008; Bauss et al. 2010; Bauss et al. 2008 (a); Brin et al. 1991).

3.6.5 Inclusion and exclusion criteria

For the OT/ TO groups, four studies reported inclusion criteria (Bauss et al. 2008; Bauss et al. 2010; Bauss et al. 2008 (a); Bauss et al. 2009). The patients had to have the following criteria: (1) dental record with the classification of the dental trauma, (2) positive response to vitality testing of traumatised teeth prior orthodontic treatment to determine pulp vitality, (3) presence of pre-treatment and post retention periapical radiographs, (4) results of post retention sensitivity testing. The remaining two studies did not describe the inclusion criteria for the OT patients (Malmgren et al. 1982; Brin et al. 1991).

Trauma group (T group) was described in five out of the six studies (Brin et al. 1991; Bauss et al. 2008; Bauss et al. 2010; Bauss et al. 2008 (a); Bauss et al. 2009). In two of the studies, the

inclusion criteria for the traumatised group (T) was positive sensibility test after trauma, a minimum of 3 year follow up after trauma and no orthodontic intervention (Bauss et al. 2010; Bauss et al. 2008 (a)). In two studies, the previous criteria were used but added positive sensibility testing during the first 6 months after trauma (Bauss et al. 2008; Bauss et al. 2009). Two studies did not discuss the trauma group's inclusion criteria (Brin et al. 1991; Malmgren et al. 1982).

3.6.6 Intervention and comparators

The six studies included in the systematic review had different treatment regimens with respect to intervention and its comparator groups. With regards to the intervention groups (OT), in two studies, the OT group underwent intrusion forces using fixed orthodontic appliance therapy at 15g of force (Bauss et al. 2008; Bauss et al. 2008 (a)); in one study, extrusion forces were applied utilising fixed orthodontic appliances with 20g of force (Bauss et al. 2010). One study applied tipping forces in a palatal direction using removable appliances to correct an overjet with no stated force (Brin et al. 1991) and a further two studies did not state the orthodontic treatment, appliance therapy or forces used in the management of their OT group (Malmgren et al. 1982; Bauss et al. 2009).

When examining the comparator groups amongst the accepted studies, Three studies had two comparator (O) groups all of which used fixed orthodontic appliances (Bauss et al. 2008 (a); Bauss et al. 2009; Bauss et al. 2010), of which one study had a 15g force applied to the teeth (Bauss et al. 2008 (a)); one study had a 20g force (Bauss et al. 2010) and one study did not stage the force applied in its course of treatment (Bauss et al. 2009). In one study, the comparator group had removable appliances without any description of the forces used (Brin et al. 1991). Finally, two studies had one comparator arm which was a control group, this group examined traumatised teeth only without orthodontic intervention (Malmgren et al. 1982; Bauss et al. 2008).

All the interventions and comparators described in the six included studies are summarised in **Error! Reference source not found.**.

3.6.7 Outcomes

The outcomes reported in the six included studies are described in **Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**. In addition, outcomes for pulp necrosis and pulp canal obliteration are summarised in **Error! Reference source not found.**.

1. **Pulp necrosis**

Five out of the six studies examined the orthodontic movement of traumatised teeth and its effect on pulp necrosis (Brin et al. 1991; Bauss et al. 2008; Bauss et al. 2010; Bauss et al. 2008 (a); Bauss et al. 2009). In the same five studies, orthodontic forces were applied to achieve extrusion, intrusion and tipping movement of permanent maxillary central and lateral incisor teeth.

In four studies, how pulp necrosis was defined was identical (Bauss et al. 2008; Bauss et al. 2010; Bauss et al. 2008 (a); Bauss et al. 2009).

- Loss of sensitivity plus 1 other clinical or radiographic sign of:
- Grey discolouration of the crown
- Periapical radiolucency

Two studies did not examine pulp necrosis as part of their outcome (Brin et al. 1991; Malmgren et al. 1982).

Percentage of pulp necrosis (**Error! Reference source not found.**)

Across five studies, the percentage of pulp necrosis in the OT group ranged from 7.3% to 18.6%; these OT results were higher than the results in the O group (0.3% to 2%) and in the T group (1.6%) (Bauss et al. 2008; Bauss et al. 2010; Bauss et al. 2008 (a); Bauss et al. 2009;

Brin et al. 1991). Pulp necrosis in the OT group was statistically significantly higher when compared with the results in the O and T groups. However, there was no statistically significant difference in results between the O and T groups.

Central versus lateral incisors

Three out of the five studies compared pulp necrosis in the OT group between central and lateral incisors (Bauss et al. 2010; Bauss et al. 2008 (a); Bauss et al. 2009). One study showed a statistically significant difference with lateral incisors suffering more pulp necrosis than central incisors (Bauss et al. 2008 (a)). The remaining two studies showed no statistically significant difference between incisors (Bauss et al. 2009; Bauss et al. 2010).

Intervention period of orthodontic treatment

Two studies examined the intervention period in the OT group and its effect on pulpal necrosis (Bauss et al. 2008 (a); Bauss et al. 2010). In one study, there was no statistically significant correlation between intrusion period (≤5.7 month or >5.7 months) or duration of orthodontic treatment (≤22.4 months or >22.4 months) on pulp necrosis (Bauss et al. 2008 (a)). This was also true for the other study in which there was no statistically significant correlation between extrusion period (≤4.8 month or >4.8 months) or duration of orthodontic (≤23.8 months or >23.8 months) on pulpal necrosis (Bauss et al. 2010).

Outcomes for hard tissue versus periodontal ligament injuries are summarised **Error! Reference source not found.**.

2. **Pulp canal obliteration** (**Error! Reference source not found.**)

Two studies looked at the OT group and the correlation between pulp canal obliteration and pulp necrosis. Both studies showed teeth in the OT group with complete pulp canal obliteration had a statistically significantly higher rate of pulp necrosis than teeth with no pulp canal obliteration or partial pulp canal obliteration (Bauss et al. 2008; Bauss et al. 2009).

In addition, one of the studies found that completely pulp canal obliterated teeth in the O group had a statistically significant higher number of teeth with pulp necrosis in the intrusion phase of treatment (Bauss et al. 2008).

3. Outcomes for hard tissue versus periodontal ligament injuries

Outcomes for hard tissue versus periodontal ligament injuries are summarised in **Error! Reference source not found.**.

Three studies examined the type of dental injury sustained in the OT group and the effect on pulp non-vitality. All three studies reported that periodontal ligament injuries had a statistically significantly higher number of pulp necrosis observed in comparison to hard tissue injuries. Furthermore, all three studies stated that no statistically significant difference was observed between the OT group and the T group with respect to hard tissue injuries (Bauss et al. 2010; Bauss et al. 2008 (a); Bauss et al. 2009).

Furthermore, there was one study that examined root resorption in the context of hard vs periodontal ligament trauma, the study showed no statistically significant difference between hard tissue and periodontal ligament injury trauma (Malmgren et al. 1982).

4. Root resorption (**Error! Reference source not found.**)

Two studies investigated root resorption and used the Malmgren 1982 classification (Brin et al. 1991; Malmgren et al. 1982). In one study (Brin et al. 1991), the OT group showed 27.8% root resorption. This study found most root resorption (grade 1 and grade 2) in the OT group compared with the O group (7.8%) and the T group (6.7%); however, there was no correlation between root resorption, relapse or type of injury. That same study did however find a correlation between the presence of a periapical lesion and root resorption in the OT group (Brin et al. 1991).

In another study, there was no statistically significant difference in root resorption between hard tissue and periodontal ligament injury in the OT group (Malmgren et al. 1982). Furthermore, intra-individual comparisons in the OT group showed that 63% of the traumatised teeth and 55% of the non-traumatised teeth had a degree of root resorption, the difference in the degree of root resorption between both groups was not statistically significant (Malmgren et al. 1982). The same study also compared two forms of orthodontic appliances, the Beg and Edgewise appliances on the OT group and O group, results again showed that traumatised teeth with mild to moderate root resorption did not have a greater tendency to root resorb during orthodontic treatment in comparison to non-traumatised teeth (Malmgren et al. 1982).

5. Root fracture (**Error! Reference source not found.**)

None of the studies examined root fractures.

Author's conclusions

The author's conclusions provide a summary of the main findings in each of the six included studies and these are presented in **Error! Reference source not found.**.

3.7 Discussion

The aim of this systematic review was to examine whether orthodontically treated traumatised teeth (OT) have an increased incidence of pulp necrosis, pulp canal obliteration, root resorption and root fractures compared to traumatised teeth with no history of orthodontic treatment (T group) or orthodontically treated teeth with no history of previous dental trauma (O group).

Due to the wide variation in study designs and methodologies of the included studies, a single overall conclusion on effectiveness could not be drawn. Furthermore, due to the

heterogeneity of the study designs, the differences in the treatment modalities and the overlapping of patient groups across several of the studies, it was not possible to carry out a meta-analysis (Moher et al. 2015).

It is widely regarded that one of the most important elements of a thorough systematic review is the evaluation of the methodological quality of the primary research. Using the NOS, we considered that the overall methodological quality of the included studies was average (at risk of medium bias). There is no tool at present which can be considered the 'gold standard' tool for quality assessing observational studies. The NOS is a tool which is recommended by the Cochrane Collaboration, however, the Cochrane Collaboration has recently published the ROBIN 1 which may supersede the NOS tool (Sterne 2016).

The systematic review results indicate a consistent pattern of increased pulp necrosis in the OT group compared to the O and T groups; this pattern was more pronounced in periodontal ligament injuries than in hard tissue injuries. Furthermore, lateral incisors were more likely to suffer from pulp necrosis in comparison to central incisors. These findings were consistent amongst most of the included studies. Moreover, the majority of the studies showed no correlation between the intervention (intrusion or extrusion forces) and the duration of the orthodontic intervention period on pulp necrosis. This finding may be statistically insignificant in the studies but may be clinically significant in practice, the evidence remains inconclusive.

With regards to PCO, orthodontically treated traumatised teeth (OT) had a greater number of cases diagnosed with PCO compared to the orthodontic control group (O). Teeth with initial pulp canal obliteration and complete pulp canal obliteration had greater incidence of pulp necrosis during the intrusion period of orthodontic movement, this was the case in both the OT and O groups respectively. Furthermore, teeth with complete pulp canal obliteration

were more likely to become necrotic compared to initial and partial pulp canal obliterated teeth.

Root resorption was also examined in this systematic review. The incidence of root resorption was similar in both traumatised and non-traumatised teeth and the results were inconclusive between groups. Failure of root development was also examined in one of the studies, however, due to the low number of participants, clinically relevant findings could not be extrapolated. Appliance therapy and its effect on root resorption was analysed in one study, the results were not statistically significant, and the appliances used are not currently utilised within modern orthodontics management.

Root fractures was one of the outcomes examined in this systematic review, unfortunately none of the accepted studies examined this outcome and therefore no results can be reported.

In this systematic review, all six studies were retrospective cohort studies which reflects the state of the published scientific knowledge on this topic. The electronic searches were supplemented with hand searches which gave the researchers confidence that all relevant work on this subject matter was included in the systematic review. All conclusions drawn by the authors were derived from this pool of evidence.

Whilst the strengths and limitations of systematic reviews of randomised controlled trials are well established, less attention has been given to the systematic review methodology for epidemiological studies (cohort, cross-sectional and case-control studies) which may contain greater sources of bias due to the inherent weakness of the original studies contained within them. Low quality studies can lead to the distortion of the systematic review conclusion(Wells et al. 2011).

The retrospective design of the included studies may have been necessary due to difficulties in devising a research project in this field and obtaining ethical approval, especially in paediatric patients who are more prone to suffer from dental trauma. Retrospective studies have advantages and disadvantages. Their main advantage is they are inexpensive, less time consuming to carry out due to the use of existing patient records and can be viewed as a 'pilot' study in many ways, thus generating a hypothesis that can later be used in prospective studies (Suchmacher and Geller 2012).

Equally, the disadvantages of retrospective studies as attested by this systematic review is that the patient records and study design are not considered at the time of patient examination; in other words, the idea of the study was developed after the initial consultation, therefore, data could have been missed from the records, wrong diagnosis made, patients giving inaccurate histories, the patients examined by an inexperienced clinicians and sensibility testing misinterpreted. Furthermore, four studies were written by the same author with the same patient population and possibility treated by one clinician who conducted the patient examinations, record keeping, determining the diagnosis and treatment plans as well as monitoring the patients over the duration of the orthodontic treatment and intervention (Bauss et al. 2008; Bauss et al. 2010; Bauss et al. 2008 (a); Bauss et al. 2009).

There appears to be selection bias within all study groups. Selection bias means that study patients may not be representative of the patients who would usually be treated in day to day clinical practice, thus affecting the generalisability of the study results. Many of the studies may also have had misclassification bias as the phrase 'worst injury' was often used to classify the trauma the tooth had endured; this can affect the outcome of the studies and may over or underestimate the effect of a given injury to the outcome. Moreover, the

orthodontic treatment regimen, appliances and forces applied in the studies varied across the studies and could have affected the magnitude of the outcomes observed.

Future research is required to study the effect of orthodontic treatment on traumatised teeth, one suggestion could come from the development of the 'Core Outcome Sets (COS)' for traumatic dental injuries in children and adults as set out by the International Association of Dental Traumatology (IADT) (Day 4 July 2014). The aim of the COS is to define what outcomes are collected, how they are measured and at what time intervals with patients who have suffered from dental trauma. COS will help collate data for evidence based comparisons of dental trauma treatment and interventions, which at present is challenging due to the diversity of outcomes reported in clinical studies based on a variety of different interventions and treatment modalities. Furthermore, many clinical studies favour the publications of interventions with a positive outcomes which adds bias in outcome reporting (Williamson et al. 2012) (Sinha, Smyth, and Williamson 2011).

To address many of the current challenges in clinical traumatology research COS can be utilised to an agreed standardised collection of outcomes. This would allow researchers and clinicians to compare similar outcomes of various interventions over a larger population sample to compare effectiveness of interventions and promote changes in guidelines in the treatment of dental trauma and orthodontic treatment of traumatised teeth (Williamson et al. 2012; Sinha, Smyth, and Williamson 2011).

3.8 Conclusion

Overall, there is insufficient good quality, robust published scientific evidence regarding the effect of orthodontic treatment on traumatised teeth. A history of dental trauma may be considered a risk factor for loss of pulp vitality and increased pulp canal obliteration during orthodontic treatment. Orthodontists should be aware of this risk and the pulpal condition

of the traumatised teeth should be monitored frequently throughout the orthodontic treatment and retention period. More high-quality research evidence is required within this field of dentistry.

3.11 Acknowledgement

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Table 3.2: Study Characteristics

Study	Country	Date of study	Where was study conducted	Study design	Follow up period (range in years)	Funding
Bauss 2008 (a) (Bauss et al. 2008 (a))	Germany	1990-2004	Private practice	Retrospective cohort	**OT:** 3.2 years **O:** 3.4 years **T:** 5.5 years	Not stated
Bauss 2008 (b) (Bauss et al. 2008)	Germany	1990-2004	Private practice	Retrospective cohort	**OT:** No data **C:** No data	Not stated
Bauss 2009 (Bauss et al. 2009)	Germany	1990-2007	3 Private practices	Retrospective cohort	**OT:** 9 months (6-12 months) **O:** 2.1 years (0.5–4.2) **T:** 5.4 years (3.0–10.9)	Not stated
Bauss 2010 (Bauss et al. 2010)	Germany	1994-2008	3 Private practices	Retrospective cohort Analysis of patient files	**OT:** 2.1 years (1.0-3.6) **O:** 2.3 years (1.3–2.8) **T:** 5.5 years (3.1–9.5)	Not stated
Brin 1991 (Brin et al. 1991)	Israel	Not stated	**T group** Paediatric dept Hebrew-University. **O group**	Retrospective cohort Pt records, study models and radiographs	3 years for all cohorts	Funded by the joint research fund, Hebrew - University

			Orthodontic student department Hebrew-university **OT Group** 1. Orthodontic student department Hebrew-university 2. Public orthodontic clinics 3. Private practice			
Malmgren 1982 (Malmgren et al. 1982)	Sweden	Over 10-year period	University	Retrospective cohort Analysis of patient dental records	Not stated	Not stated

C (Control), Class 2 Div 1, (Class 2 division 1 incisal relationship), Enamel # (Enamel fracture), Enamel-dentine # (Enamel and dentine fracture), IOPA (Intra-oral periapical radiograph), O (Orthodontic treatment on teeth with no history of dental trauma), Ortho (Orthodontics), OT/ TO (Orthodontic treatment on teeth with dental trauma), Ortho tx (orthodontic treatment), PA (periapical), PO (Pulp obliteration), PCO (pulp canal obliteration), RCT (root canal treatment), RR (root resorption), SS (statistically significant), T (trauma without orthodontic treatment), Tx (treatment), TDI (traumatic dental injuries)

Table 3.3: Participant characteristics

Study	Groups	Males (%)	Traumatised incisors Central & Lateral Incisors	Type of injury as per number of teeth (n)	Mean age at time of trauma (range in years)	Age at start of orthodontic treatment (years)	Mean age at end of orthodontic treatment (range in years)	Mean age at re-examination (years)
Bauss 2008 (a) (Bauss et al. 2008 (a))	Intervention (OT) N=186	69.8%	269 Incisors Central (n=194) Lateral (n=75)	Enamel # (n=67) Enamel- Dentine # (n=84) Subluxation (n=31) Lateral luxation (n=30) Extrusive luxation (n=28) Intrusive luxation (n=29)	9.5 years (6.5–15.1)	Not stated	15.0 years (13.7–17.1)	Not stated
	Control (O) N=200	70%	800 Incisors	Not stated	Not stated	Not stated	14.9 years (13.5 – 17.3)	Not stated
	Control (T) N=173	64.7%	193 Incisors Central (n=146) Lateral (n=47)	Enamel # (n=36) Enamel- Dentine # (n=32) Subluxation (n=31) Lateral luxation (n=33) Extrusive luxation (n=30) Intrusive luxation (n=31)	9.3 years (6.6–16.4)	Not stated	No Intervention	14.7 years (12.5-27.3)

Bauss 2008 (b) (Bauss et al. 2008)	Intervention (OT) N=186	69.8%	269 Incisors	Uncomplicated crown fractures (n=151) Subluxation (n=31) Lateral luxation (n=30) Extrusive luxation (n=28) Intrusive luxation (n=29)	9.5 years (6.5 –15.1)	Not stated	15.0 years (13.7–17.1)	Not stated
	Control (T) N=173	64.7%	193 Incisors	Uncomplicated crown fractures (n=68) Subluxation (n=31) Lateral luxation (n=33) Extrusive luxation (n=30) Intrusive luxation (n=31)	9.3 years (6.6 – 16.4)	Not stated	Not stated	14.7 years
Bauss 2009 (Bauss et al. 2009)	Intervention (OT) N=46	60.8%	59 Incisors Central (n=43) Lateral (n=16)	Enamel # (n=13) Enamel-Dentine # (n=15) Subluxation (n=8) Lateral luxation (n=2) Extrusive luxation (n=9) Intrusive luxation	11.2 year (9.5–16.7) **Orthodontic treatment time before trauma** (Months) 13.9 months (7-24) **Orthodontic treatment time after trauma**	Not stated	Not stated	Not stated

				(n=12)	**(Months)** 12.7 months (6-24)			
	Control (O) N=200	70%	800 Incisors	Not stated	12.7 (9.7–17.5)	Not stated	Not stated	Not stated
	Control (T) N=173	64.7%	193 Incisors Central (n=146) Lateral (n=47)	Enamel # (n=36) Enamel- Dentine # (n=32) Subluxation (n=31) Lateral luxation (n=30) Extrusive luxation (n=33) Intrusive luxation (n=31)	9.3 years (6.6–16.4)	Not stated	Not stated	Not stated
Bauss 2010 (Bauss et al. 2010)	Intervention (OT) N=66	68.1%	77 Incisors Central (n=50) Lateral (n=27)	Enamel # (n=14) Enamel- Dentine # (n=18) Subluxation (n=14) Lateral luxation (n=9) Extrusive luxation (n=10) Intrusive luxation (n=12)	10 years (7.3–16.7)	Not stated	15.5 years (13.5–18.5)	Not stated
	Control (O) N=100	36%	400 Incisors	Not stated	Not stated	Not stated	15.9 years (13.5–19)	Not stated

	Control (T) N=173	64.7%	193 Incisors	Enamel # (n=36) Enamel- Dentine # (n=32) Subluxation (n=31) Lateral luxation (n=33) Extrusive luxation (n=30) Intrusive luxation (n=31)	9.3 years (6.6–16.4)	Not stated	Not stated	14.7 years
Brin 1991 (Brin et al. 1991)	Intervention (TO) N=28	Not stated	54 Incisors	Injuries to crown only (n=33) Injuries to attached apparatus (n=10) Unknown injury (n=11)	9.6 years (+/-1.6)	10.3 years (+/-2.6)	Not stated	14.8 years (+/-1.4)
	Control (O) N=29	Not stated	Not stated	Not stated	Not stated	11.3 years (+/-2.1)	Not stated	14.6years (+/-2.0)
	Control (T) N=56	Not stated	104 Incisors	Injuries to crown only (n=65) Injuries to attached apparatus (n=39)	9.1 years (+/-1.7)	Not stated	Not stated	12.0 years (+/-1.9)
	Control (C) N=26	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated	14.3 years (+/-2.1)

Malmgren 1982 (Malmgren et al. 1982)	Intervention (TO) N=27	55.5%	55 Incisors	Uncomplicated crown fracture (n=17) Complicated crown fracture (n=1) Concussion (n=17) Subluxation (n=19) Luxation (n=1)	7-15 years	Not stated	Not stated	Not stated
	Control (C) N=55	38%	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated

C (Control), Class 2 Div 1, (Class 2 division 1 incisal relationship), Enamel # (Enamel fracture), Enamel-dentine # (Enamel and dentine fracture), IOPA (Intra-oral periapical radiograph), O (Orthodontic treatment on teeth with no history of dental trauma), Ortho (Orthodontics), OT/ TO (Orthodontic treatment on teeth with dental trauma), Ortho tx (orthodontic treatment), PA (periapical), PO (Pulp obliteration), PCO (pulp canal obliteration), RCT (root canal treatment), RR (root resorption), SS (statistically significant), T (trauma without orthodontic treatment), Tx (treatment), TDI (traumatic dental injuries)

Table 3.4: Intervention and comparators

Study	Intervention	Comparison	Orthodontic appliance	Forces	Duration of intervention (range in months)	Total orthodontic treatment time (range in months)	Retention period (range in years)
Bauss 2008 (a) (Bauss et al. 2008 (a))	OT with Intrusion forces		Fixed appliance	15g	5.7 (4.6–7.2)	22.4 (10.9–30.4)	3.2 (2.8-3.6)
		O with no Intrusion forces	Fixed appliance	15g	6.2 (5.1-7.5)	23.7 11.6-31.7)	3.4 (2.0–4.0)
		T group	No intervention	No intervention	No intervention	No intervention	No intervention
Bauss 2008 (b) (Bauss et al. 2008)	OT with Intrusion forces		Fixed appliance	15g	5.7 (4.6-7.2)	22.4 (10.9-30.4)	3.2 (2.8-3.6)
		Traumatised teeth with no ortho tx (C)	No intervention	No intervention	No intervention	No intervention	No intervention
Bauss 2009 (Bauss et al. 2009)	OT		Fixed appliance	Not stated	Not stated	26.6	9 months
		O Group	Fixed appliance	Not stated	Not stated	23.7 (11.6-31.7)	2.1 (0.5-4.2)
		T group	No intervention	No intervention	No intervention	No intervention	No intervention
Bauss 2010 (Bauss et al. 2010)	OT with extrusion forces		Fixed appliance	20g	4.8 months (3.2-6.5)	23.8 months (11.7-31.2)	2.1 years (1.0-3.6)
		O Group	Fixed appliance	20g	5.2 months (3.4-7)	24 months (12.2-31.7)	2.3 years (1.3-2.8)
		T Group	No intervention	No intervention	No intervention	No intervention	No intervention

Brin 1991 (Brin et al. 1991)	OT with Incisor teeth tipping in palatal direction For overjet correction		Removable appliance	Not stated	Not stated	Not stated	Not stated
		O Group	Removable appliance	Not stated	Not stated	Not stated	Not stated
		T Group	No intervention	No intervention	No intervention	No intervention	No intervention
		C Group	No intervention	No intervention	No intervention	No intervention	No intervention
Malmgren 1982 (Malmgren et al. 1982)	O Group		Fixed appliance only (n=14) Fixed and removable appliance (n=10) Removable appliance only (n=3)	Not stated	Not stated	Less than 1 year (n=1) 1-2 years (n=16) Over 2 years (n=10)	Not stated
		C Group (uninjured teeth)	Extraction of all 4 first premolars Fixed appliances (n=55) of which: Edgewise appliance (n=33)	Not stated	Not stated	Edgewise 21 months (13-25) Begg 17 months (14-22)	Not stated

			Begg appliance (n=22)				

C (Control), Class 2 Div 1, (Class 2 division 1 incisal relationship), Enamel # (Enamel fracture), Enamel-dentine # (Enamel and dentine fracture), IOPA (Intra-oral periapical radiograph), O (Orthodontic treatment on teeth with no history of dental trauma), Ortho (Orthodontics), OT/ TO (Orthodontic treatment on teeth with dental trauma), Ortho tx (orthodontic treatment), PA (periapical), PO (Pulp obliteration), PCO (pulp canal obliteration), RCT (root canal treatment), RR (root resorption), SS (statistically significant), T (trauma without orthodontic treatment), Tx (treatment), TDI (traumatic dental injuries)

Table 3.5: Outcomes 1 – Pulp necrosis and Pulp canal obliteration

Study	% Pulp necrosis	Diagnosis of pulp necrosis	Pulp necrosis Central v lateral incisors	Pulp necrosis and intervention period	Pulp canal obliteration
Bauss 2008 (a) (Bauss et al. 2008 (a))	OT Group: 10.4% (n=28) OT Group significantly higher frequency of pulp necrosis than O Group (P <0.001) & T Group (P <0.001) No significant between the T and the O Groups	OT Group Pulp necrosis was diagnosed during intrusion (n=18, 64.3%). Of these, 14 were identified within the first 6 months of intrusion Diagnosis was made during ortho tx after intrusion (n=8) and during retention period (n=2)	SS difference between central & lateral incisors in OT Group. Pulp necrosis was observed in 7.2% (n=14) of the traumatised central incisors and in 18.7% (n=14) of lateral incisors (P =0.011)	OT Group No SS correlation between pulp necrosis & intrusion period (≤5.7 month or >5.7 months) or duration of ortho tx (≤22.4 months or >22.4 months)	Not stated
	O Group: 0.3% (n=2)	Diagnosed during ortho tx after intrusion (n=2)		Not stated	Not stated
	T Group 1.6% (n=3)	Not stated		Not stated	Not stated
Bauss 2008 (b) (Bauss et al. 2008)	OT Group 10.4% (n=28) SS difference between in pulp necrosis OT and C Groups (p<0.001) In O group with total pulp obliteration, incidence of pulp necrosis significantly higher during intrusion period	**Teeth without initial pulp obliteration,** pulp necrosis diagnosed in (n=5) during ortho intrusion with (n=5) pulp necrosis with ortho tx after intrusion. During intrusion (n=3) developed pulp necrosis At end of retention period, (n=2) diagnosed with pulp necrosis. **Teeth with total pulp obliteration** Pulp necrosis during intrusion period (n=10). During ortho tx	Not stated	Not stated	OT group pulp necrosis reported in: 4.9% in no pulp obliteration group (n=10) 14.7% in partial pulp obliteration group (n=5) 41.9% in total pulp obliteration group (n=13) Teeth with total PO had significantly higher rate of pulp necrosis than teeth without PO (p < 0.001) or only partial PO (p = 0.025). In the OT group, (n=4) teeth without signs of PO on the pre-

		after intrusion period (n=3). In O Group with PO, incidence of pulp necrosis significantly higher during the intrusion period as compared to later tx (p = 0.017)			treatment IOPA had partial PO at end of retention period
	C Group (Trauma) **1.6**% (n=3)	Not stated	Not stated	Not stated	Not stated
Bauss 2009 (Bauss et al. 2009)	**OT Group:** 18.6% (n=11) Teeth in OT-group had significantly higher frequency of pulp necrosis than teeth in O or T group (P < 0.001)	Severe periodontal injury were treated as one group (n=23). Pulp necrosis was found in 40.0% of central (n =8) and 33.3% of lateral incisors (n=1). Difference was not SS	Pulp necrosis was found in 40.0% of central & 33.3% of lateral incisors	Not stated	Severe periodontal injury: Absence of PO at final follow up was 43.5% of teeth with severe periodontal injury (n=10) Partial PO was seen in 21.7% (n =5). Total PO in 34.8% of the sample (n=8). Teeth with total PO had significantly higher pulp necrosis than teeth without PO (P =0.013)
	O 0.3% (n=2)	Not stated	Not stated	Not stated	Not stated
	T Group 1.6% (n=3)	Not stated	Not stated	Not stated	Not stated
Bauss 2010 (Bauss et al. 2010)	OT Group: 9.1% (n=7) Teeth in OT group had significantly higher pulp necrosis than teeth in O (P < 0.001) or T group (P < 0.009)	OT Group (n=5) diagnosed during ortho extrusion and (n=2) diagnosed during later ortho stages. No significant correlation found between pulp necrosis and extrusion period (≤4.8 or >4.8 months) or duration of ortho tx (≤23.8 or >23.8 months	No SS differences in OT group between central & lateral incisors. Pulp necrosis observed in 8.0% (n=4) of traumatised central incisors and 11.1% (n=3) of lateral incisors.	Stated and discussed earlier	Not stated

	O Group: 0.5% (n=2)	O group, (n=2) pulp necrosis diagnosed during active ortho tx after extrusion	Not stated	Not stated	Not stated
	T Group: 1.6% (n=3) No significant differences between T and O groups.	Not stated	Not stated	Not stated	Not stated
Brin 1991 (Brin et al. 1991)	OT Group: 7.3% (n=7) No correlation between PA lesion and ortho tx following trauma	Not stated	Not stated	Not stated	OT Group (n=4) cases
	O Group: 1.7% (n=2)	Not stated	Not stated	Not stated	Not stated
	T Group No pulp necrosis	Not stated	Not stated	Not stated	T Group (n=3)
Malmgren 1982 (Malmgren et al. 1982)	No observation	No observation	No observation	No observation	7 teeth had reduced lumen prior to treatment, after treatment: Unchanged (n=2), Grade 1 (n=1), Grade 2 (n=1), Grade 3 (n=1) **2 teeth had RCT prior to** treatment of grade 1 root contour After ortho tx: Unchanged (n=1), Grade 2 (n=1)

C (Control), Class 2 Div 1, (Class 2 division 1 incisal relationship), Enamel # (Enamel fracture), Enamel-dentine # (Enamel and dentine fracture), IOPA (Intra-oral periapical radiograph), O (Orthodontic treatment on teeth with no history of dental trauma), Ortho (Orthodontics), OT/ TO (Orthodontic treatment on teeth with dental trauma), Ortho tx (orthodontic treatment), PA (periapical), PO (Pulp obliteration), PCO (pulp canal obliteration), RCT (root canal treatment), RR (root resorption), SS (statistically significant), T (trauma without orthodontic treatment), Tx (treatment), TDI (traumatic dental injuries)

Table 3.6: Outcomes 2 – Hard tissue and periodontal tissue injuries

Study	Hard tissue injury	Periodontal tissue injury
Bauss 2008 (a) (Bauss et al. 2008 (a))	**OT group: pulp necrosis** Enamel fracture (1.5%, n=1) Enamel- dentine fracture (3.6%, n=3) No significant correlation between pulp necrosis in OT & O with enamel only fractures	**OT Group: pulp necrosis** Subluxation injury (9.7%, n=3) Lateral luxation (20%, n=6) Extrusion injury (21.4%, n=6) Intrusion injury (31%, n=9) 1. Teeth in the OT group with fracture of enamel-dentin (P = 0.002), subluxation (P <0.001), lateral luxation (P <0.001), extrusion (P <0.001), and intrusion injuries (P <0.001) showed a significantly higher rate of pulp necrosis than did the teeth in the O group 2. In the OT group, a significantly higher frequency of pulp necrosis was observed for teeth with lateral luxation (P = 0.047), extrusive luxation (P = 0.009), and intrusive luxation (P = 0.005) injuries. No significant differences were determined between the OT and the T groups for the remaining types of trauma **T Group: Pulp necrosis** Subluxation, lateral and intrusion injuries combined (n=3)
Bauss 2008 (b) (Bauss et al. 2008)	Not stated	Not stated
Bauss 2009 (Bauss et al. 2009)	**OT pulp necrosis** No pulp necrosis in enamel only fracture 6.7% in enamel- dentine # (n=1)	**OT pulp necrosis** 12.5% in subluxation (n=1) 36.4% in lateral or extrusive injury (n=4) 41.7% in teeth with intrusive injury (n=5) 1. Teeth with extrusive or lateral luxation (P = 0.031) and teeth with intrusive luxation (p=0.015) showed a significantly higher rate of pulp necrosis than teeth with fracture of enamel. 2. No significant differences were noted between the remaining types of trauma

Bauss 2010 (Bauss et al. 2010)	1. No cases of pulp necrosis were observed in teeth with fracture of enamel, fracture of enamel-dentin, or subluxation injury. 2. No significant differences were determined between the OT group and T groups with respect to hard tissue injuries	**OT group: pulp necrosis** 22.2% of the teeth after lateral luxation (n=2) 20.0% with extrusion injury (n=2) 25.0% after intrusion injury (n=3) 1. No cases of pulp necrosis were observed in teeth with fracture of enamel, fracture of enamel-dentin, or subluxation injury. 2. Teeth in the OT group with periodontal tissue injuries showed a significantly higher rate of pulp necrosis than teeth in the Orthodontics group ($P < 0.001$). 3. No significant differences were observed between teeth in the OT group with previous hard tissue injuries and teeth in the O group. 4. Significant differences were determined between teeth with periodontal tissue injuries in the OT group and the corresponding teeth in the T group ($P = 0.004$). 5. No significant differences were determined between the OT group and the Trauma groups with respect to hard tissue injuries **Trauma group**, the 3 cases of pulp necrosis occurred after previous subluxation and lateral and intrusive luxation injuries.
Brin 1991 (Brin et al. 1991)	Not stated	Not stated
Malmgren 1982 (Malmgren et al. 1982)	Root resorption (Grade 2-4) was seen in 39% of incisors with crown fracture.	1. RR (Grade 2-4) was seen in 57% of incisors with periodontal injury. 2. No significant difference between hard and periodontal injuries.

C (Control), Class 2 Div 1, (Class 2 division 1 incisal relationship), Enamel # (Enamel fracture), Enamel-dentine # (Enamel and dentine fracture), IOPA (Intra-oral periapical radiograph), O (Orthodontic treatment on teeth with no history of dental trauma), Ortho (Orthodontics), OT/ TO (Orthodontic treatment on teeth with dental trauma), Ortho tx (orthodontic treatment), PA (periapical), PO (Pulp obliteration), PCO (pulp canal obliteration), RCT (root canal treatment), RR (root resorption), SS (statistically significant), T (trauma without orthodontic treatment), Tx (treatment), TDI (traumatic dental injuries)

Table 3.7: Outcomes 3 – Root resorption.

Study	Percentage root resorption (%)	Root development	Grade of RR Malmgrens classifications	Root resorption after orthodontics	Root resorption with pulp obliteration	Orthodontic appliance	Root fracture (%)
Bauss 2008 (a) (Bauss et al. 2008 (a))	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated
Bauss 2008 (b) (Bauss et al. 2008)	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated
Bauss 2009 (Bauss et al. 2009)	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated
Bauss 2010 (Bauss et al. 2010)	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated
Brin 1991 (Brin et al. 1991)	OT group 27.8% (n=15) A correlation between PA lesion and root resorption in OT group	Root development stopped in two teeth (3.9%)	Not stated	Not stated	Not stated	Not stated	Not stated
	O group 6.7% (n=9)	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated
	T group 7.8% (n=7)	T group 5% (n=5) of roots stopped developing	Not stated	Not stated	Not stated	Not stated	Not stated

Malmgren 1982 (Malmgren et al. 1982)	**Intra-individual comparison (n=27, 46 teeth)** 63% of traumatised teeth and 55% of teeth not injured had: unchanged RR (n=20) > RR in traumatised teeth (n=13) < RR in traumatised teeth (n=13) Difference of RR between traumatised and control incisors no SS. Neither intra nor inter-individual comparisons showed that teeth with trauma had a greater RR than non-injured teeth.	Not stated	After ortho tx in the OT group 9% Grade 1 RR 32% Grade 2 RR 15% Grade 3 RR 4% Grade 4 RR	Unchanged (n=2) Grade 2 (n=4) Grade 3 (n=2) Grade 4 (n=1)	7 teeth had PO prior to ortho tx, however, after ortho tx: Unchanged (n=2) after tx Grade 1 RR (n=1) after tx Grade 2 RR (n=1) after tx Grade 3 RR (n=1) after tx **2 teeth had RCT prior to** treatment of Grade 1 root contour After ortho tx: unchanged (n=1), Grade2 (n=1)	**OT v O** In O group 72% had Grade 1 RR with Edgewise v 83% in Begg appliance. Grade 2 33% with Edgewise and 43% in Begg appliance Grade 3 with 10% Edgewise and 5% Begg TO 51%, with Edgewise 43% and Begg 48% had defined root resorption (Grade 2-4) The degree of RR between both methods was not statistically significant.	Not stated

C (Control), Class 2 Div 1, (Class 2 division 1 incisal relationship), Enamel # (Enamel fracture), Enamel-dentine # (Enamel and dentine fracture), IOPA (Intra-oral periapical radiograph), O (Orthodontic treatment on teeth with no history of dental trauma), Ortho (Orthodontics), OT/ TO (Orthodontic treatment on teeth with dental trauma), Ortho tx (orthodontic treatment), PA (periapical), PO (Pulp obliteration), PCO (pulp canal obliteration), RCT (root canal treatment), RR (root resorption), SS (statistically significant), T (trauma without orthodontic treatment), Tx (treatment), TDI (traumatic dental injuries)

Table 3.8: Authors conclusions

Study	Conclusion
Bauss 2008 (a) (Bauss et al. 2008 (a))	1. Previously traumatized maxillary incisors, and especially lateral incisors, with severe periodontal injuries have higher susceptibility to pulp necrosis during orthodontic intrusion than non-traumatized teeth. 2. Most cases of pulp necrosis occurred during orthodontic intrusion, particularly during the initial intrusion period. 3. Orthodontic intrusion of previously traumatized maxillary incisors with a utility archwire should be performed with lower intrusion forces than those used in this investigation, and pulpal vitality should be screened regularly until the end of the retention period
Bauss 2008 (b) (Bauss et al. 2008)	1. Orthodontic intrusion of previously traumatized teeth displaying total pulp obliteration seems to be very hazardous. 2. Even if orthodontic intrusion is avoided, late pulp necrosis cannot be ruled out during the progress of orthodontic treatment. 3. The amount of pulp obliteration might not be representative of the degree of trauma, it is not possible to draw any conclusions concerning the influence of the type of trauma 4. The orthodontist should be aware of this risk, and the treatment plan should be adapted accordingly.
Bauss 2009 (Bauss et al. 2009)	1. Teeth with severe periodontal injury during orthodontic therapy and subsequent total pulp obliteration have an increased risk of pulp necrosis during later orthodontic treatment stages. 2. The pulpal condition should be monitored frequently by intraoral radiographs after resumption of orthodontic treatment, and in cases of progressive pulp obliteration, orthodontic movement of these teeth should be terminated, or at least limited to a minimum
Bauss 2010 (Bauss et al. 2010)	1. Maxillary incisors with a history of trauma and severe periodontal tissue injuries have a higher susceptibility to pulp necrosis during orthodontic extrusion than do non-traumatized teeth. 2. Most cases of pulp necrosis occurred during the initial extrusion period, Therefore, orthodontic extrusion of maxillary incisors with a history of trauma should be performed with lower extrusion forces 3. Pulpal vitality should be screened regularly until the end of the retention period
Brin 1991 (Brin et al. 1991)	1. The study indicates, that complications are more prevalent following orthodontic treatment to traumatised teeth. This is even true when removable appliances are used to treat simple malocclusions. 2. The complications include root resorption, pulp non-vitality and pulp calcification 3. It is advised that traumatised as well as adjacent 'non-traumatised' teeth undergoing even limited orthodontic treatment, should be checked periodically for vitality and root resorption.
Malmgren 1982 (Malmgren	1. The conclusion drawn from this study is that teeth with slight or moderate trauma and an intact periodontal ligament after an

et al. 1982)	observational period of 4-5 months can be moved with a prognosis comparable to uninjured teeth.

C (Control), Class 2 Div 1, (Class 2 division 1 incisal relationship), Enamel # (Enamel fracture), Enamel-dentine # (Enamel and dentine fracture), IOPA (Intra-oral periapical radiograph), O (Orthodontic treatment on teeth with no history of dental trauma), Ortho (Orthodontics), OT/ TO (Orthodontic treatment on teeth with dental trauma), Ortho tx (orthodontic treatment), PA (periapical), PO (Pulp obliteration), PCO (pulp canal obliteration), RCT (root canal treatment), RR (root resorption), SS (statistically significant), T (trauma without orthodontic treatment), Tx (treatment), TDI (traumatic dental injuries)

Chapter 4: Do orthodontists consider endodontic complications in their orthodontic management of teeth with a history of dental trauma? A vignette Survey

4.1 Background

Decision making from a clinical prospective, is defined as choosing between alternatives. This process is undertaken on a daily basis to make a clinical judgement about a particular patient care and providing the patient with alternatives in the management of a particular issue. With experience clinicians find this process much easier and more manageable. Their decision-making process becomes more intricate as the clinician's knowledge and skill set improves over time and repetition especially in dealing with more complex issues and decisions (Adair et al. 1997). For clinicians to develop their decision-making skills autonomously, they need to acquire the right knowledge, the correct clinical training and the right experience in a supportive environment in order to gain the cognitive skills to manage complex clinical situations and make the right judgement call for their patient's wellbeing. (Trimble and Hamilton 2016).

Within orthodontic literature, there is a scarcity of orthodontic research looking into orthodontist's treatment planning of patients who have had a history of dental trauma. The current papers that have examined orthodontists knowledge and treatment management of patients with a history of dental trauma have tended to be traditional surveys with closed questions that 'examine' the orthodontists knowledge rather than allowing the orthodontist, through open answered survey format, to explore their reasoning behind their treatment planning options and understanding orthodontists opinion regarding their own experiences and limitations. (Sandler et al. 2019; Tondelli et al. 2010; Van Gorp et al. 2019).

This body of work will explore orthodontist's management of traumatised teeth and gain an understanding to their opinion and treatment planning strategies of several hypothetical cases based on vignette surveys. This will give us a greater and deeper understanding of their thought process and limitations of current provision of care.

4.1.1 Orthodontist's perception of dental trauma: current guidelines

Kindelan and Day, 2008 published a two-part paper in the Journal of Orthodontics which investigated this subject matter, is the best evidence currently available on this topic and is regarded by orthodontists in the United Kingdom as the go to protocol when faced with patients with an orthodontic need and have a history of trauma. With that in mind, timing of orthodontic treatment post trauma is an unresolved question. Kindelan et al suggested a 3 month monitoring period for minor injuries and 6-12 months for more severe injuries which is based on expert opinion. The paper also stated limitations within current literature surrounding the orthodontic treatment of traumatised teeth which comprises of anecdotal evidence, case reports and retrospective review articles which look into small cohort samples with a wide variety of dental traumas and diagnoses. (Kindelan et al. 2008).

The current literature breaks down the effect of orthodontic on traumatised teeth into two domains; the effect of orthodontic treatment on traumatised teeth during active movement and orthodontic treatment following dental trauma.

4.1.2 Trauma during orthodontic treatment & trauma after orthodontic treatment

Evidence from retrospective cohort studies have shown that teeth experiencing trauma during active orthodontic treatment have a significantly greater risk of developing pulp necrosis compared to teeth undergoing orthodontic treatment without a history of dental trauma or traumatised teeth without orthodontic intervention (Bauss et al. 2009). Moreover, teeth that have experienced extrusion, intrusion or lateral luxation injuries were significantly more likely to suffer from pulp necrosis than teeth experiencing trauma without orthodontic intervention. (Bauss et al. 2009).

In chapter 3, the systematic review investigated the effect of orthodontic treatment on traumatised teeth and the parameters of pulp necrosis, pulp canal obliteration, root resorption and root fracture. Six retrospective studies were included in the final analysis with a medium risk of bias based on the Newcastle-Ottawa scale. The study showed pulp necrosis ranged from 7.3%-18.6% in the OT group

(Orthodontic treatment of traumatised teeth group) this was higher than the O group (orthodontic treated teeth without previous trauma, 0.3-2%) and T group (traumatised teeth with no history of orthodontic treatment, 0-1.6%). Pulp necrosis in the OT group was statistically significantly higher than the O and T groups. However, there was no statistical significance between the O and T groups respectively. Moreover, there was no statistically significant correlation in the intervention period (intrusion and extrusion forces) and orthodontic duration on pulp necrosis in the OT group.

With regards to pulp canal obliteration, the systematic review revealed teeth in the OT group with complete pulp canal obliteration had a statistically significantly higher rate of pulp necrosis than teeth with no pulp canal obliteration or partial pulp canal obliteration.

When examining the outcome of hard tissue injuries versus periodontal ligament injuries and its effect on pulp necrosis in the OT group, the study showed that periodontal ligament injuries had a statistically significantly higher number of pulp necrosis observed in comparison to hard tissue injuries. Furthermore, there was no statistically significant difference observed between the OT group and the T group with respect to hard tissue injuries.

Root resorption was also analysed in the systematic review, the study showed no correlation between root resorption, relapse or type of injury. Moreover, there was no statistically significant difference in root resorption between hard tissue and periodontal ligament injury in the OT group, as well as, no statistically significant difference in the intra-individual comparison between traumatised and non-traumatised teeth and root resorption. Finally in terms of root fractures, the systematic review had no results as none of the studies investigated this outcome.

A prudent clinician would monitor these teeth at defined intervals clinically and radiographically depending on the extent of injury, tooth development and the stage of orthodontic treatment. At which point the clinician may elect to discontinue treatment, modify the existing treatment plan or finish treatment as planned.

4.1.3 Vignette based surveys

Vignette studies have been utilised in the field of social sciences for over 60 years and have over the years been adopted by other fields of scientific studies including anthropology, nursing, marketing, sociology, economics, psychology, education amongst other fields. Vignette studies have become increasingly popular due to the recognised limitations of questionnaire studies into the beliefs, attitudes and perceptions of its subjects. (Gould 1996; Wallander 2009; Alexander and Becker 1978; Veloski et al. 2005).

Vignettes can therefore be described as concise description of situation which is designed to replicate key features of a real-world event. Creating these controlled environment vignettes allows researchers to understand an individual's thoughts, behaviour and decision making in clinical settings which may not be possible to replicate or study in a true-to-life situation. Vignettes over the last few years have become popular in health care settings specifically in understanding clinician's decision making, quality of care and conforming to clinical guidelines, all of which are important markers for the provision of healthcare and government policy makers. (Veloski et al. 2005; Evans et al. 2015).

4.1.4 Characteristics of a Vignette survey

Vignettes scenario must be designed to simulate a real-world environment and an environment which mirrors the participant's day to day encounter, thus creating a 'construct validity'. When drawing conclusion on construct validity, it is important to recognise that Vignettes are intended to isolate and record key aspects of decision-making processes made by participants in the real word, the vignette is therefore not recreating but imitating real word environments. (Atzmüller and M. Steiner 2010; Veloski et al. 2005).

The vignette must prompt the participant into an effect which is hypothesised to exist in the real-world environment. This element creates the 'Internal Validity' of the vignette in which we predict the degree of change within a dependant variable and how accurately it is attributed to changes in the independent variable. (Atzmüller and M. Steiner 2010; Veloski et al. 2005).

The results of the vignette study should show generalised results in real world situations which maybe encountered by the participants or others in a similar background. This would define the external validity of the vignette. In vignettes, the generalised findings of participants behaviours is not there to be interpreted as that of their behaviour in real world environments but the results give indicators of their behaviour within the circumstances of the vignette in question. (Veloski et al. 2005; Evans et al. 2015).

4.1.5 Vignette based – surveys versus clinical vignettes

Vignette based survey over the years have been confused with clinical vignettes, the latter is a test of knowledge used in examination questions within medical and dental training. Vignette based surveys differ from clinical vignettes in 3 distinct ways:

Firstly, Vignette based surveys are most effective when open ended questions are utilised rather than multiple choice questions. The open-ended nature of the survey allows the clinician to express as personal response to each question thus ensuring that the survey gathers a full range of clinician experiences and variations. (Veloski et al. 2005; Evans et al. 2015).

Secondly, the vignette-based survey recreates a carefully constructed written history of realistic clinical scenario that explores the clinician's response when presented with this true-to-life situation. Therefore, the clinician responding to this scenario instructed to respond to the question as they would ordinarily in everyday practice and not what they know to be the correct answer according to clinical teaching or current guidelines and evidence-based literature. Therefore, the vignette survey is not looking to test the clinician on what they know but rather what the clinician would do and how they would react to a specific situation. (Veloski et al. 2005; Evans et al. 2015).

Thirdly, the vignette-based survey is trying to collate data and information about a group of clinicians rather than individuals. The clinicians must therefore by fully aware and convinced that their answers are not 'marked' or assumed to be correct or incorrect as they would in any other examination. This ensures that the data produced will be scientifically credible. (Veloski et al. 2005; Evans et al. 2015).

4.1.6 Vignette based surveys: Advantages and Disadvantages

Vignettes have a great advantage in that they can control the case mix of the scenario and therefore can isolate the clinician's decision making from other factors within the environments, such as low prevalence or high prevalence issues which are unique within a population or where outcomes can be difficult to conclude, are ambiguous or simply cannot be measured due to ethical considerations. Moreover, vignette-based surveys when compared to chart-based studies that investigate patient records or recruitment of patients is that they are cost effective and they do not intrude into the clinicians actual clinical setting with the turnaround time for the data collection much faster and can be completed by a number of clinicians simultaneously. Furthermore, their methodology is reliable, valid, cost efficient in studying clinical practice. (Veloski et al. 2005; Evans et al. 2015).

Vignette based surveys, like all forms of research methodology, have their limitations. Their greatest criticism is that a vignette is based on an artificial environment cannot replicate the behaviours of real-world events. It is therefore difficult to measure the response of hypothetical reaction versus a real-life behaviour. Moreover, the participant maybe subjugated to the 'Hawthorne effect' whereby the participant's behaviour changes when they are observed or a 'sentinel effect' where the participant's behaviour changes when they are perceived to be evaluated and try to give the 'correct' answer. In addition, vignettes have little value in assessing the variation in clinician's skill set or communication and dealing with actual real-life situations. (Veloski et al. 2005; Evans et al. 2015).

4.1.7 Vignette based surveys: design recommendations

When developing a vignette-based survey, three main issues must be addressed to create a survey which would make the clinicians more inclined to get involved with. Firstly, a successful vignette survey must be written without ambiguity with well-designed scenarios that mimic realistic situations with a distinctive data analysis strategy. (Veloski et al. 2005; Evans et al. 2015).

A covering letter is therefore essential and must unequivocally state that that survey is not a test of knowledge or competence. The covering letter must convince the clinicians to take part in the survey

and answer all the questions as if they are real so that's the clinicians respond to the situation with actual clinical behaviour and not what they perceive as being the correct answer. The clinician taking part in the survey should feel comfortable taking part in the survey especially when they realise the survey isn't a test and that the survey isn't looking at an individual's response but the response of a group of clinicians. Trust is therefore crucial between the clinician and the researchers conducting the survey, this trust must be reinforced in the instructions of the covering letter and the manner in which the results are kept confidential and anonymised throughout the study. Anonymising the survey sample however makes it difficult to follow up certain clinicians that may have more interesting answers or clinicians who failed to complete the whole survey. (Evans et al. 2015; Veloski et al. 2005). The design of the vignettes is very important and must be presented in a logical sequence as if the patient is being seen by the clinician with plenty of information to prevent any ambiguity which may mislead the clinician. The vignette must reduce any confusion within the hypothetical situation so that the clinician can concentrate on the problem at hand and express the desired response. Finally, the data must be analysed in the appropriate fashion as to not examine individual responses but patterns amongst a group of clinicians facing identical scenarios. (Veloski et al. 2005; Evans et al. 2015).

Table 1 Recommendations for vignette content.

Vignettes should
1. Derive from the literature and/or clinical experience
2. Be clear, well-written, and carefully edited
3. Not be longer than necessary (typically between 50 and 500 words)
4. Follow a narrative, story-like progression
5. Follow a similar structure and style for all vignettes in the study
6. Use present tense (past tense only for history and background information)
7. Avoid placing the participant ''in the vignette'' (e.g., as first- or third-person character)
8. Balance gender and age across vignettes*
9. Be as neutral as possible with respect to cultural and socio-economic factors*
10. Resemble real people, not a personification of a list of symptoms or behaviors
11. Be relatable, relevant, and plausible to participants
12. Avoid ''red herrings'', misleading details, and bizarre content
13. Highlight the key variables of interest, facilitating experimental effects
14. Facilitate participant engagement and thinking by including vague or ambiguous elements
15. Cover all pertinent variables (or omit selected variables for specific purposes)

Key references: (Ganong & Coleman, 2006; Gould, 1996; Hughes, 1998; Hughes & Hughes & Huby, 2001; Jenkins et al., 2010; Kim, 2012; Veloski et al., 2005; Wallander, 2009).

* Exceptions may apply if these factors are included among the experimental variables.

4.2 Research Aims & Objectives

Aim:

The aim of the study is to evaluate the perspective and decision making process of orthodontic specialists in the orthodontic management of traumatised teeth.

Objectives:

A. To gain an understanding of orthodontists experience of dental trauma within their working day to day environment and exposure to dental trauma management within their respective specialist training programme.
B. To gain an understanding of orthodontist's treatment planning of patients with dental trauma with the help of written clinical scenario.
C. To determine whether guidelines are available to aide orthodontic specialists in the treatment management of traumatised teeth.

4.3 Methodology

4.3.1 Study population

The study aimed at examining the orthodontist's perspective to dental trauma and how their decision making is influenced based on several fictitious scenarios within a vignette-based survey. In order to do this the study examined GDC registered orthodontic specialist practicing orthodontics within the UK. According to the GDC website there is 1375 orthodontists registered in the UK. The study aimed to recruit as many orthodontists as possible to take part in the study.

In order to recruit as many orthodontists as possible, the initial strategy was to contact the British Orthodontic Society (BOS) to allow the vignette survey to be sent via the BOS to its orthodontic specialist members. The vignette survey, covering letter and ethical approval was sent to the educational board of the BOS for approval. Unfortunately, the BOS replied that they had multiple studies being circulated through their society, after reviewing our proposal, they decided not to send

the survey to their members. Orthodontic update was then approached and due to GDPR they couldn't accommodate our request. The General Dental Council was also contacted and they also declined to help due to GDPR. Following that and due to time restraints, the author opted to recruit specialists directly from electronic forums and social media outlets.

Facebook was chosen as the platform in which the survey would be distributed online to select Facebook groups, both open and private group were contacted to reach out to as many specialist orthodontists within these forums. Furthermore, orthodontists within the dental hospital, orthodontic colleagues known by the researcher and by their colleagues were also contacted via emails with a link to the survey.

Prior to the distribution of the vignette based survey, the study was piloted internally and corrections made to make sure the survey was succinct and delivered to its intended purpose. We acknowledge within our study design the limitations that the web based surveys may have on generalisability of the results due to non-respondent (participant) bias, selection bias and coverage bias.

4.3.2 Inclusion & Exclusion Criteria

Inclusion	Exclusion
GDC registered orthodontic specialists	All other dental specialties
	General dental practitioner with special interest in orthodontics
	Orthodontic Specialist Trainees
	Orthodontists who participated in the pilot study
	Incomplete surveys

4.3.3 Vignette survey design

The implementation of a vignette survey involves several steps: (I) development of vignette study population (II), determining the number of vignettes, (III) construction of the vignettes scenarios, (IV)

sampling of the participants and collection of data (V) analysis of the vignette data with interpretation of the results. (Atzmüller and M. Steiner 2010).

From the onset of the study, the design of the survey had three arms: (I) Participant professional background, (II) Participant trauma experience and exposure, (III) Three vignette scenarios. These domains were constructed from several meetings between the researcher and lead supervisor which took place over 4 months and the development, correction and amendment of the vignette survey eight times. The final survey we believed served he purpose in answering the research aims of the research project. The vignette consisted of closed and open answer questions. The open answer questions were defined to the vignette scenarios in order to capture the participant's thoughts in greater depth.

The vignette survey was chosen as it is not regarded as a constructed reality but a method to isolate and measure key aspects of decision-making processes of a group of clinicians being examined. Furthermore, the decisions made from the clinicians in the vignette are not intended to be interpreted as a representation of a clinician's behaviour but as a strong predictor of their behaviour in the real-world setting. Moreover, there is evidence to suggest that participants in vignettes respond to hypothetical scenario's in a similarly to real world events, this is another reason why we adopted the vignette as the key study design. (Evans et al. 2015).

4.3.4 Covering letter

The covering letter was designed to inform the participants taking part in the study of the studies aims and objectives, as well as, displaying the current knowledge and limitations of the literature.

It was emphasised that the study had the University of Liverpool ethical approval and participants were reassured that the data collected is confidential and their data would be protected as per the university protocols. The covering letter outlined the names, roles and specialities of the researchers to gain trust between the participants and the research group.

The covering letter highlighted that the research project is part of a doctorate thesis that is being undertaken by the researcher at the University of Liverpool. As the participant population is orthodontic specialist, it was hoped that this would draw attention to the specialists and encourage them to complete the survey especially if some of the participants had been involved in research or academia within their career pathway.

The covering letter noted that the survey would take no more than 10-15 minutes. It was hoped that the transparency of the covering letter as well as the importance of participant's individual responses would encourage the recipients to take part in this research project and highlight its impact on the profession and future research studies. This is shown in Appendix 9.

4.3.5 Consent

Taking part in the study was voluntary and participants we given the choice to opt in or out of the study at the opening screen of the online survey.

4.3.6 Ethical approval

Ethical approval was sought from the ethics committee at the University of Liverpool (ID 3002) and approved on 08 March 2018. Shown on Appendix 10.

4.3.7 Piloting

The vignette study was piloted by three orthodontic specialists who work within the orthodontic department at Liverpool University Dental Hospital and one orthodontist who worked in an NHS orthodontic practice.

The pilot study was a trial run of the vignette study before its online distribution. It allows the researcher to examine the participants response to the survey, whether they can answer all the questions, iron out any technical issues within the software and correct any issues that maybe encountered by the participants (van Teijlingen and Hundley 2002).

Written and verbal feedback about the survey were taken on board and the following amendments were corrected:

- Some questions had grammatical or spelling errors that confused the participant and needed amendments.
- Some vignette studies needed to be corrected to create a clearer picture of the injury sustained, the age of the child correlates with the stage of tooth development, as well as, the correct terminology for orthodontic diagnosis and clinical presentation.
- Some questions did not allow more than one answer to be chosen, this needed to be corrected
- Some questions did not state how many answers the participants were allowed to give. This was confusing and needed amendments.
- Look at the time it takes to complete the survey. The participants were happy with the length to complete the survey.

4.3.8 Data collection

This vignette study utilised the web based survey method specifically employing social media (Facebook) as the platform to connect with the orthodontic specialists. The use of social media especially Facebook has been seen as a relatively new methods of sampling participants, however to date this form of surveying is relatively new which is also reflected in literature (Yetter and Capaccioli 2010). The built in matrix and ease of user interaction of Facebook makes it an attractive proposition for future researchers including the health care sector. Facebook with its 500 million users has been increasing used as a recruitment tool for researchers due to its popularity, low cost of use, efficiency and anonymity, moreover, Facebook was one way to recruit participants in hard to reach populations. (Yetter and Capaccioli 2010; Basa-Martinez, Cabrera, and Dionaldo 2018).

The web based survey was constructed using 'Select Survey' software by ClassApps provided by the IT department at the University of Liverpool. This online software can be customised to have a cover page as well as up to 21 different question types that can be answered by a single or multiple users.

The software can help analyse data and present results in graphs or tables, furthermore, the malleable design of the software allows the data to be exported to SPSS (Statistic Package for Social Science, IBM) or to Microsoft Excel spreadsheets for further analysis. Once the survey had been designed, piloted and amendments made it was trialled several times to make sure it is working sufficiently. Once the survey was approved by the research supervisors, a unique email link was generated and placed on various Facebook groups which allowed participant's direct access to the web based survey. Using 'Select Survey' allowed the researchers to keep count on how many participants completed the survey throughout its duration of recruitment. The survey was run over four months from May-Sept 2018. Recruitment of participants was repeated twice per month to target as many participants as possible to the survey. Copy of the full vignette survey is shown in Appendix 11.

4.3.9 Vignette analysis

Qualitative approach

The vignettes were analysed using thematic analysis. This analytical technique is defined as a method for identifying and reporting patterns that emerge from within qualitative data (Braun and Clarke 2006; Braun and Clarke 2013). Thematic analysis is seen as a cornerstone for the analysis of qualitative data.

Themes capture important concepts and topics which emerge from the open ended data in relation to the research question. In essence the themes categorise values which continually re-emerge from the raw data. (Patton 1999; Knafl 1991; Braun and Clarke 2013). Within this study 'Inductive Contents Analysis' will be utilised (Boyatzis 1998) . Inductive contents analysis allows the researcher to examine the raw data from the research findings and from it decipher frequent, dominant and significant themes within the text without the restraints from traditional forms of qualitative data analysis, moreover, the themes identified are strongly linked to the data rather than conforming the data to the researchers preconceptions (Thomas 2006; Patton 1999).

The original research results were printed and read multiple times highlighting emerging themes within the raw data. Different themes will be highlighted with different coloured pens. The raw data collated from the 'survey select' software was uploaded as a Microsoft excel sheet and the data cleaned and reorganised by removing participants who didn't complete the data, as well as, assign anonymised ID for each response based on their grade as an orthodontist. Consultants were assigned the ID for 'C', specialists 'S' and Post CCST 'CCST'. The data was then uploaded onto NVIVO 12 to allow further analysis of the data and to modify the themes and subthemes. Moreover, the software will help the researcher in analysing the data as a mind map and examine correlation between themes.

Themes were constructed primarily by examining the open ended questions and assigning them with a theme. The answers to the question from each participant was then read several times by the author to become familiar with recurrently emerging themes and subthemes within the transcripts. On NVIVO 12 the themes are named 'Nodes' and within those nodes 'Sub-nodes' were created which are the subthemes. This iterative process of back and forth reading of all the transcripts for every question created 5 main themes with many overlapping subthemes which will be showcased in the results section.

Quantitative analysis

Section 1 and section 2 of the survey described the professional background of the participants as well as their trauma experience. The survey select software processed the data into percentages of all the participants that took part in the completion of the survey. The results for this section were examined with descriptive analysis only.

4.4 Results

4.4.1 Professional Background

After 4 months of data collections via an online survey approach, 130 participants took part in the survey. However, only 82 of the participants completed the survey. 6 participants were undertaking

specialist training and therefore did not fulfil the inclusion criteria and were excluded from the study. In total 76 participants full filled the inclusion criteria and their responses were analysed.

The included participants make up 5% of orthodontic specialists registered on the GDC register. The participants (n=76) were 55% male and 45% female. From which 48% (n= 36) were consultant in orthodontics, 44% (n=34) were orthodontic specialists and 8% (n=6) Post CCST trainees in orthodontics.

Post CCST trainees are orthodontists who have completed 3 years of specialist training and undergo a further 2 years of training leading to eligibility in becoming a consultant in orthodontics within the NHS.

The primary place of work varied, 39% (n=30) worked within a dental teaching hospital, with a similar number 37% (n=28) working in district general hospital and 32% (n=24) working in an NHS specialist practice. A further 21% (n=16) worked in a private specialist practice and 16% (n=12) working in a mixed practice. Under half of the respondents worked in England (45%, n=34) with the rest of the respondents practicing in Scotland (34%, n=26), Northern Ireland (12%, n=9) and Wales (9%, n=7) respectively.

With regards to the number of years qualified as specialist orthodontists, the results were somewhat comparable. There was an equal number of respondents who have worked as orthodontists between 0-5 years and 6-10 years (28%). 22% of respondent have worked as orthodontists for 11-20 years, 20% for 21-30 years. Two orthodontists have been specialists for over 30 years.

4.4.2 Teaching Experience

The majority of orthodontists sampled (58%, n=44) in this survey participated in teaching. On a closer inspection of the 44 participants who took part in some form of teaching, 68% (n=32) are consultant with 6 specialists (16%) and 6 Post CCSTs (16%). All post CCSTs contributed to teaching as this is stipulated as part of their further education.

When examining the grade of dentists/ therapists the participants trained it was clear that the consultants are heavily involved in post graduate teaching (93.7%, n=30), post CCTSs (81.3%, n=26) and orthodontic therapists (59.3%, n=19), whereas specialist orthodontists (n=29) had no input in any StR or post CCST training. Only 7 orthodontist specialists took part in teaching, the majority taught orthodontic therapists (67%, n=4) and undergraduate students (50%, n=3).

4.4.3 Trauma Experience

A. Within your Orthodontic Specialist Training programme, do you feel you gained sufficient experience in the management of dental trauma?

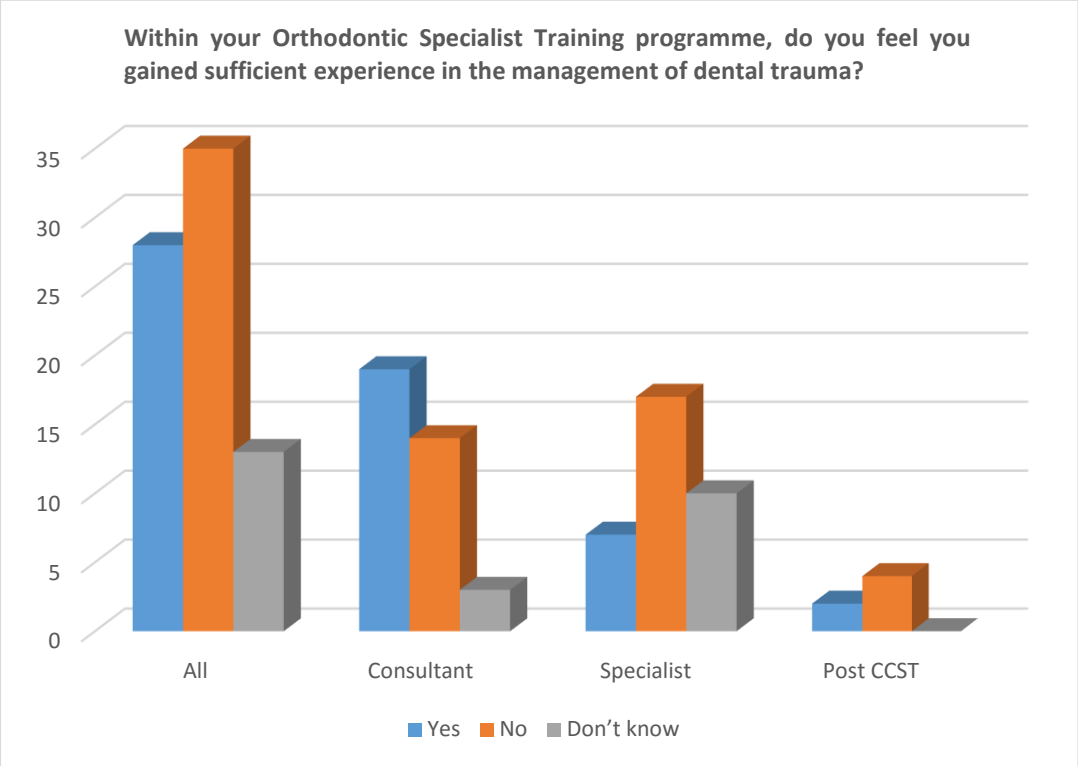
The orthodontists were asked about their trauma experience during their orthodontic specialist training years. Over half of consultants felt they had sufficient experience to dental trauma throughout their training (53%, n=19), compared to specialist orthodontists (21%, n= 7) and post CCST trainees (33%, n=2).

Half of the orthodontic specialist (50%, n=17) and two-thirds of post CCSTs (67%, n=4) felt they had gained insufficient trauma experience throughout their years in specialist training. This compares less to the consultants surveyed (39%, n=14). Almost a third of specialists (29%, n=10) 'did not remember' if they had trauma experience compared to post CCSTs (0%) and consultant orthodontists (8% n=3) respectively.

Post CCST training

The majority of respondent's did not undergo Post CCST training (78%, n=59). Of those who did 14% (n=11) felt they had sufficient training in dental trauma compared to 8% (n=6) who felt the opposite way. This is shown in **Error! Reference source not found.**.

Figure 4. 1: Within your Orthodontic Specialist Training programme, do you feel you gained sufficient experience in the management of dental trauma?



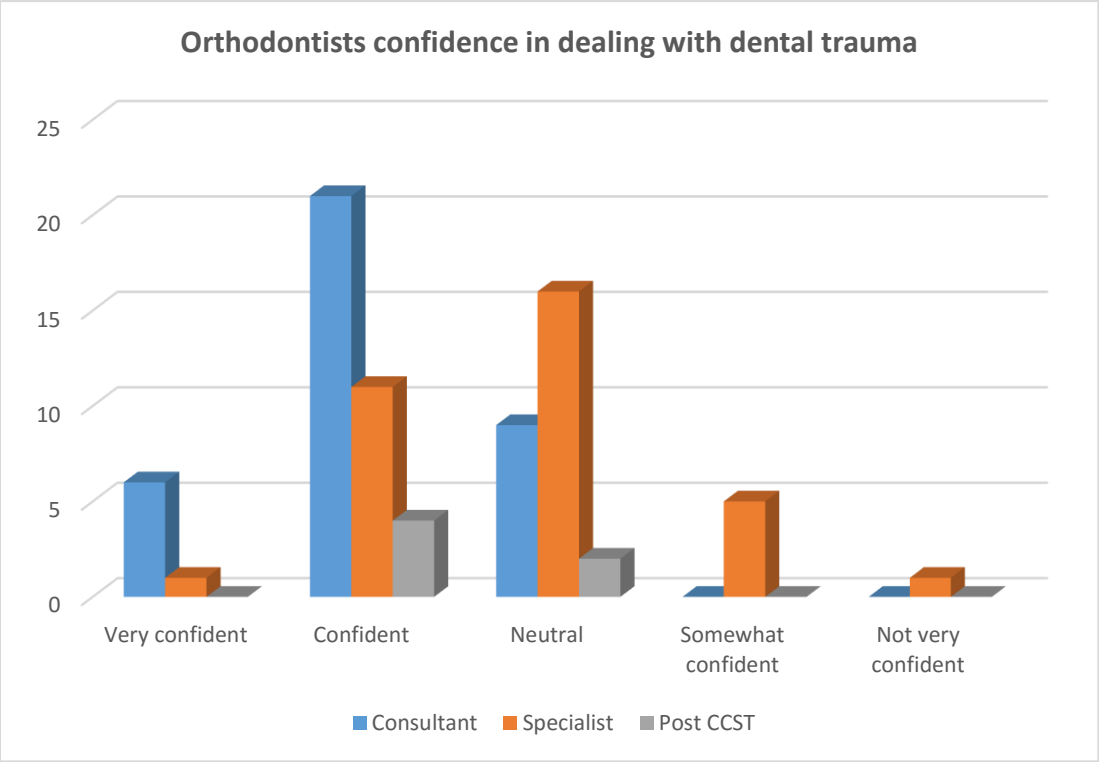
Orthodontist's confidence in dealing with dental trauma

Examination of the results shows that consultants were confident or very confident in dealing with trauma (75%) compared to specialists (35%). Post CCSTs had the most confidence in dealing with dental trauma (83%). Furthermore, 20% of specialists were not confident to deal with dental trauma in comparison to consultant and Post CCSTs. Shown in **Error! Reference source not found.** and Table 4.1.

Table 4.1: Orthodontist's confidence in dealing with dental trauma

	Very confident	Confident	Neutral	Somewhat confident	Not very confident
Consultant (n=36)	6 (17%)	21 (58%)	9 (25%)	0	0
Specialist (n=34)	1 (3%)	11 (33%)	15 (44%)	6 (17%)	1 (3%)
Post CCST (n=6)	0	5 (83%)	1 (17%)	0	0

Figure 4. 2: Orthodontists confidence in dealing with dental trauma



B. **Within a 12-month calendar, how often do you examine or treat patients with an acute and/or recent trauma in the permanent dentition?**

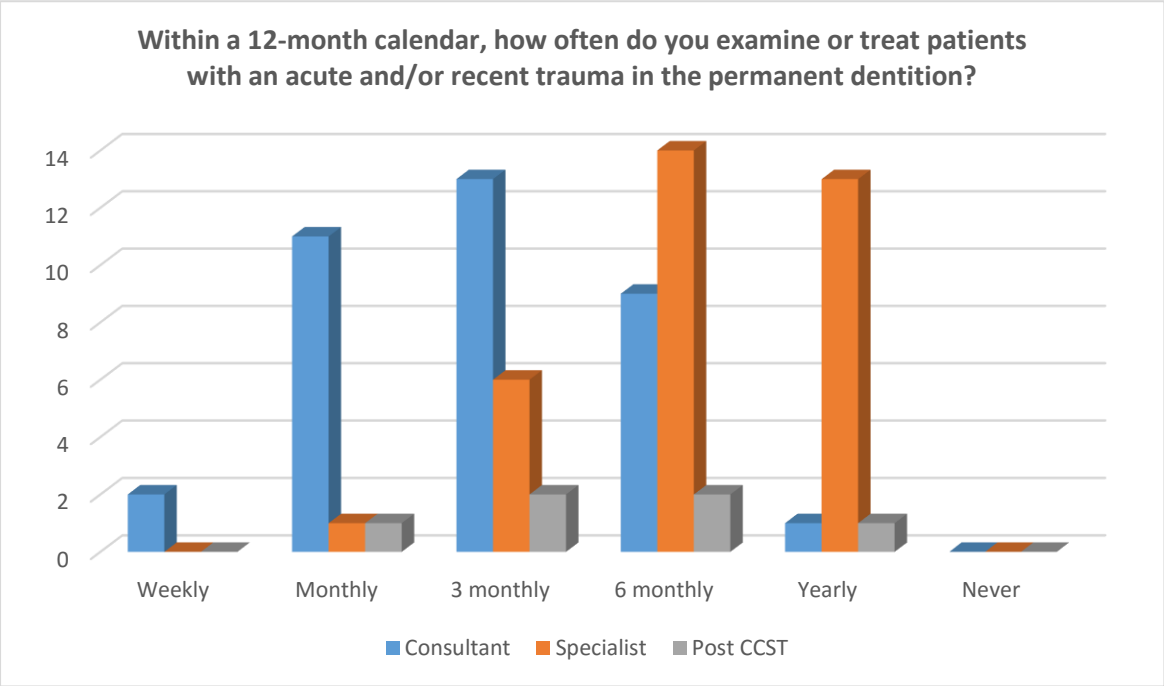
The results of this question shows that consultants see a greater number of trauma patients on a monthly and 3 monthly basis (31% and 35%) compared to specialists (3% and 17%) and post CCSTs (17% and 33%). Specialists seem to examine trauma sporadically at 6 months and 12 month intervals (41% and 38%) compared to consultants (25% and 3%) and post CCSTs at 33% and 17% respectively. The survey shows that all grades of specialists are dealing with patients with acute or past trauma. Shown in **Error! Reference source not found.** and **Error! Reference source not found.**.

Table 4.2: Within a 12-month calendar, how often do you examine or treat patients with an acute and/or recent trauma in the permanent dentition?

	Weekly	Monthly	Every 3 months	Every 6 months	Every year	Never
Consultant (n=36)	2 (6%)	11 (31%)	13 (35%)	9 (25%)	1 (3%)	0

Specialist (n=34)	0	1 (3%)	6 (17%)	14 (41%)	13 (38%)	0
Post CCST (n=6)	0	1 (17%)	2 (33%)	2 (33%)	1 (17%)	0

Figure 4. 3: Within a 12-month calendar, how often do you examine or treat patients with an acute and/or recent trauma in the permanent dentition?



C. **How many patients currently under your care have experienced a dental trauma to their permanent dentition?**

The results above show that consultants deal with a greater volume of patients with dental trauma in their day to day working pattern compared to specialists. The majority of specialists (61%) currently treat a very low number of patients (less than 5%) who have sustained trauma compared to consultants. Furthermore, over 10% of patients treated by consultants have had trauma (81%) compared to specialists (30%). Post CCSTs had the greatest number of patients being treated with dental trauma at 83%. Shown in **Error! Reference source not found.**.

Table 4.3: How many patients currently under your care have experienced a dental trauma in their permanent dentition?

	None that I know of	<5%	6-10%	11-20%	21-30%	31-40%	>40%
Consultant (n=36)	0	7 (19%)	11 (31%)	13 (36%)	4 (11%)	1 (3%)	0
Specialist (n=34)	3 (9%)	21 (61%)	5 (15%)	3 (9%)	2 (6%)	0	0
Post CCST (n=6)	0	1 (17%)	3 (66%)	1 (17%)	0	0	0

D. **If you suspect a patient has had previous dental trauma, would you regularly take radiographs prior to orthodontic treatment, furthermore, would you routinely perform sensibility testing prior to orthodontic treatment?**

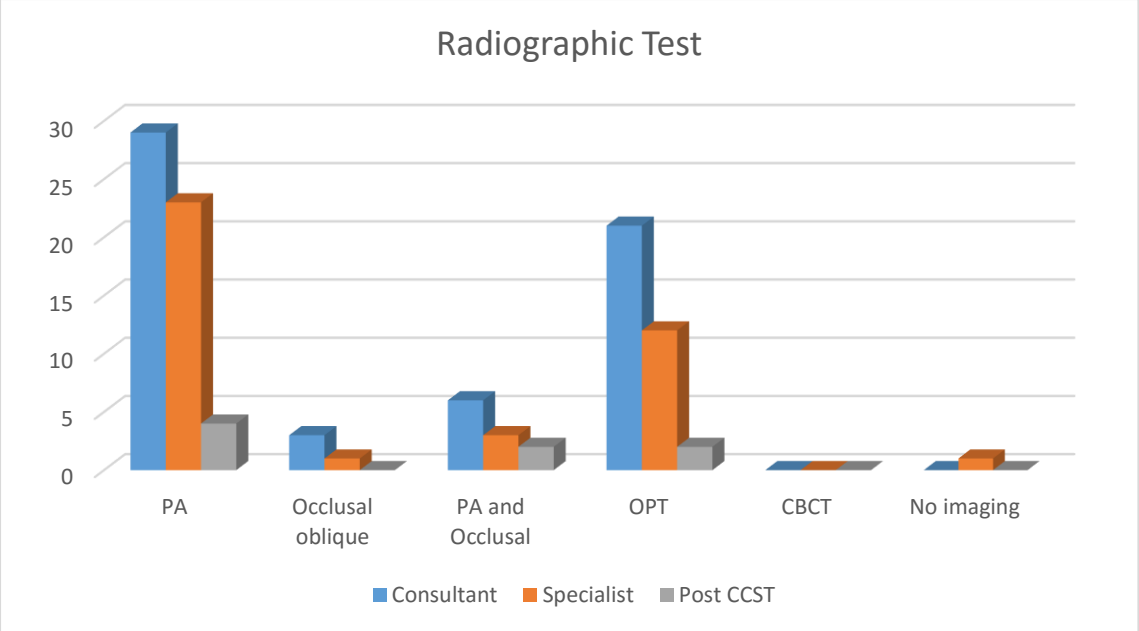
Radiographic investigation

The table above shows that 80% of consultants would take a periapical radiograph to examine a tooth they suspected of having trauma compared to 67% in both post CCST and specialist groups respectively. Only 8% of consultants and 3% of specialists would take a stand alone occlusal oblique. 33% of Post CCSTs would take a PA and occlusal oblique to examine a traumatised tooth compared to 17% of consultants and 9% of specialists. Moreover, 58% of consultants, 35% of specialists and 33% of Post CCSTs would take an OPT. It was interesting to note that no grade took a CBCT to examine for past trauma. Shown in Figure 4.4 and **Error! Reference source not found.**.

Table 4.4: Radiographic Test

	Periapical	Occlusal oblique	Periapical and Occlusal	OPT	CBCT	None
Consultant (n=36)	29 (80%)	3 (8%)	6 (17%)	21 (58%)	0	0
Specialist (n=34)	23 (67%)	1 (3%)	3 (9%)	12 (35%)	0	1
Post CCST (n=6)	4 (67%)	0	2 (33%)	2 (33%)	0	0

Figure 4. 4: Radiographic Test



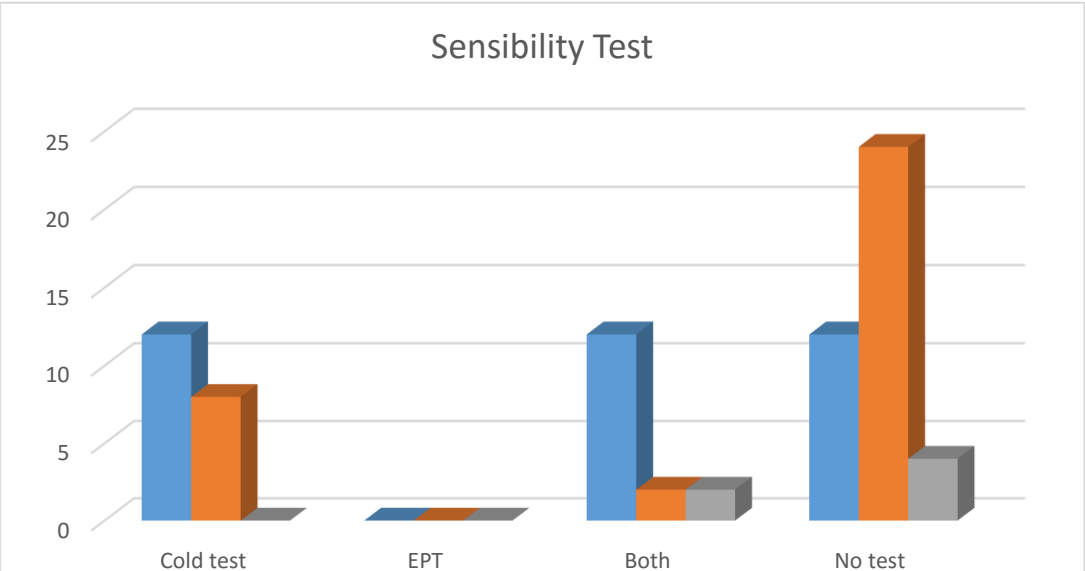
Sensibility testing

The results surprisingly show that 70% of specialists, 67% of Post CCSTs and 33% of consultants do not carry out any form of sensibility testing for a traumatised tooth. A third of Post CCSTs and consultants would carry out both a cold test and an electric pulp test (EPT). 33% of consultants and 24% of specialist would carry out a cold test alone in comparison to Post CCSTs who had no respondents to cold testing. Shown on **Error! Reference source not found.** and **Error! Reference source not found.**.

Table 4.5: Sensibility Test

	Cold test	EPT	Both	No testing
Consultant (n=36)	12 (33%)	0	12 (33%)	12 (33%)
Specialist (n=34)	8 (24%)	0	2 (6%)	24 (70%)
Post CCST (n=6)	0	0	2 (33%)	4 (67%)

Figure 4. 5: Sensibility Test



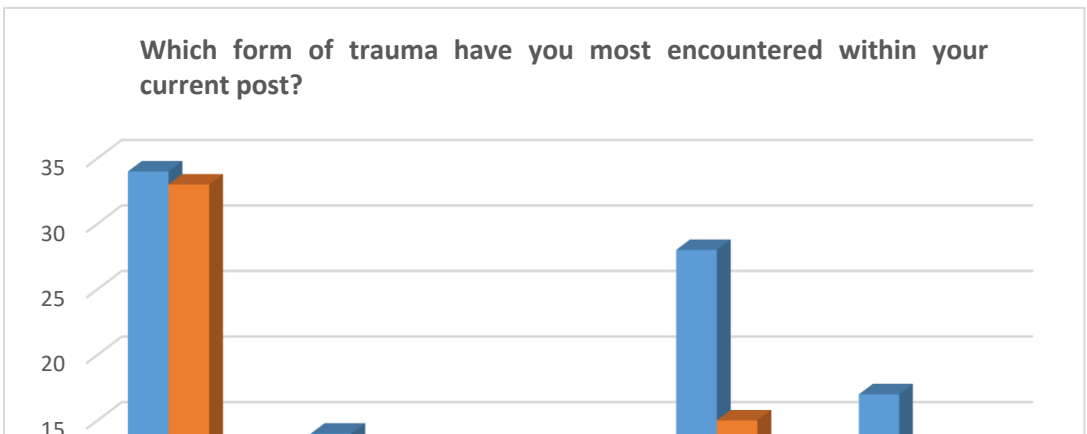
E. Which form of trauma have you most encountered within your current post?

In this question participants were allowed to answer more than one answer. The majority of trauma seen by consultants, specialists and post CCSTs were crown fractures. Consultants were also likely to treat more root fractures (39%), crown root fractures (27%) and luxation injuries (77%) than specialists who treated 11% of root fractures, 6% crown-root fractures and 44% of luxation injuries. Post CCSTs and consultants saw almost equal number of avulsion injuries. Shown on **Error! Reference source not found.** and Table 4.6.

Table 4.6: Which form of trauma have you most encountered within your current post?

	Crown #	Root #	Crown- root #	Luxation injuries	Avulsion
Consultant (n=36)	34 (94%)	14 (39%)	10 (27%)	28 (77%)	17 (47%)
Specialist (n=34)	33 (97%)	4 (11%)	2 (6%)	15 (44%)	2 (6%)
Post CCST (n=6)	6 (100%)	1 (17%)	0 (0%)	4 (67%)	3 (50%)

Figure 4. 6: Which form of trauma have you most encountered within your current post?



4.4.4 Resources and Guidelines

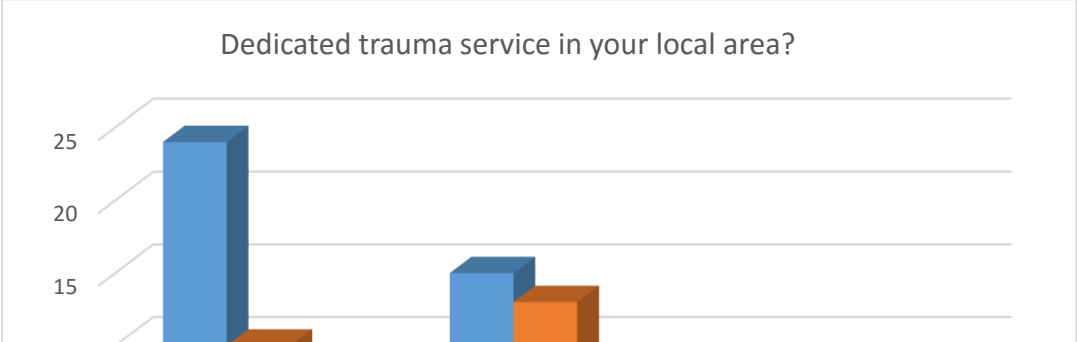
A. In your local area, is there a dedicated trauma service?

The orthodontists were asked if within their local area they had a dedicated trauma service. Orthodontic consultants and Post CCSTs responded positively with 67% having a local trauma service compared to 44% of orthodontic specialists. In contrast, 56% of specialist orthodontists either didn't have a local service or didn't know if a service existed locally compared to 33% of consultants and 18% of post CCSTs. This is shown on **Error! Reference source not found.** and **Error! Reference source not found.**.

Table 4.7: In your area is there a dedicated trauma service?

	Dedicated trauma service in your local area?		
	Yes	No	Don't know
Consultant (n=36)	24 (67%)	10 (27%)	2 (6%)
Specialist (n=34)	15 (44%)	13 (38%)	6 (18%)
Post CCST (n=6)	4 (67%)	1 (17%)	1 (17%)

Figure 4. 7: Dedicated trauma service in your local area?



B. Are you aware of any guidelines or any other resources relating to the orthodontic treatment of traumatised teeth?

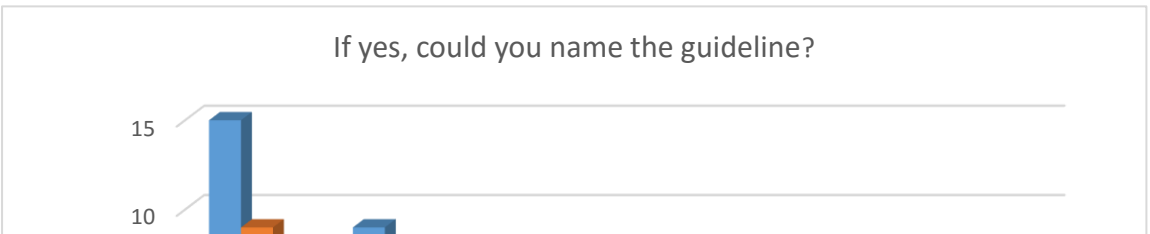
When participants were asked about guidelines they are aware of with regards to the orthodontic management of traumatised teeth, 100% of post CCSTs, 83% of consultants and 47% of specialists were aware of a guideline. A further question asked the participants to name the guideline. This was an open ended question and the participants were allowed to write freely their point of view. The guidelines mentioned were Kindelan and Day, IADT, BSPD, Dental trauma website, NICE guidelines.

Some participants answered 'Yes' but did not name any given guideline. The results are shown on **Error! Reference source not found.** and **Error! Reference source not found.**.

Table 4.8: Are you aware of current guidelines relating to the orthodontics and dental trauma?

Are you aware of current guidelines relating to orthodontics and dental trauma?			
	Yes	No	Don't know
Consultants	30 (83%)	5 (14%)	1 (3%)
Specialists	16 (47%)	10 (29%)	8 (24%)
Post CCSTs	6 (100%)	0 (0%)	0 (0%)

Figure 4. 8: If yes, could you name the guideline?



4.4.5 Vignette analysis

In total 76 participants completed the survey with three vignette scenarios and in total 5 open ended questions. The mean length of completing the surveys was 7 minutes and 28 seconds, as per the analysis from the survey select software.

Vignette results

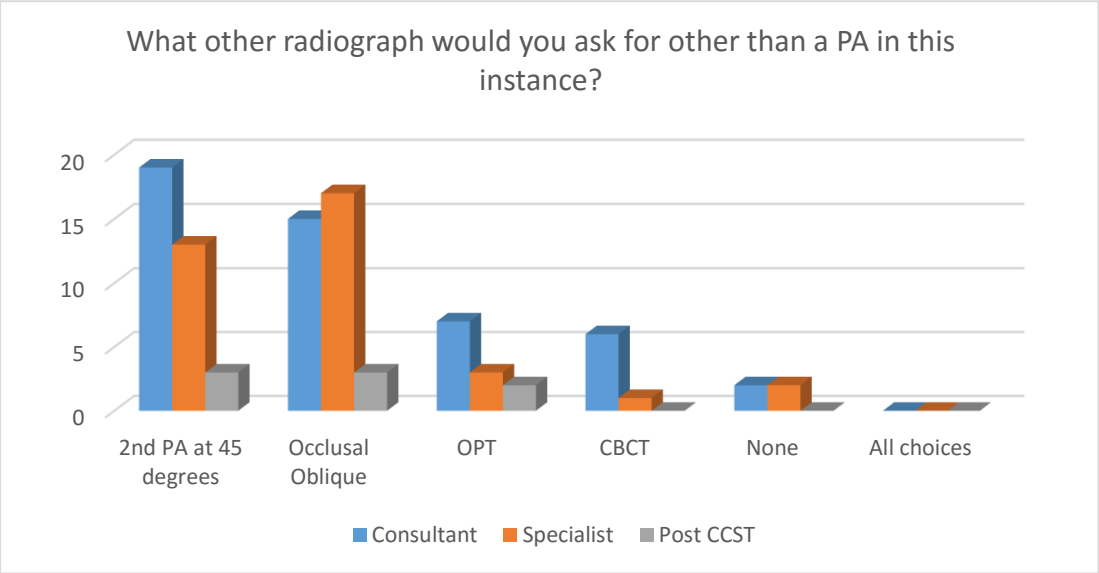
Case Scenario One

A 12-year-old boy, fit and well with no known medical problems, attends the Orthodontist with his parents having fallen onto the handle bars of his scooter 2 weeks ago; He is suffering from tenderness and bleeding around the gingiva of the UR1 and UL1, he has tenderness on tapping his teeth with some mobility on both teeth. The patient is due to start orthodontic treatment for moderate upper arch crowding. On taking a Periapical radiograph, you suspect a mid-root fracture to the UL1 and UR1 respectively.

What other radiograph would you ask for other than a PA in this instance?

The results show that the almost half the number of respondent would order an occlusal oblique to examine for a root fracture. Again 53% of consultants and 50% of Post CCSTs would take a PA at 45 degrees. Interestingly 17% of consultants would request a CBCT. Surprisingly, 5% of consultants and 6% of specialists would take no radiographs at all for this presentation. This is shown in **Error! Reference source not found.**.

Figure 4. 9: What other radiograph would you ask for other than a PA in this instance?

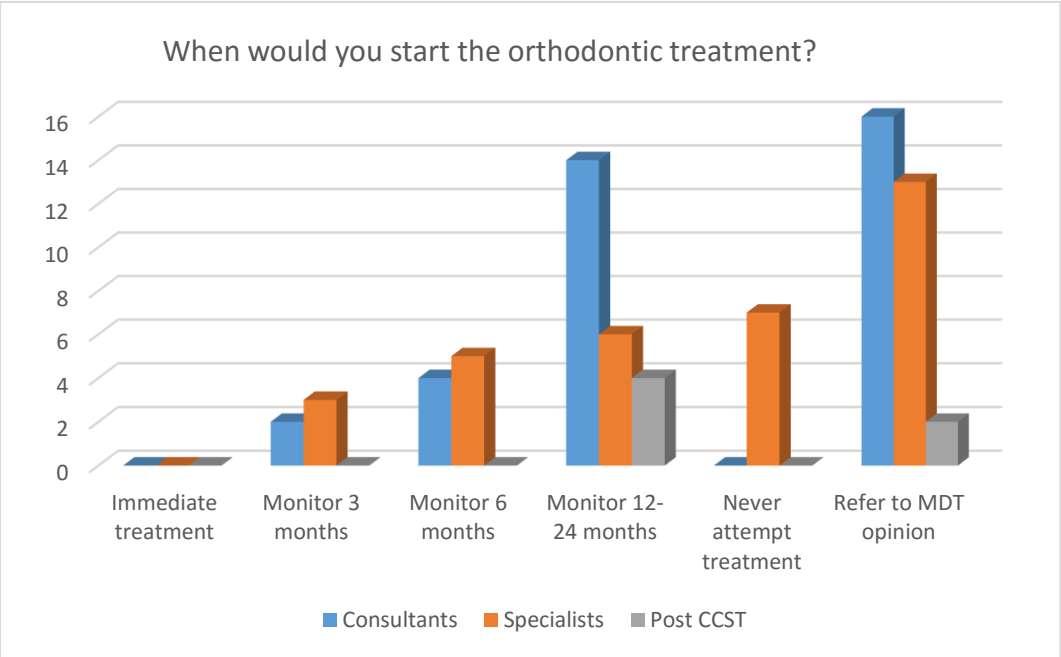


The results show that the majority of consultants (44%) and specialists (38%) would refer the case for a second opinion in an MDT clinic, whilst 67% of Post CCSTs would monitor for 12-24 months prior to treatment in comparison to 39% of consultants and 18% of specialists. Another interesting aspect is that the specialists were the only group which had 21% of responses which would never attempt the treatment. Shown in **Error! Reference source not found.** and **Error! Reference source not found.**.

Table 4.9: Vignette one - When would you start orthodontic treatment?

	Start tx immediately	Monitor 3/12 months	Monitor 6/12 months	Monitor 12-24 months	Would never attempt tx	Refer to MDT
Consultant (n=36)	0	2 (6%)	4 (11%)	14 (39%)	0	16 (44%)
Specialist (n=34)	0	3 (9%)	5 (14%)	6 (18%)	7 (21%)	13 (38%)
Post CCST (n=6)	0	0	0	4 (67%)	0	2 (33%)

Figure 4. 10: Vignette one - When would you start orthodontic treatment?



Would you give the patient and parents any specific warning or advice prior to starting orthodontic treatment?

Participants were asked to write down their answers as part of an open ended question. The written responses were analysed, recurrent risks were mentioned repeatedly. These risks were then examined further and two forms of risks emerged from the written answers, they were orthodontic risks endodontic risks. The results are illustrated on **Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**.

Figure 4. 11: Vignette one – Orthodontic risk

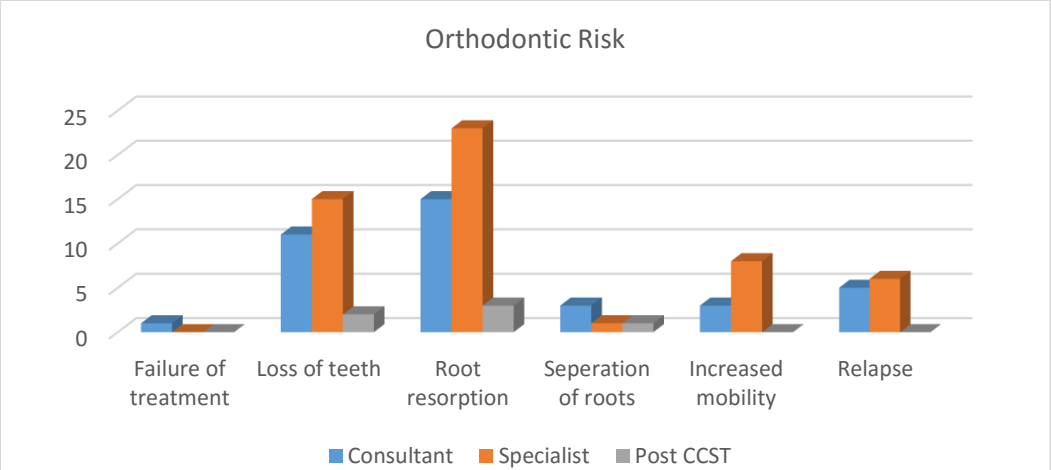


Figure 4. 12: Vignette one – Endodontic risk

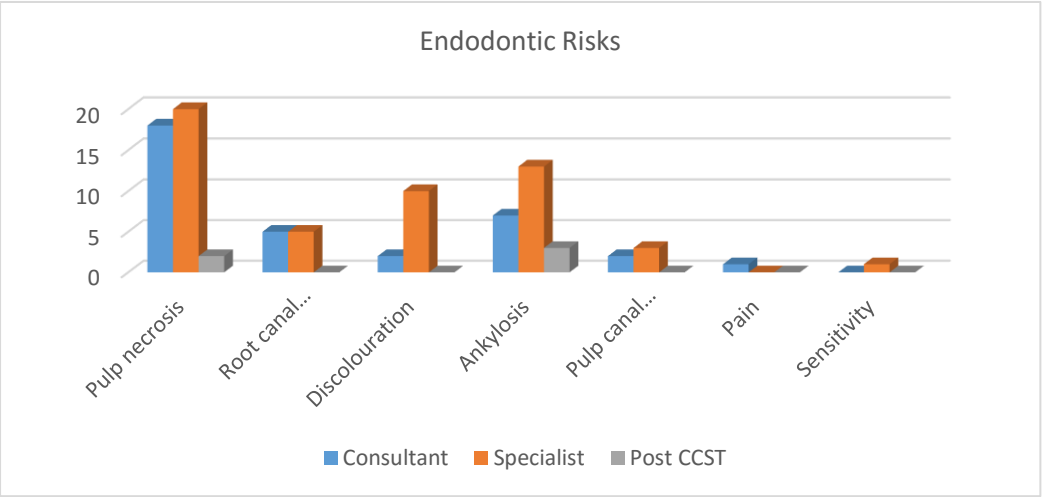
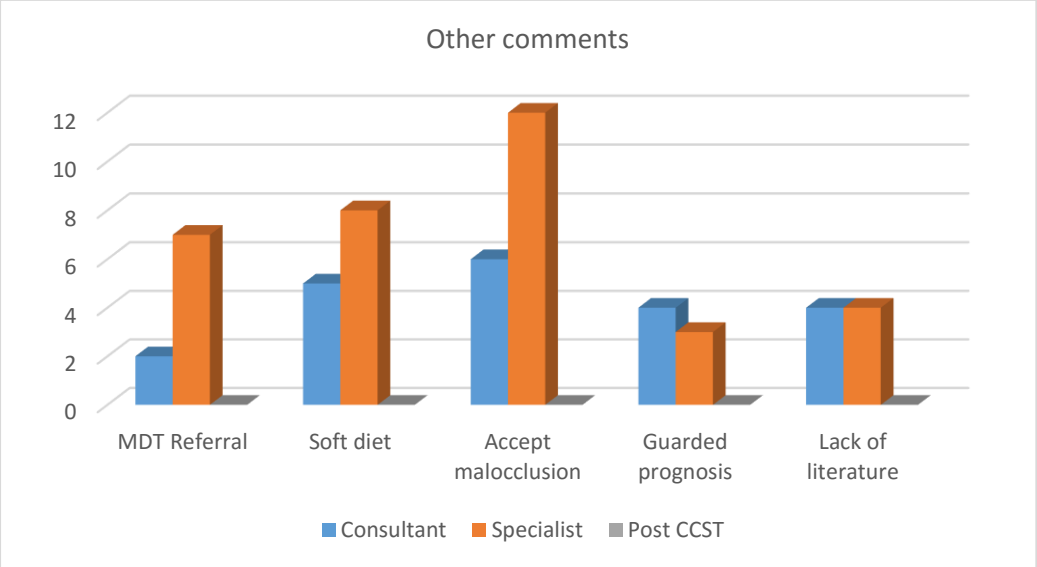


Figure 4. 13: Vignette one - Other risk



[Case Scenario Two]

A 13-year-old boy, fit and well with no known allergies, accidentally traumatised his tooth whilst playing sport 3 years ago. He presents to your orthodontic clinic with discolouration of the UL1. The patient has a Class 2 Div 1incisor relationship with an 8mm overjet. The patient's mother is concerned with the yellow discolouration of this tooth. Otherwise, the tooth is asymptomatic. A periapical radiograph of the UL1 shows a completely obliterated canal. The patient is about to start orthodontic course of treatment.

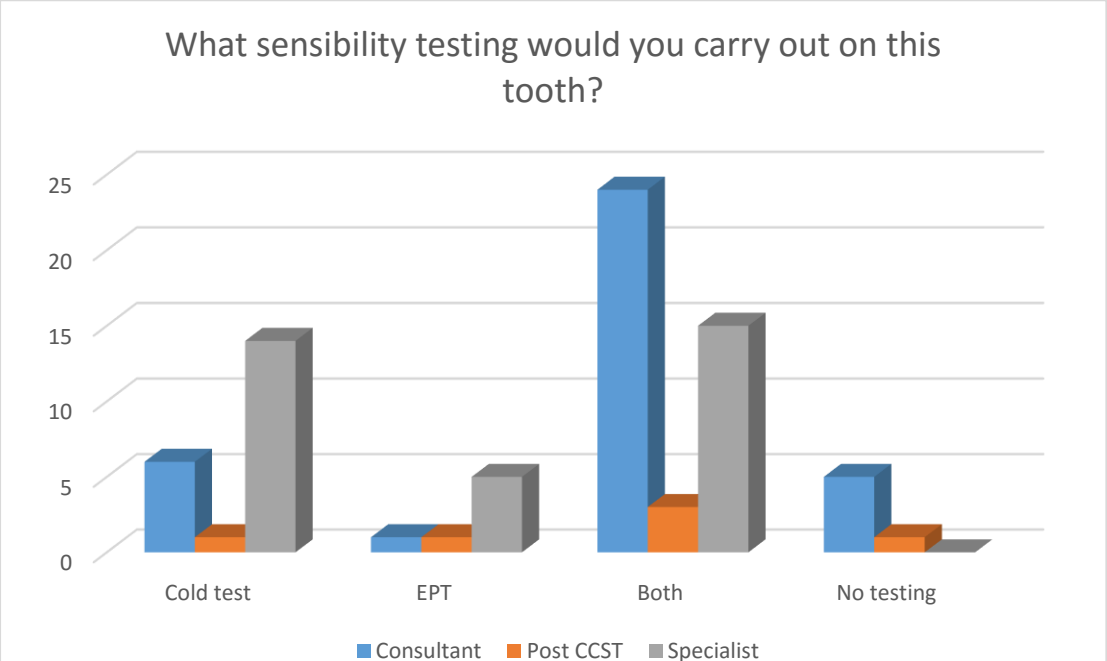
Q1: What sensibility testing would you carry out on this tooth?

The scenario depicts a case with pulp canal obliteration following previous trauma. When participants were asked about the sensibility test most appropriate for this case, 67% of consultants, 50% of post CCSTs and 44% of specialists would carry out cold testing and EPT. However, 17% of post CCSTs and 14% of consultants wouldn't carry out any sensibility testing at all. Shown on **Error! Reference source not found.** and **Error! Reference source not found.**.

Table 4.10: Vignette two - What sensibility testing would you carry out on this tooth?

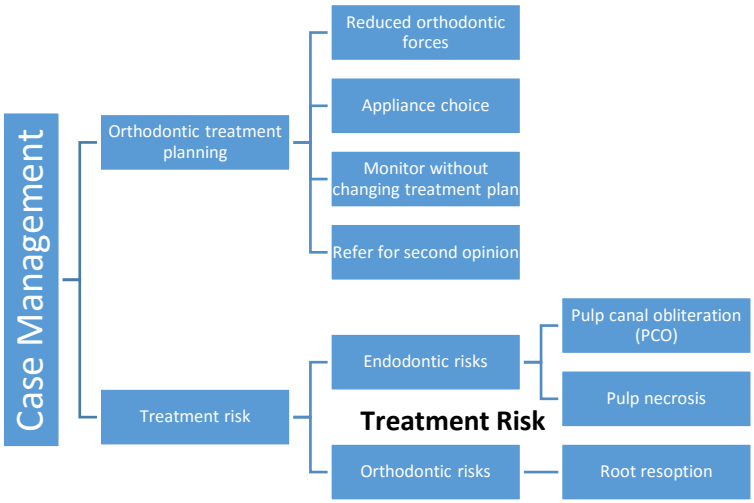
	Cold test	EPT	Both	No testing
Consultant (n=36)	6 (17%)	1 (3%)	24 (67%)	5 (14%)
Specialist (n=34)	14 (41%)	5 (15%)	15 (44%)	0
Post CCST (n=6)	1 (17%)	1 (17%)	3 (50%)	1 (17%)

Figure 4. 14: Vignette two - What sensibility testing would you carry out on this tooth?



Q2: Orthodontic treatment is planned for this patient, how would this change your management? Would you do anything differently and what warnings would you give the patient?

This questions was open ended, qualitative analysis of the written text described the following theme and subthemes:



Endodontic Risk

Some of the orthodontists stressed the importance of treatment complications and highlighted the following risks:

1. Need for root canal treatment

'Again, I would warn the patient that there is a likelihood of pulp non-vitality as there is clearly a previous history of trauma that may have triggered the canal obliteration. I would warn that RCT may be required, may have to use a lighter force and longer duration of treatment'. C 30

2. Pulp canal obliteration

‘Pulp canal obliteration and discolouration indicate loss vitality - risk symptoms occurring and overall poor long term prognosis. Monitor through treatment’. C5

Orthodontic Risk

1. Root resorption

‘Warn Increased risk root resorption, need for RCT, risks of ankylosis Would keep forces as light as possible, would re-radiograph 6 months after upper FA placed to check for increased resorption’.S4

Treatment Planning

Orthodontic treatment planning

1. Orthodontic Appliances

‘Aim to keep forces as light as possible - achieve antero-posterior correction with functional appliance and minimise fixed appliance treatment. Possible need for endodontic treatment and symptoms may arise’. C1

2. Orthodontic Forces

‘Possible use of light forces and breaks in treatment to assess vitality, longer duration of orthodontic treatment with light forces’. S 28

3. Commit to treatment without change in management

‘No change in management other than warn the patient that the tooth is likely to need RCT during or after treatment’. S 10

4. Second opinion prior to orthodontic treatment

‘Some orthodontists wanted a second opinion on the treatment management of this case whilst some participants opted to refer the patient to secondary care for treatment’. C 14

A. Some wished for an endodontist opinion

'Endo referral for opinion prior to starting and increased risk of root resorption, devitalisation, ankylosis etc. Keep under observation throughout orthodontic treatment'.

S 5

B. Whilst some orthodontists wanted a restorative opinion

'Ask for a restorative/ endodontic opinion'. S16

C. And a number of orthodontists sought a paediatric referral

'Ref to Paediatric dentistry ASAP'. S2

Endodontic treatment planning

1. Monitor for pulp necrosis

Some orthodontists believed that the tooth is non-vital or may become non-vital, for which reason they would review the vitality status of the tooth throughout treatment.

'I would move the teeth slowly whilst monitoring the vitality frequently, I would warn the patient that this tooth may become non vital and RCT may be quite difficult if the sclerosis worsens.' C 22

It was interesting to note that some of the orthodontists believed the tooth to still be vital and best to be monitored.

'I would continue to review, the tooth may still be vital and because of the sclerosis is not responding.' C 31

2. Effect of PCO on treatment management

'Unlikely to change management but would monitor radiographically during orthodontic treatment.'

C 28

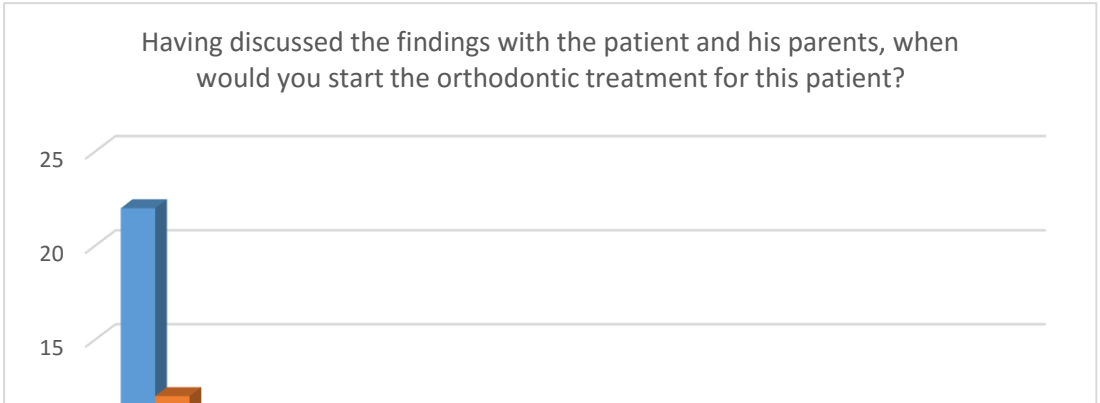
Q3: Having discussed the findings with the patient and his parents, when would you start the orthodontic treatment for this patient?

The results showed that the majority of consultants (61%) would begin treatment immediately in this case compared to over a third of specialists (36%) and Post CCSTs (33%). A considerable number of participants opted to refer the patient for a second opinion as part of an MDT type setting in secondary care. Over a fifth of consultant (22%) opted for a second opinion, this was lower than specialists (26%) with half the Post CCSTs referring for a second opinion. This is shown on **Error! Reference source not found.** and Table 4.11.

Table 4.11: Vignette two - Having discussed the findings with the patient and his parents, when would you start the orthodontic treatment for this patient?

	Start tx immediately	Monitor 3/12 months	Monitor 6/12 months	Monitor 12-24 months	Would never attempt tx	Refer to MDT
Consultant (n=36)	22 (61%)	3 (8%)	2 (6%)	1 (3%)	0	8 (22%)
Specialist (n=34)	12 (36%)	3 (9%)	10 (29%)	0	0	9 (26%)
Post CCST (n=6)	2 (33%)	1 (17%)	0	0	0	3 (50%)

Figure 4. 15: Vignette two - Having discussed the findings with the patient and his parents, when would you start the orthodontic treatment for this patient?



Vignette Scenario Three

A 12-year-old patient, otherwise fit and well, had a fall whilst playing with her friends in the playground 4 years ago. The patient's mother is concerned about the gradual discolouration associated with the UR1. The patient has no other symptoms. The tooth is not mobile and has no localised deep pocketing. She is due to start orthodontic treatment and on taking a periapical radiograph, you diagnose an immature UR1 with open apex.

Q1: Sensibility testing of the UR1 was deemed unreliable, would you consider root canal treat for this tooth or wait for further root development? And why?

The question came up with the following themes, and shown in **Error! Reference source not found.**.

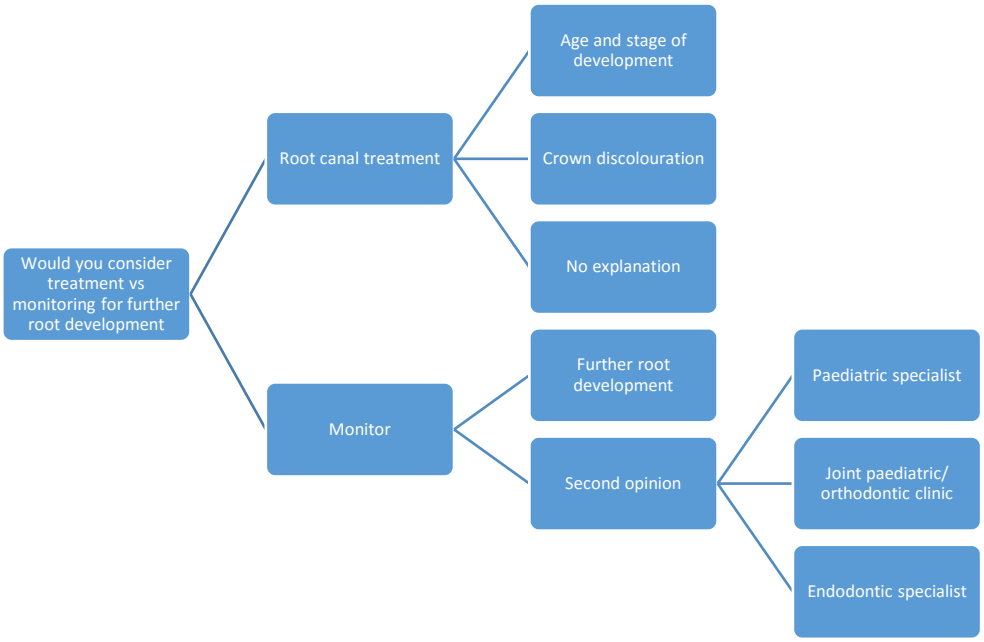
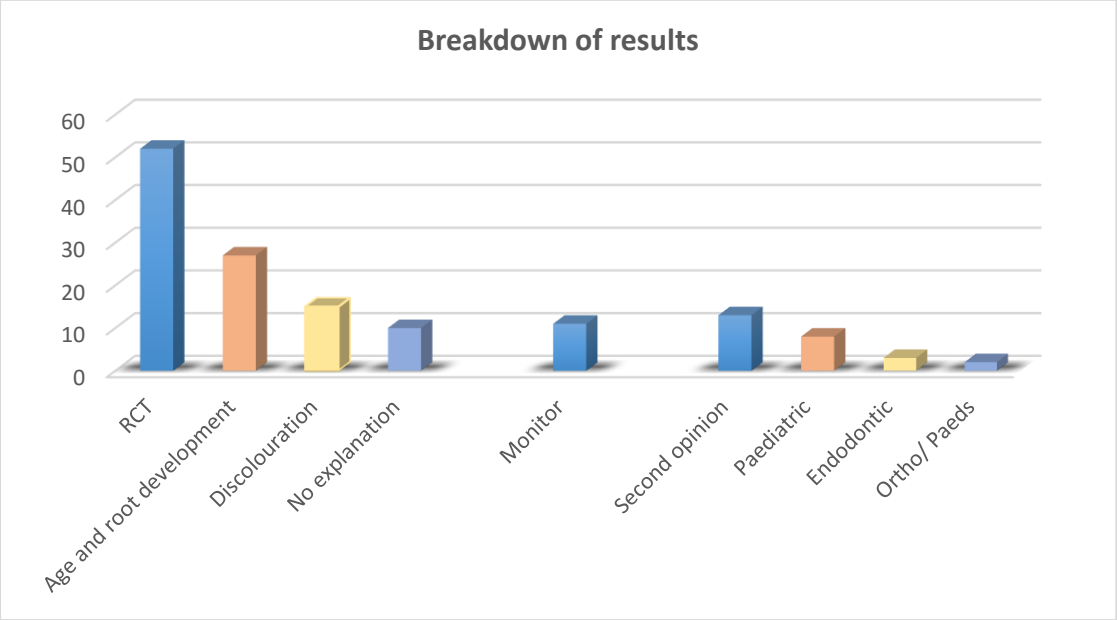


Figure 4. 16: Vignette Three – Breakdown of results



Treatment option: Root Canal Treatment

1. 36% of orthodontists believed that the tooth is non-vital based on the patient's age and stage of root development:

'Consider root canal as root apex should have fully developed 4 years ago so little chance of spontaneous change'. C21

2. A further 20% of orthodontists believe the tooth is non-vital and requires root canal treatment due to the signs of discolouration of the crown.

‘Discolouration is due to possible pulp necrosis so I would seek an endodontic assessment from a specialist Paediatric Dentist or Endodontist’. C23

Treatment option: Monitor

1. 14% of orthodontists wished to wait and monitor the tooth for further root development.

‘Await: current guidelines suggest there should be at least 2 signs or symptoms in order to justify commencing RCT’. C19

2. Whilst 17% would refer for a second opinion for a decision to be made on the fate and treatment to be provided to the tooth in question.

A. Paediatric Dentist

‘I'd refer for an opinion for Paediatric dentistry’. C1

B. Joint Paediatric- Orthodontic clinic

‘I would take specialist opinion regarding root end closure. I will compare apices of UL1 with UR1 and assess the length of the root of the central incisors. It will be a joint decision’. C12

C. Endodontist

‘Refer for specialist opinion (Endo) and do as they say. My thoughts would be to RCT as root development should have completed by 10-11 years of age. If the immaturity of the tooth root is the same as when the patient had trauma- then no further root development has taken place and therefore need RCT’. CCST 6

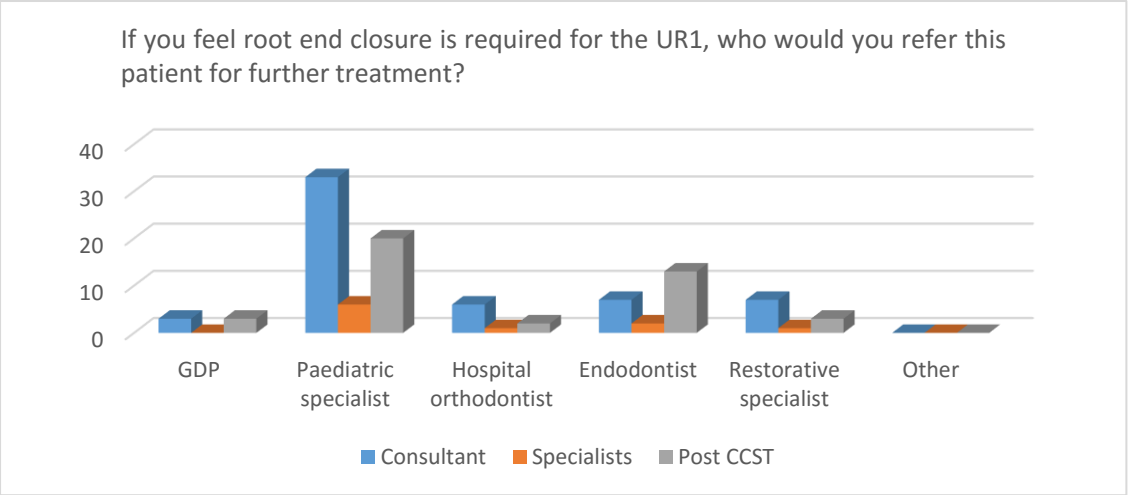
Q2: If you feel root end closure is required for the UR1, who would you refer this patient for further treatment and could you explain your choice?

Orthodontists were given the option to express and describe who and why they would chose certain specialists to treat the patient in vignette case 3, the results are shown in **Error! Reference source not found.** and **Error! Reference source not found.**.

Table 4.12: Vignette three - If you feel root end closure is required for the UR1, who would you refer this patient for further treatment?

	GDP	Paediatric specialist	Orthodontic consultant	Endodontist	Restorative dentist	Other
Consultant (n=36)	3 (8%)	33 (92%)	6 (17%)	7 (19%)	7 (19%)	0
Specialist (n=34)	3 (9%)	20 (59%)	2 (6%)	13 (38%)	3 (9%)	0
Post CCST (n=6)	0	6 (100%)	1 (17%)	2 (33%)	1 (17%)	0

Figure 4. 17: Vignette three – If you feel root end closure is required for the UR1, who would you refer this patient for further treatment?



The reasons for choosing a paediatric specialist were:

1. Training and experience

'They see many cases similar to this one and are well trained for spotting when a tooth is likely to become non vital and when to respond to treatment'. C13

'Trained to a high level in the treatment and management of trauma and non-vital immature teeth'. CCST 2

2. Age of the patient

'Pt is within age group to see Paeds. They deal with the dental trauma injuries in paediatric patients and carry out this type of treatment on a regular basis'. C23

3. Local links

'Apexification or apexigenesis managed by paediatric dentists in our area'. C22

'We have a very good paediatric dentistry department in our dental hospital'. C2

Endodontists

Complexity of treatment, experience and outcome

'Excellent at root canal therapy with the best success rates'. C36

'They are excellent in this field of treatment and would have the greatest survival rate in my opinion'. S10

Restorative dentist

'Restorative dentist as they will also be specialists in endodontic treatment and can predict to some extent long term success of the treatment and subsequent treatment options should the tooth be lost'. C11

Hospital based orthodontists

'If resources are available for more specialized treatment in this case, then due to the complexity and joint treatment (MDT) with Ortho then hopefully - hospital services could be utilised as it is a joint case'. S1

Available services

'There are no local specialists in Shropshire for paediatrics. There is also no NHS specialist endodontists. The only options would be to refer to Birmingham dental hospital for opinion and treatment is any if required'. C9

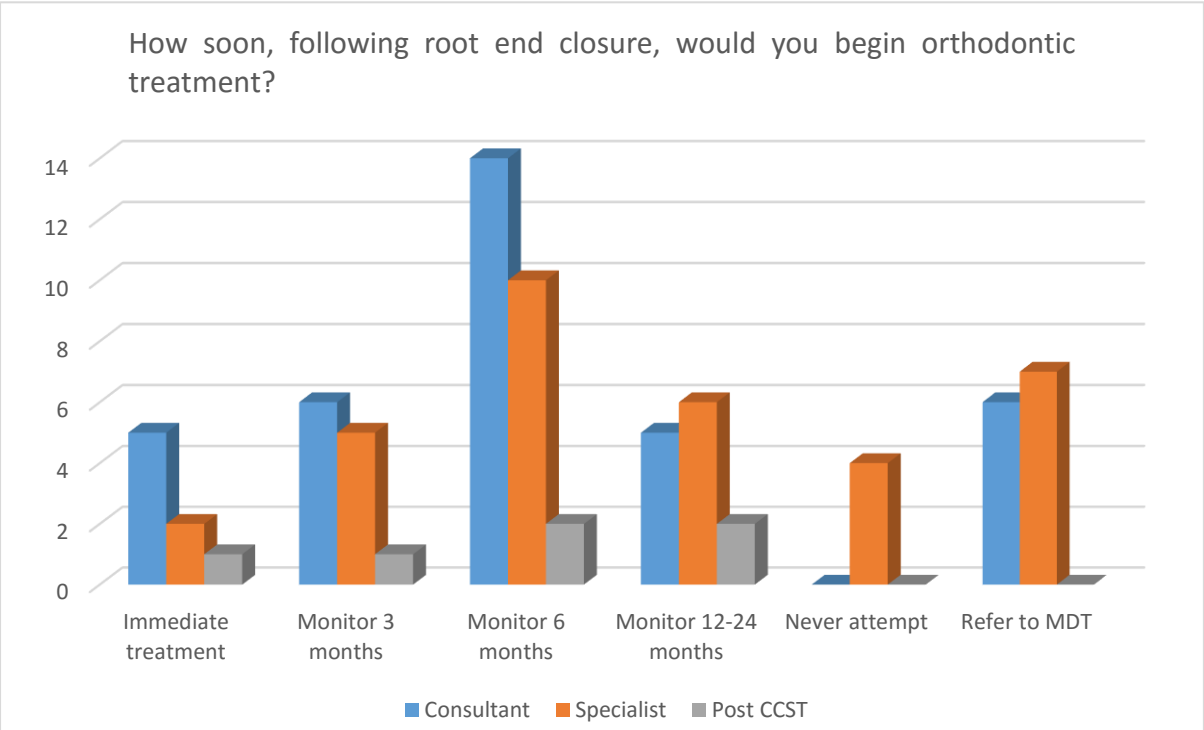
Q4: How soon, following root end closure, would you begin orthodontic treatment?

The results show that's the majority of consultants (39%), specialists (29%) and post CCSTs (33%) would wait 6 months before proceeding with treatment. Around 1/5 of consultant (17%) and specialists (21%) would refer the patient for a second opinion prior to treatment. However, 12% of specialists wouldn't carry out the treatment. Shown in **Error! Reference source not found.** and **Error! Reference source not found.**.

Table 4.13: Vignette three - How soon, following root end closure, would you begin orthodontic treatment?

	Start tx immediately	Monitor 3/12 months	Monitor 6/12 months	Monitor 12-24 months	Would never attempt tx	Refer to MDT
Consultant (n=36)	5 (14%)	6 (17%)	14 (39%)	5 (14%)	0	6 (17%)
Specialist (n=34)	2 (6%)	5 (15%)	10 (29%)	6 (18%)	4 (12%)	7 (21%)
Post CCST (n=6)	1 (17%)	1 (17%)	2 (33%)	2 (33%)	0	0

Figure 4. 18: Vignette three – How soon, following root end closure, would you begin orthodontic treatment?



Q5: Would this injury and subsequent treatment affect your orthodontic management of the case?

If so, how would it affect it? Several themes were evident in this answer and also shown on Figure 4.19.

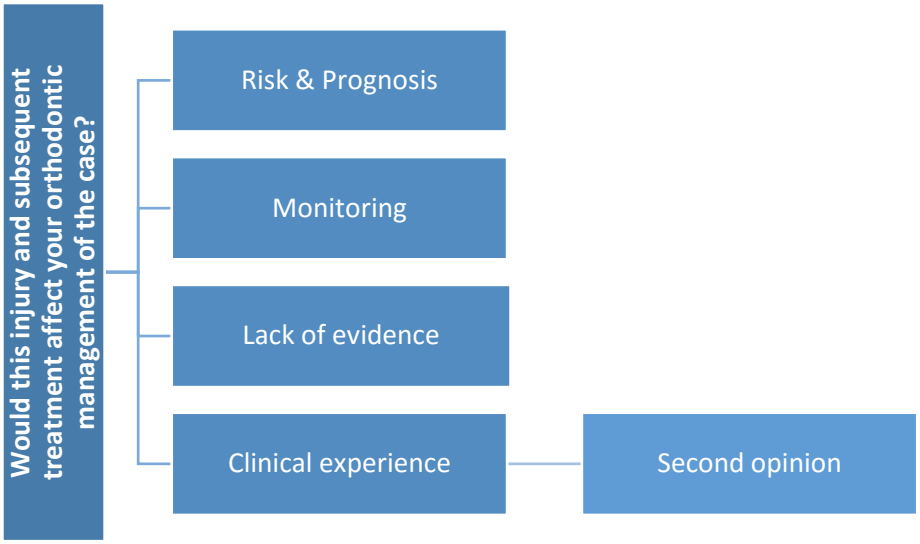
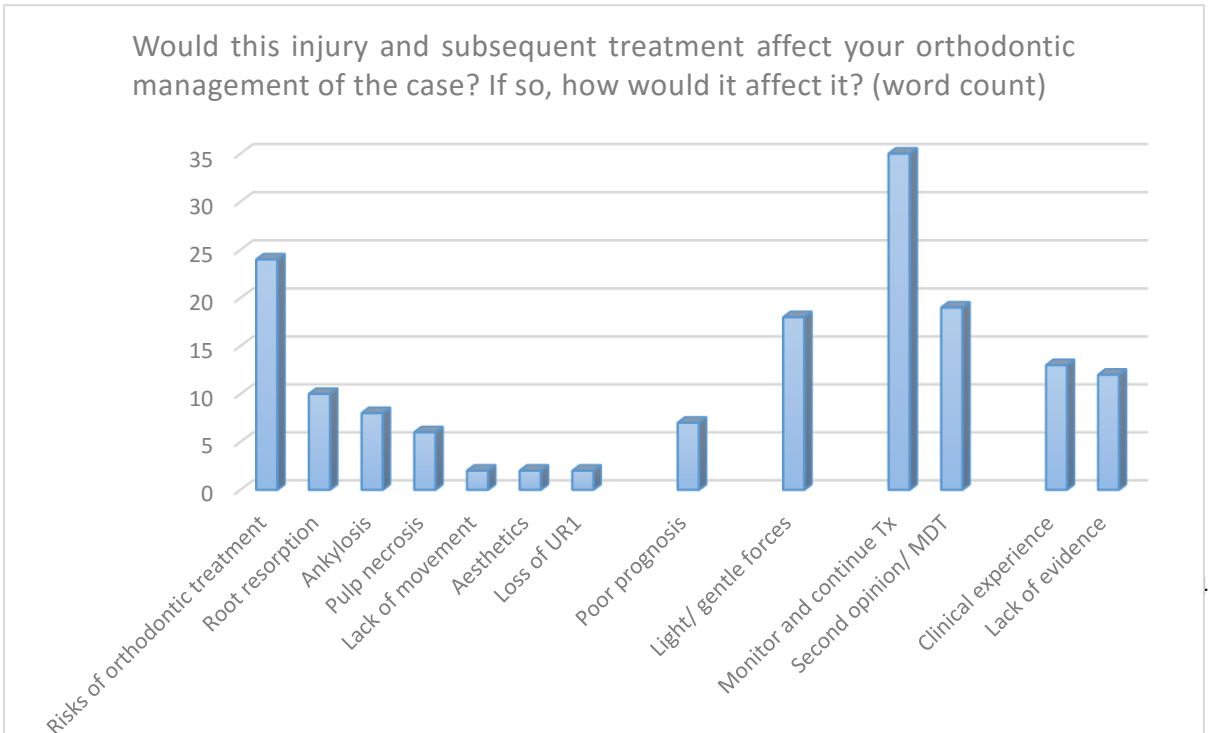


Figure 4. 19: Vignette three – Would this injury and subsequent treatment affect your orthodontic management of the case? If so, how would it affect it?



1. Risk and prognosis associated with orthodontic treatment

Orthodontists clearly highlighted their thoughts with regards to the orthodontic movement of the immature UR1 and its prognosis with the following comments:

'They would be a guarded prognosis for this tooth but it is likely that the treatment plan would not be changed. If the incisor is eventually lost a restorative solution would be likely rather than an orthodontic one'. C28

In addition, the risks associated with the orthodontic treatment of the UR1 included:

'Warnings about sensitivity, root resorption and possible poor long term prognosis'. S34

2. Monitoring and re-assessment with consideration to the orthodontic appliance therapy

- With regards to the treatment management of this case, 46% of orthodontists felt their treatment management wouldn't be changed, however, they would regularly monitor the tooth throughout the active orthodontic movement to diagnose changes occurring to the tooth clinically and radiographically.

'Not really, may take more regular PA'S during treatment but if teeth need straighten then they need straighten. Possibly less rectangular wires and more round'. S30

- 24% of orthodontists were also conscious about the appliance choice and therapy in the movement of the UR1. They tender to prescribe light and gentle forces on the UR1 to prevent ankylosis or root resorption.

'I would be cautious about taking other healthy teeth out before confirming that the anterior tooth is reacting positively to force especially root resorption. I would trying and avoid torque on that particular tooth for long periods warn patients about risk of root resorption'. C3

3. Lack of current evidence

16% of orthodontists felt that there was no current literature or evidence to help them decide on the best treatment option for this open apex tooth. Many of the orthodontists felt treatment options on this type of case was based on experience and anecdotal evidence, for this reason many would refer this case for a second opinion.

'I would wait for a period of time especially if there is a lesion periapically as per Kindalan and Days description. Little evidence on the treatment of these teeth'. S11

4. Clinical experience

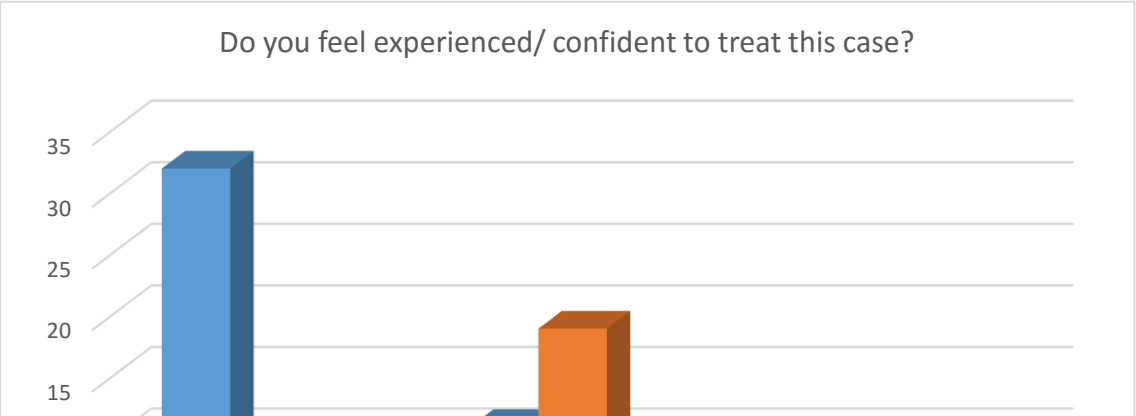
17% of clinicians felt they did not have the experience to deal with these cases in their current clinic practice and 25% of orthodontists referring this case for a second opinion prior to treatment.

'Yes, I don't feel I know enough about the treatment of such cases, very limited literature on this and anecdotal evidence/ experience of more senior clinicians would be required'. S19

Q6: Do you feel experienced/ confident to treat this case?

The answers of this question was analysed by word count frequency based on the open ended responses which had the following results, which are shown on **Error! Reference source not found.**.

Figure 4. 20: Vignette three – Do you feel experienced/ confident to treat this case?



- The majority of consultant specialists were confident to carry out treatment whereas over half of specialists were not confident to commit to the treatment of the UL1 with pulp canal obliteration.
- With regards to the consultants, although they were happy to carry out the treatment, they would do so with the help/ assistance of their paediatric or restorative colleagues. Some of their responses were:

'I would be confident after a joint specialist opinion and considering all different treatment plans to cover all eventualities'. C18

Post CCSTs also responded with varying degree of confidence and responses:

'With the current training I feel more prepared to treat this case than before'. CCST1

Specialist orthodontists on the whole did not feel confident treating this case:

'Not experience to commit to its treatment'. S15

Q7: Are there any guidelines for the orthodontic treatment of MTA root end closured teeth? If so can you name it? If yes, they named the following guidelines:

The vast majority of orthodontists (77.6%) were aware that there is no guidelines available that have looked at the orthodontic treatment of teeth with immature apices or that have had apical plugs. Conversely, 22.3% believed a guideline was present and they cited Kindalan and Day, International

Association of Dental Traumatology (IADT), Royal College of Surgeons of England (RCS Eng), British Society of Paediatric Dentistry (BSPD) and Textbook of Dental Traumatology as presenting with current evidence and guidance on this subject matter. The result are shown in **Error! Reference source not found.** and **Error! Reference source not found.**.

Figure 4. 21: Vignette three – Are then guidelines for the orthodontic treatment of MTA root end closured teeth? If so can you name it?

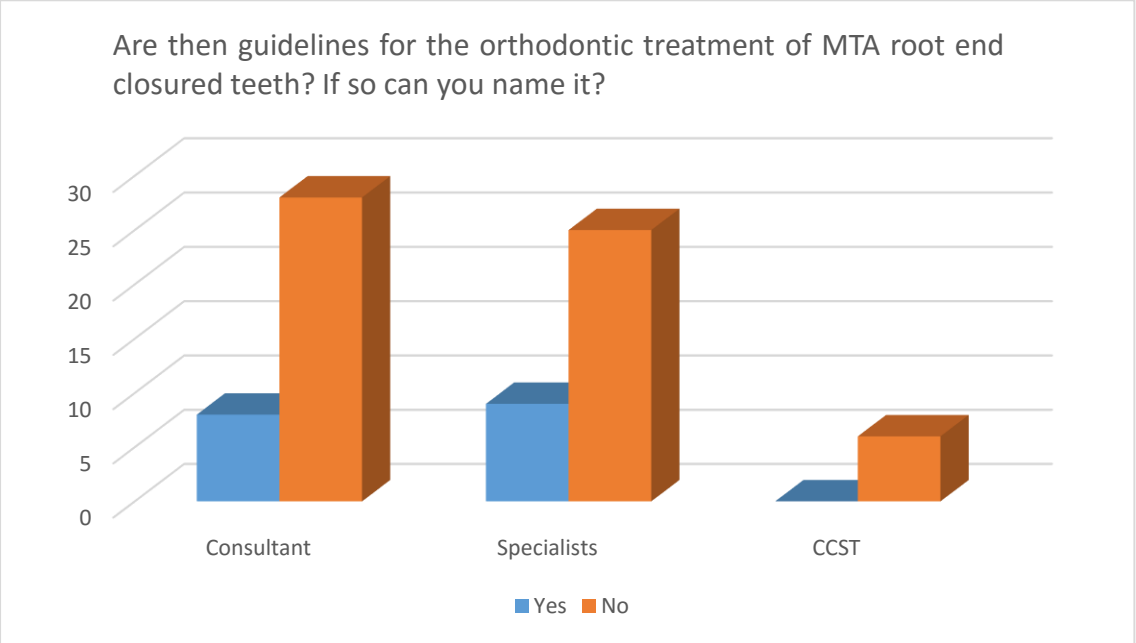
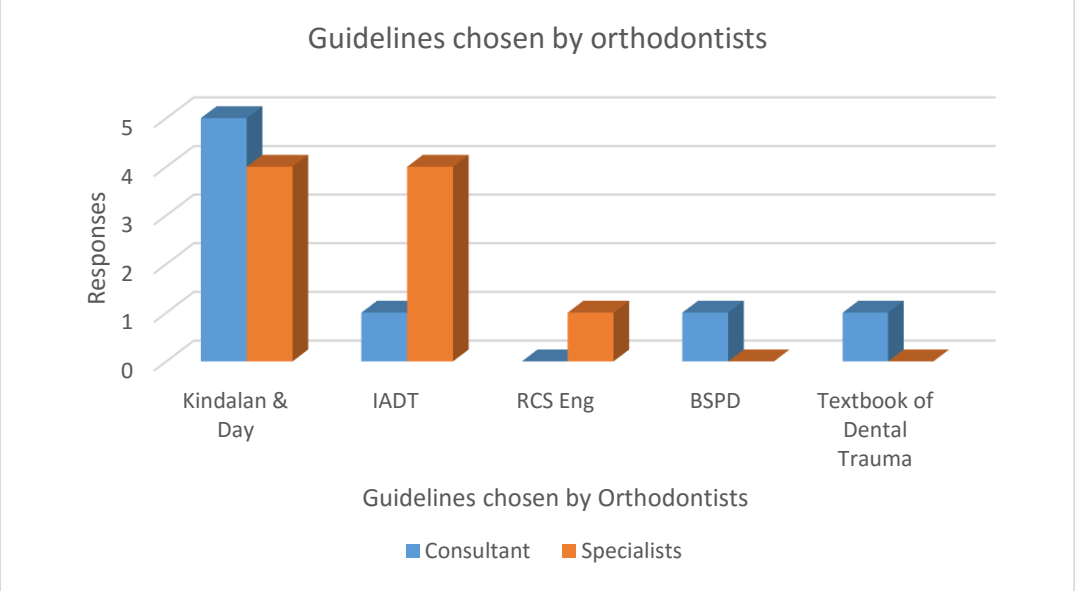


Figure 4. 22: Vignette three – Guidelines chosen by orthodontists?



4.5 Discussion

The study utilised an electronic online approach to collect data by subscribing participants to take part in the survey via emails and Facebook social media forums. Previous literature has highlighted the perceived potential benefits and drawbacks from web based surveys against traditional survey methods including face to face, traditional paper based surveys and telephone interviews. The latter forms are increasingly failing to provide qualitative results and data to a high standard especially within an ever evolving internet based working environment, furthermore, traditional survey methods are more time consuming to construct and are more expensive to run in comparison to web based surveys. The advantages of the traditional survey methods is that participants can be tracked and therefore can know with greater certainty the number of participants and drop outs making the process of identifying who hasn't completed the survey more predictable and easier to target. Another positive feature is randomisation and reduced bias with regards to the traditional survey, meaning anyone with an address can be targeted instead of online based surveys, which may bias those with no internet, no email, participants of an older population who may be unfamiliar with the use of online forums and therefore the participant mix may not be representative of the overall population.

Although web based surveys are now commonly used in market research and psychological studies, their frequent use in medical studies remains low at merely 1% of published articles (Ekman and Litton 2007). In addition, there are only a few successful studies that are currently available which has adopted the web based study, these are namely the Danish pregnancy planning study (Mikkelsen et al. 2009), the millennium cohort study (Smith et al. 2007) and the nurses and midwife electronic cohort

study (Turner 2008). Those studies were successful in collecting large sample numbers via web based portal and producing meaningful results.

Limitation of web based survey within this study

Although web based surveys carry many advantages, they also have their limitations which we encountered during this study. To begin with, we had many participants who contacted the author to mention that they did not receive the survey link via email and therefore couldn't take part in the study. Whilst the number of emails sent was low, nevertheless, the author was unable to determine how many participants received the survey and how many completed it. This is certainly well published in literature with non-delivery rates ranging from 18% - 67% (Fan and Yan 2010). Some of the reasons for the non-delivery could have been caused by the email sent to the participants spam file, wrong email address, participant deleting the email as they don't know the recipient, or participant has been emailed by other studies and fails to participate in the survey (Fan and Yan 2010).

Another limitation within this study is sampling bias. Some participants may lack familiarity of the internet and confidence in its correct usage. Some of the participants struggled to open the link to the survey and the researcher was made aware of this via verbal communication on the clinic. The link was examined and there was no issues in opening the link attached to the emails. Whilst this could have been a one off case, it is difficult to prove this across the vast number of participants recruited and this could be another reason for some participants not taking part in the study and giving up on it leading to non-response bias.

The internet seems to be used more often by younger, more affluent and educated urban populations compared to non-web users with males more likely to complete an online based survey compared to females participants. One reason for this is males maybe more comfortable with new technology whereas females maybe less self-sufficient in its use. Such limitations may question the generalisability of the web based surveys due to the non-respondent bias, coverage bias and self-selection bias which may not sample individuals who have the internet or chose not to access it.

Another limitation which may have been encountered within this study is that the survey could have been completed by a non-specialist orthodontists, as well as, possible duplication of the results within the software, this unfortunately cannot be tracked or accounted for as the software used doesn't have the ability to notify the researcher of this. This is a considerable drawback of using Facebook forums. This may possibly skew the results and dilute the generalisability of the overall results. (Basa-Martinez, Cabrera, and Dionaldo 2018; Yetter and Capaccioli 2010; Reips 2002).

The Survey design and piloting on orthodontic participation

With regards to the survey design, the survey had a clear title with a cover page that explained to the participant why the study was conducted and its importance to the research community, the length it would take to complete the survey, the sponsor which in this case is Liverpool University and the researcher, their grade and their supervisors. The participants were given the option to 'opt in' or 'opt out' at any point of the survey process, as well as the data being anonymised and data protected.

Literature has shown that respond rates by participants is linked to the topic, the length of the survey and the sponsor of the survey. Generally, higher survey rates were seen by sponsors of studies from academic or government agencies in comparison to commercial sponsors. They also responded highly when it's a subject of high salience and this is seen by some studies as one of the most important influencers in response rates within surveys (Fan and Yan 2010). Moreover, the sensitivity of the topic and whether facts are required to answer the survey also influences response rates. In addition, length of the survey had a negative effect (Fan and Yan 2010). The longer the survey with regards to time and effort the less interested participants were to partake in the study or they stopped responding part way through the survey. Length of a survey by some studies was deemed to include not only length in time but number of questions, number of pages and screens to complete. Several studies showed that a survey which took less than 13 minutes to complete was considered an ideal length to obtain a high response rate (Fan and Yan 2010; Nair, Adams, and Mertova 2008). With regards to the vignette study, the average time to complete the survey was less than 7.5 minutes, however, the cover

page stated it may take up to 15 minutes, this may have potentially turned off some orthodontists from completing the survey due to time constraints, perceived effort required to complete the survey, boredom, lack of interest or having a busy schedule and unable to free time to complete the survey (G. Smith 2008).

One way of improving the response rates for the study was to send two reminders to the participants at 2 month intervals, we hoped by prompting participants via email and facebook forums that more orthodontists would partake in the survey as well as remind participants who wanted to take part in the survey to hopefully do so. This form of positive notification and reminders has been shown by some studies to be one of the most important factors in predicting response rates (Porter 2004), with its effect being modest to doubling response rates in certain studies, moreover, some studies have suggested a period of 2-5 days to be the best time frame between the first pre-notification and reminder (Couper 2000; Fan and Yan 2010).

Orthodontist's teaching and trauma experience

There is a scarcity of vignette based surveys within orthodontics and a lack of research into the perspective of orthodontist's exposure, experience, training and treatment planning of traumatised teeth requiring orthodontic intervention and how this may impact on patient care. As far as we are aware only three study has looked into the orthodontist's knowledge of dental trauma and orthodontic management of traumatised teeth (Tondelli et al. 2010; Van Gorp et al. 2019; Sandler et al. 2019).

In this study, when comparing orthodontic consultants, orthodontic specialists and Post CCST trainees that orthodontic consultants were more involved in post graduate teaching, see a greater volume of traumatised teeth needing orthodontic consultation, had greater confidence with treating cases with complex dental trauma and felt they had sufficient postgraduate training to deal with dental trauma compared to their orthodontic specialist and post CCST orthodontic colleagues.

These results are unsurprising as orthodontic consultants usually undergo further training post specialisation in order to treat patients with more complex orthodontic treatment needs within secondary and tertiary care. Within the UK, orthodontic consultants have to undergo 2 years of Post CCST training. This training enables consultants to deal with cases of higher complexity, this would encompass cases of dental trauma that require orthodontic movement or an orthodontic opinion as part of a multi-disciplinary case.

With regards to postgraduate teaching consultant orthodontists, within the parameters of the study, showed the greatest involvement in supervision and seminar teaching of orthodontic specialists, Post CCST trainees as well as undergraduate students and orthodontic therapists. Orthodontists involved in teaching their peers will continue to evolve within their field of practice, from being competent clinicians technically, and being able to develop and execute the correct treatment plan for their own patients, to developing learning theories which enables them to bridge their thoughts and experiences to their students within the professional environment. The teacher experience, knowledge and effectiveness has been shown to improve with time. This was shown by Podolsky et al, reviewed over 30 studies and concluded that tutors experience and knowledge was positively associated with student achievement and their effectiveness as a teacher continues to develop with time (Podolsky, Kini, and Darling-Hammond 2019).

Furthermore, orthodontic consultants felt the most confident when dealing with cases of dental trauma compared to specialist orthodontists and Post CCST trainees. Literature has shown that clinicians carry out their professional duties more effectively and comfortably when they perceive themselves to be confident. This notion is underpinned by two rationales, the clinician's assessment of their knowledge, skills and previous experience as well as the clinician's belief on how successful they can be on achieving a particular task. Confidence is therefore contextual in nature and is therefore deemed subjective, personal and individual to each clinician. Another factor that cannot be understated and has an important contribution on an individual's development into a confident

clinician is learning amongst colleagues with similar objectives, skill sets and ambitions. This allows clinicians not only to learn from one another but also support each other and move forward together as a unit. Consultant orthodontists may have this support structure through their work in the hospital environment with multi-disciplinary teams and consultant colleagues. Multidisciplinary teamwork has been shown to be a core component to effective care delivery and enhances co-ordination between clinicians especially in clinician situations in which there is uncertainty regarding a treatment plan (Schepman et al. 2015).

Consultant orthodontists also work in secondary/ tertiary care setting and alongside other consultant specialists, this forms relationships between peers and allows dissemination and transfer of knowledge and experience from one colleague to another, furthermore, secondary/ tertiary care setting are designed to see more complex cases and through this referral pathway, orthodontic specialists refer many of their complex cases to the orthodontic consultants, cases such as trauma and its management within an orthodontic treatment plan.

This creates an environment where the orthodontic consultants will see a higher proportion of trauma cases and with experience and peer support develops greater confidence in the treatment of complex cases. Moreover, it maybe hypothesised that in secondary/ tertiary care orthodontic consultants may have the luxury of greater time to treat more complex cases with less financial clawbacks or penalties that orthodontic specialists in primary care maybe faced with. They may also have the comfort of working in larger teams and also alongside colleagues of different specialities which may help in the treatment planning of cases and shared knowledge. Many orthodontic consultants are also involved in the training of orthodontic specialists and post CCST trainees, this experience allows them to continue updating their clinical and academic knowledge as part of their working remit.

Conversely, orthodontic specialists work in primary care settings see a greater volume of cases of mild – moderate complexity, they may not have the facility or experience to treat cases of higher complexity which they will refer for a second opinion or treatment by a secondary/ tertiary care unit. Whilst this allows the patient to see a clinician with extended skills in dealing with their complex case, it may also, inadvertently also cause possible deskilling of specialist orthodontists who may examine and treat less patients with a history of trauma or feel a lack of confidence and training to do so and therefore refer on to a consultant orthodontists to treat the patient in the appropriate manner. These suggestions maybe substantiated by a UK based orthodontic survey study , in which the orthodontists highlighted the cause for referrals and this was guided by fear of litigation (0.47%), lack of training (8.1%), lack of experience (11%) and lack of guidelines (11.4%) (Sandler et al. 2019).

Orthodontist's pre-treatment examination

The frequency and number of cases with trauma or have had trauma under the care of participants differed between the grade of orthodontists. The majority of orthodontists examined a patient with a history of trauma every 3 or 6 months (28% and 33%), this was in line with another similar study which showed frequency of trauma in specialist practice to be 38.6% at 3 months and 33.3% at months (Sandler et al. 2019), in addition, over 38% of orthodontists had less than 5% of their patients who have had a history of trauma. As eluded previously, these results varies greatly with the grade of orthodontist. Orthodontic consultants see a greater number of trauma patients on a monthly and 3 monthly basis (31% and 35%) compared to specialists (3% and 17%) and post CCSTs (17% and 33%). Specialists seem to examine trauma sporadically at 6 months and 12 month intervals (41% and 38%) compared to consultants (25% and 3%) and post CCSTs at 33% and 17% respectively.

In hindsight, one question that should have been considered is to ask the orthodontists if they examine traumatised teeth prior to orthodontic treatment or rely on the patient's dentist to make this clinical examination and base their treatment on their judgement call. The current guidelines orthodontists

follow on the management of traumatised teeth underline a set plan on how to examine these teeth and their contra-lateral teeth prior to any intervening treatment (Kindelan et al. 2008). Ironically however, the results of this study showed that 58% of consultants would take an OPT radiograph to examine a tooth they suspected of having trauma compared to 35% of specialist orthodontists and 33% of Post CCST trainees. More surprisingly 70% of specialists, 67% of Post CCSTs and 33% of consultants do not carry out any form of sensibility testing for a traumatised tooth and that 33% of consultants and 24% of specialist would carry out a cold test alone in comparison to Post CCSTs who had no respondents to cold testing.

These results are lower than similarly published study that looked at the utilisation of sensibility tests at times of trauma between GDPs and paediatric specialists, the study showed that 93.7% of paediatric specialists routinely used dental pulp testers and that 98.7% of paediatric specialists would use pulp testers at initial consultations and regular intervals following dental trauma. GDPs in the same study used pulp testers regularly in 80.6% of the time and 83.8% following trauma and in regular intervals (Ghouth, Duggal, and Nazzal 2019). These results are far greater than this current survey would suggest with orthodontic specialists, however, this should not come as a surprise for several reasons:

- Patient with trauma will tend to see their own dentist, an emergency dentist who would examine, treat and stabilise the trauma.
- Orthodontists in general are not regarded the first line of referral for trauma cases and as such their interaction with trauma cases will be far less than general dentists or paediatric dentists. They will tend to see patients long after a trauma incident had occurred or when treatment has been stabilised by their dentist or by a referring specialist as part of an MDT case.

Vignette Scenario One

This scenario demonstrated a 12 year old boy with horizontal root fractures associated with the UL1 and the UR1 respectively, the patient was to have orthodontic treatment and it allowed the researcher to gauge the orthodontists on how they would plan the treatment of this case. The results showed that around 50% of the orthodontists in all grades would choose a second image being an occlusal oblique view, with 53% of consultants, 50% of Post CCSTs and 38% of orthodontic specialists taking a PA at 45 degrees. Interestingly 17% of consultants would request a CBCT. Surprisingly, 5% of consultants and 6% of specialists would take no radiographs at all for this presentation.

At present there is no protocol in place for the correct imaging choice following a horizontal root fractures. The IADT suggests a standard periapical should be able to demonstrate a coronal third fracture, however, due to the oblique nature of the horizontal fractures in the mid and apical third of the root then an occlusal oblique may help to locate and diagnose the fracture more accurately (Diangelis et al. 2012). CBCT have become an increasingly used modality in recent years and have been shown to be not only useful in diagnosing periapical disease but also luxation injuries associated with trauma (Palomo and Palomo 2009; Li et al. 2018). In certain cases when a standard periapical or occlusal oblique cannot locate a fracture, then CBCT maybe justifiable (Li et al. 2018). The drawbacks of CBCT is the increased radiation dose in paediatric cases as well as increased cost and the need to be able to read and interpret the CBCT findings. An OPT was the choice of radiograph for around 16% of all orthodontists, whilst still a commonly used radiograph for trauma, its accuracy is less than that of a PA or occlusal oblique due to superimposition of the radiation beam which may produce artefacts resulting in poor definition to be able to examine for a fracture correctly (Ridsdale 2013). The reason an OPT is taken by orthodontists could be several, including:

- Orthodontist take OPTs to examine not only the traumatised teeth but also the stages of tooth development of permanent teeth as part of their holistic treatment planning.
- Orthodontists may work in a teaching hospital or general district hospital where an OPT can be easily taken or is already present.

- Orthodontists are not the first line of treatment for trauma cases and it may be assumed that the treating dentist may have referred the patient with their PA's and therefore new Pas are not required. In addition, some of the trauma cases are being discussed in an MDT meeting where pre-treatment checks including a PA or other images have been already established.
- Orthodontists misunderstood the survey question.

When asked about the monitoring interval prior to orthodontic intervention, an array of results were evident with mixed views by the varying grades of orthodontists. The results showed that 39% of consultants, 18% of specialists and 67% of Post CCSTs would review the case for 12 – 24 months prior to any orthodontic intervention. This is in line with the guidelines proposed by Kindelan and Day which advised a waiting period of 1-2 years (Kindelan et al. 2008). The results of the specialists however, is very similar to a recently published survey which showed that 40.5% of orthodontists would wait 12 months before ay orthodontic movement of a root fractured tooth with a further 21.4% referring on for a second opinion (Sandler et al. 2019). In this study 41% of orthodontists in all grades would refer for a second opinion via MDT, whilst 21% of orthodontic specialists would never attempt the treatment of this tooth and therefore would assume referral to an orthodontic consultant.

This is unsurprising as the evidence regarding the treatment of root treated teeth is extremely weak within literature and is loosely based on literature reviews, opinion pieces and case reports, therefore, meaningful conclusions that are evidence based are hard to find, leaving many orthodontists unsure on how to proceed with treatment and left with ambiguity on how to take these cases forward. Therefore, many will refer looking for guidance from consultant colleagues or MDT meetings that will include a number of specialists discussing the case to come up with the best treatment strategy for the patient at hand.

When the orthodontists where probed about the possible risks associated with the orthodontic movement of a tooth with root fracture, many cited root resorption as the greatest risk followed by loss of tooth and increased mobility. With regards to endodontic complications, pulp necrosis and its

sequelae including discolouration, pulp canal obliteration and the need for root canal treatment were noted. The complications are frequently consented for by clinicians prior to the treatment of patients regarding orthodontic treatment and trauma. Some orthodontists, particularly specialist orthodontists chose to accept the malocclusion, this may be related to lack of experience or to simply limit any further insult to the tooth from orthodontic forces. Lack of literature and referral to MDT clinic was cited as a factors that may complicate treatment.

Vignette Scenario Two

Vignette scenario two asked orthodontists about their experience with regards to the treatment planning of an UL1 which had become discoloured after trauma with a diagnosis of pulp canal obliteration. When questioned about the sensibility test they would carry out to diagnose pulp vitality 17% of consultants, 41% of specialists and 17% of post CCSTs chose cold testing alone, in comparison to 67% of consultants, 44% of specialists and 50% of post CCSTs who would chose both electric pulp testing and cold testing.

Literature suggests that teeth that undergo periodontal ligament injury tend to have delayed response rates to sensibility testing for up to 9 months and sometimes longer after the initial stimulus (Alghaithy and Qualtrough 2017). Fortunately this lack of response is reversible over time with positive results to sensibility testing recorded over time. With regards to PCO, it is generally accepted that sensibility tests are unreliable with a progressive decrease in response rates to both thermal and electric pulp testing as the PCO becomes ever more pronounced (McCabe and Dummer 2012). However, teeth with partial PCO showed greater response to electric pulp testing than teeth with complete PCO, however, caution must be taken not to mistake a negative thermal or electrical pulp test for a non-vital pulp and other signs and radiographic images must be taken to collate further evidence of pulp necrosis (Alghaithy and Qualtrough 2017). Whilst there seems to be evidence to suggest EPT as the more appropriate test for PCO, care must be taken to differentiate this and false positive results which

maybe the case in children, anxious patients and patients with adjacent metallic restorations or innervation of the PDL rather than pulpal tissue (Jafarzadeh and Abbott 2010).

Surprisingly, 14% of consultants and 17% of post CCSTs did not carry out any testing. This result could have occurred due to:

- The answer being chosen by accident due to lack of concentration whilst filling out the survey.
- Consultants alongside Post CCSTs are based in secondary/ tertiary care centres where the patients with PCO are looked after by their restorative/ paediatric colleagues or GDPs and the prognosis and progression of the PCO is being reviewed regularly, meaning that the orthodontists are not the first line of examination for any injury, but rather, examining the viability of orthodontic movement and treatment planning rather than the prognostic care of the injured tooth in question.
- It could also be hypothesised that orthodontists may not feel comfortable examining injured teeth due to lack of training, experience or knowing what the look for in such cases and rely on their paediatric/ restorative or mono-specialist colleagues/ GDPs to monitor the prognosis of the injured tooth.

The orthodontists were questioned whether the PCO would alter their treatment management of the tooth, what they may do differently and what warning they would pre-empt to the patient. The answers positively show that many of the orthodontists diagnosed the tooth as having PCO due to the yellow discolouration. From an endodontic view point, they felt that PCO may lead to pulp necrosis and the need for endodontic intervention in the future. Some orthodontists felt it was best to monitor the pulp response clinically and radiographically, with periapical lesion being the cut off point for endodontic intervention, therefore, they were looking for 2 or more signs of non-vitality before

justification of endodontic therapy. The orthodontists were keen to give the tooth a chance and delay any need for endodontic therapy, thus encouraging a more conservative approach to the tooth.

The risk that most orthodontists worried about when applying orthodontic forces on a tooth with PCO is pulp necrosis. The literature on this is very weak, however, a systematic review carried out at Liverpool Dental School, which examined the effect of orthodontic treatment of traumatised teeth, showed that teeth with complete pulp canal obliteration that underwent orthodontic treatment had a greater risk of pulp necrosis compared to teeth with no PCO or partial PCO. So teeth with a visible canal maybe able to withstand the orthodontic forces applied to them and be able to maintain vitality over the course of the orthodontic therapy, it would however, be very difficult to determine if the tooth has lost vitality throughout treatment as orthodontic treatment in its own right can cause false negative results with sensibility testing, this may be the case for up to 3 months post orthodontic treatment and appliance debond.

The majority of the orthodontists were happy to immediately begin with orthodontic treatment, as discussed earlier, many would monitor the tooth clinically and radiographically for signs of pulp non vitality and deal with this complication if and when it occurred rather than delay the treatment given the severity of the malocclusion. This seems, on the whole, a wise option however, there is no evidence or guideline on this, and moreover, there are no studies that have looked into this previously.

It could be said, that with PCO that as long as there is no periapical lesion treatment can be continued as normal, showed there be a lesion then RCT would be initiated and treatment put on hold for 6 months to examine for resolution. Interestingly, CBCT was not mentioned as a method to examine the periapical tissue prior to orthodontic treatment, almost all the orthodontists mentioned periapical radiographs rather an exploring a CBCT image to determine the presence or absence of a periapical lesion. As discussed previously, CBCTs have become a more popular option amongst clinicians to diagnose periapical disease. Studies have also demonstrated that CBCTs showed 30% more periapical

lesions than a standard periapical radiograph (Patel et al. 2012; Patel et al. 2015). In this case, where orthodontics is to be carried out, it maybe justifiable to carry out a CBCT to examine the status of the periapical tissue prior to treatment as the tooth may very well be non-vital and have a periapical lesion which maybe in its early stages. Waiting in this case may cause an enlarged lesion which ironically, would be picked up with a standard periapical radiograph, however, prognostically, based on some studies, the lesion size may have a negative outcome on the endodontic therapy in the long term (Ng, Mann, and Gulabivala 2011b).

Vignette Scenario Three

This case explored the orthodontist's treatment planning of a non-vital of an UR1, otherwise asymptomatic with gradual grey discolouration and an immature apex. Orthodontists were asked whether to monitor or endodontically treat the UR1 prior to any orthodontic intervention. The written responses were varied with 36% of the orthodontists believing that the tooth is non vital due to the age of the patient and expected stage of root development, 20% answered that the tooth required root canal treatment as a result of the discolouration of the crown, 14% wished to monitor the tooth for a period of time to examine for any further root development and 17% wouldn't begin any treatment without a second opinion.

When examining the development of permanent central incisors, calcification begins at 3-4 months, the crown forms by 4-5 years and the root is completely developed by 9-10 years of age. Given the patient is 12 years old, it is unlikely that the tooth will continue to further develop and therefore (Welbury 2019), the majority of orthodontists diagnosis of pulp necrosis is justified, however, this diagnosis was made purely based on patients age, expected root development, root closure age and discolouration of the crown, none of the written responses eluded to the utilisation of sensibility tests to confirm diagnosis or having at least 2 signs to justify root canal treatment (Jafarzadeh and Abbott 2010).

There was a sizable minority of orthodontists who wished to monitor for root development, this is at odds with the majority of answers. The reason for this answer could be as a result of lack of knowledge on the subject matter, lack of experience to deal with such cases, reliance on the patients GDP to give a definitive treatment plan on this tooth prior to treatment or misunderstanding the question and responding to the answer in a manner that they wouldn't do in a day to day examination of similar patients. A further 17% would ask for a second opinion, this is understandable especially if they are unsure prior to commencing with orthodontic treatment, thus knowing their clinical limitation and asking for advice to give the patient the best treatment options possible and the best long term prognosis.

An interesting element within this question was examining who orthodontists would refer to for the root canal treatment and the reason behind their choice. The vast majority of specialists felt it was best to refer this case to a paediatric specialist. The reason for choosing a paediatric specialist was the patients age, many orthodontists felt that as the patient is 12 years old it falls under the remit of a paediatric dentist who are greatly trained to deal with the behavioural management of child cases, see greater cases of dental trauma than other departments, are best trained in trauma management and its sequalae but interestingly, many orthodontists work with a paediatric specialist or have a great local link with their paediatric department and feel they 'trust' their opinion and have great rapport with them.

Endodontists were the second most sought after speciality for referral of this case, the reason for this according to the answers were that endodontists are best trained in pulp therapy and its complications, have the best success rates, use magnification and specialist equipment and have the greatest technical experience to carry out this form of treatment. Literature has shown that endodontists have a high success rate when dealing with root canal therapy, some studies have shown a success rate of 83% for primary RCT and 80% for retreatment cases (Ng, Mann, and Gulabivala 2011b), whilst one study on endodontic specialist success rate showed rates of 94% for primary RCT

and 86% for retreatments (Imura et al. 2007). With regards to survival rates of endodontists, this was 95.4% for primary RCT and 95.3% for retreatment cases (Ng, Mann, and Gulabivala 2011a). These studies however, were not based on specialists but postgraduate students undergoing specialist training, furthermore, success and survival whilst interlinked are also based on many other prognostic factors and therefore, they can only be assessed on a case by case basis as well as clinician by clinician basis.

Available referral services were cited as a factor when wanting to referrer patients for clinical care and who to refer to, some orthodontists had no local referral services and patients had to travel considerable distances to local dental hospitals for treatment with considerable waiting times. Others specified that they referred to restorative dentists as they were the only specialists around at the local district general hospital.

Several orthodontists explained that there were no specialist endodontists in the local area to refer to and this prompted them to refer to a consultant orthodontist instead for a further opinion. The referral pattern is therefore being dictated by the available specialists or in some cases the lack of any specialists in the area they reside and clinically work in. This lack of services and shortage of GDPs in the UK has been already highlighted by the British Dental Association, in 2019 LaingBuisson's UK Market Report, showed a 22% reduction in new dental registrations over the last 2 years compounded by a greater drop in EU dentist registration within the UK following the recent Brexit vote and economic as well as policy insecurity(BDA 2019). Furthermore, the current shortfall of the UDA (Unit of Dental Activity) contract and the reduction of its value over the years has created a recruitment and retention problem in many areas within the UK. The UK government currently spends £32.6 million on upskilling dentists within its Dental Core Training and Specialist training programmes, however the majority of the programmes, 45% are based in London were only 16% of the population reside (Assael 2017). East of England was the most disadvantaged area and this does reflect to the answers by many orthodontists, that geographical location plays a large role on where patients can be referred to and

it comes down to the 'postcode lottery' as with many other medical services across the UK. These statistics by HEE England doesn't reflect the fact that the majority of monospecialist training programmes are 3-4 years in duration and are self-funded by the trainee, many of which commit their clinical work in the private sector, this has an implication on accessibility to patients who cannot afford the cost of private treatment and cannot gain access to such specialist treatment under the NHS where there is a lack of monospecialists working within the national health system. Moreover, the number of monospecialists being trained in the UK and currently on the list are low and cannot meet the demand of the UK population as a whole or help train the future work force of general dentists or specialists (Assael 2017).

When looking at the monitoring time for this case prior to starting orthodontic treatment the majority of consultants (39%), specialists (29%) and post CCSTs (33%) would wait 6 months before proceeding with treatment. Around 1/5 of consultant (17%) and specialists (21%) would refer the patient for a second opinion prior to treatment. However, 12% of specialists wouldn't carry out the treatment. Again, there is no literature that has looked into the effect of orthodontic treatment on teeth with an open apex with our without apical closure. Kindelan and Day suggested examining the tooth radiographically at 6, 12, 24 month period to check for root closure and continued development (Kindelan et al. 2008). It could be argued that a tooth requiring an apical plug can be viewed similarly as a root treated tooth, however, this is too simplistic as many teeth with an open apex can clinically have a short crown to root ration, thin root walls and maybe at greater risk of fracture if temporised for a period of time with non-setting calcium hydroxide. The timing of treatment with root treated teeth is also based on the presence or absence of a periapical lesion and the type of trauma the tooth has sustained.

The orthodontic movement of teeth with an open apex, as explained, has been poorly studied in literature. A systematic review by Milhem et al, which examined the results of 4 papers which were finally included as part of its inclusion criteria, found conflicting results (Wasserman-Milhem 2016).

The systematic review had two conclusions, the first being that immature teeth underwent less root resorption, however, if the duration and force of treatment is high and long then their risk is comparable to teeth with closed apices. Secondly, starting orthodontic treatment prior to full apical closure in immature teeth may reduce root resorption risk, however, this study did not take into effect other confounding factors such as genetics, systemic disease, allergy, trauma or habits.

A recurrent theme with all the vignette scenario is lack of guidance and literature on this topic, 16% of all specialist felt that there was a lack of guidance on this matter. 17% felt a lack of experience treating this case with 25% of clinicians referring this type of case on for a second opinion before committing to any orthodontic intervention. Furthermore, when probed on guidelines referring to the orthodontic movement of MTA root end closed teeth and orthodontic movement, the vast majority of specialists highlighted a lack of guidance or literature. Those who replied positively to this question stated the paper by Kindelan and Day, IADT, BSPD, RCS Eng and textbook of dental trauma as stating guidelines on this topic, unfortunately, these sources have no guidelines on this topic.

Generalisability of the study

This study recruited specialist orthodontists who are registered with the UK General Dental Council. The findings of this study therefore cannot be generalised to setting and backgrounds out with the UK, such as non UK trained orthodontists, DWSI in orthodontics, orthodontist practicing outside the UK or any other speciality.

Application of the Results

The participant population for this study were UK registered orthodontic specialists who are currently residing and practicing in the UK. Males and females included in the study were almost even, however, this was by chance as here was no direct way to making sure this would take place given the nature of the web based application of the survey, meaning there was no control over the gender, race, age, city or university they had trained in or the practice setting they work in predominantly. This lack of

control over the participant group may have had a negative impact on the generalisability of the results. This could be seen in the disproportionate number of consultant orthodontists recruited to the study compared to specialist orthodontists. However, a study conducted by the University of Leeds, which recruited 210 respondents, of which 43.8% (n=92) were specialist orthodontists, did not state the number of consultants within that cohort of specialist, furthermore, they also included non-specialists from a GDP background with MSc's or MClinDent degrees to participate in the study. The results therefore of this publication, may not be truly representative of the orthodontist population. It can therefore be said, that the vignette study and its results have greater generalisability and application to the orthodontist population in the UK than previously published studies.

The online, web based sampling method which utilised Facebook forums and emails meant that the sample of participants was a sample of convenience, due to the aim of the study to recruit as many people to the study as possible to gain a richer data set. The sample was also not selected randomly, meaning that selection bias of the participants must be considered within this research study.

4.6 Conclusion

The effect of orthodontic movement on traumatised teeth and its impact on orthodontists treatment planning is a key concern shared amongst many orthodontists. This impacts orthodontists in various ways based on training, experience, environment, teaching experience, lack of tangible evidence and guidelines on this subject matter, all of which has created an environment of ambiguity in the treatment planning of many commonly reported dental injuries and their complications with regards to orthodontic interception.

A core finding was the lack of trauma training throughout orthodontic specialist training, orthodontists as a whole felt that their orthodontic training lacked trauma management and experience, this seemed to be less of a case for orthodontic consultants who may have had additional training in trauma management and higher complexity cases within their extended post CCST training pathway. This finding can also explain the lack of confidence orthodontic specialists have in dealing with dental trauma and its orthodontic management. Consultants in general however did not share this lack of confidence and this again could be down to their continued up to date knowledge acquired from teaching postgraduate orthodontic trainees, the dental environment they work in with its multidisciplinary background and also the experience gained from treating a greater number of trauma patients, as seen in this study, in comparison with specialist orthodontists examine less traumatised cases and have a greater referral pattern to MDT clinics.

Another conclusion is the lack of a uniformed consensus in the orthodontic management of traumatised teeth. It is evident that there is no standardised pre-examination protocol in the evaluation of traumatised teeth amongst orthodontists and a greater reliance of referrals of such cases to consultant orthodontists from specialist orthodontists due to the ambiguity surrounding treatment planning these cases.

A notable conclusion cited by the orthodontists in a lack of evidence and robust guidelines to treatment plan traumatised teeth, this is leaving many clinicians feeling uneasy at treating higher

complexity cases of trauma due to common complications that can be encountered as well as, in some cases, a lack of certainty about potential risks associated with certain traumatic presentations. This is further confounded by a lack of referral services in some areas to ask for a second opinion from a consultant orthodontist colleague and reliance on paediatric specialists to help manage traumatic cases. These accumulation of factors are negatively contributing to a lack of confidence within the majority of orthodontists to treat patients with a history of dental trauma.

Chapter Five: Conclusions and Future Research

5.1 Overall Conclusions

The aim of this study project was to examine the current literature surrounding the effect of orthodontic treatment on traumatised teeth and its endodontic implications. This was carried out by analysing the current literature through a carefully constructed question and pre-planned inclusion and exclusion criteria which answered this question through a systematic review. The results of which incentivised the utilisation and design of a web based vignette study to understand orthodontist's perspective of dental trauma and how this may affect their orthodontic management of these cases, by exploring their background, teaching experience, trauma experience and how they may tackle three vignette, true to life scenarios through open and close ended questions and analysing their written responses to formulate themes to gain a primary understanding of their experiences, limitations and difficulties with such cases. The conclusions of the studies were discussed in-depth in both chapters 3 and 4 respectively, the main conclusions were as follows:

6. Literature regarding the effect of orthodontic treatment on traumatised teeth is scarce within current known literature with a lack of robust published scientific evidence.
7. A history of dental trauma maybe considered a risk factor for potential loss of vitality and pulp canal obliteration during or after orthodontic treatment.
8. The evidence surrounding the risk of root resorption from the accumulative sequalae of orthodontic treatment and dental trauma is inconclusive, however, there seems to be no greater risk of root resorption in both hard and periodontal tissue injuries.
9. Orthodontists should be aware of this risk and the pulpal condition of the traumatised teeth should be monitored frequently throughout the orthodontic treatment and retention period.
10. The lack of evidence based knowledge surrounding this subject matter has contributed to a lack of guidance within the orthodontic field in the treatment management of traumatised

teeth within an orthodontic environment leading to ambiguity in treatment planning as well as:-

- Increased referrals to paediatric, orthodontic and endodontic specialists with a knock on effect leading to greater waiting times, greater patient and parent inconvenience, the need to travel greater distances for treatment provision at increased financial and time cost to parents and guardians, as well as, an increased demand for specialist services at a time of fiscal constraints within the NHS coupled.
- Confusion amongst orthodontists with regards to waiting times for various injuries prior to orthodontic treatment.
- Lack of trauma experience within their orthodontic specialist training and postgraduate orthodontic trauma refreshment CPD courses.
- Reliance on general dental practitioners in the trauma management and review of cases, who themselves may possibly feel uneasy and lack confidence, training and experience in dealing with trauma. Thus leading to trauma mismanagement, misdiagnosis and planning leading to reduced outcomes.
- From a public viewpoint, the above named factors may help government bodies, educational institutes, health authorities and commissioners to explore these deficiencies, given that the NHS financially provides funding for orthodontic provision to children of certain age groups and complexity within the UK. The high prevalence of dental trauma which, in many circumstances is linked to malocclusion, may prompt commissioners to evolve specialist training programmes, undergraduate dental programmes and postgraduate CPD programmes to improve teaching of dental trauma, as well as, preventative programmes that educate clinicians to spot patients which maybe more prevalent to trauma within a population base and thus reducing long term cost of care provision.

5.2 Clinical Implication

The systematic review and the qualitative study, raised the following points:

- Lack of literature and robust clinical guidelines

The systematic review as well as the literature review both shed light on the limited knowledge that surrounds the topic of orthodontics treatment and its interplay with trauma. The current evidence is made of literature reviews and opinion pieces which are backed by low grade evidence. This very evidence is outdated, whereby the orthodontic treatment carried out utilised outdated techniques which are now out of touch with modern orthodontic principles. Furthermore, the sample sizes in many of the studies were far too small to be able to get meaningful outcomes. All the studies examined are retrospective in nature and the patients included in the studies had sustained a variety of dental traumas, which may have been inaccurately recorded with possible misdiagnosis and reliance of patient's recollection of their trauma, all these factors add great bias in the studies. In addition, within the same studies various orthodontic treatments, forces, durations and treatment modalities were adopted. These additional factors coupled with the uncertain trauma diagnosis creates multifactorial data, the outcome of which cannot be relied on in day to day clinical use.

The lack of current literature is reflected in the current guidelines which does not cover all pulpal complications, some notable examples is pulp canal obliteration and orthodontic treatment of immature apices with or without an apical plug. The monitoring times are based on trauma and perceived complications to the pulp and not the accumulative effect of trauma and orthodontic movement. This ambiguity in literature means that treatment plans are based on anecdotal or clinicians own experiences rather than evidence based approaches. This approach may leave clinicians and patients vulnerable to unknown clinical implications of treatment, as well as, changes in treatment plans and additional treatment for unexpected complications such as root canal treatment or tooth loss.

It is worth noting that the current guidelines are over 10 years ago and although this is outdated there is no emergence of new evidence to merit re-writing it. Much of the guidelines written are based according to the findings of Andreasen and his colleagues (Andreasen et al. 2007). This evidence did not examine the effect of orthodontic treatment on these traumatised teeth, therefore, the guidelines are based on weak evidence that doesn't factor orthodontic intervention, that said this is the best evidence at present and the original attempt to write these guidelines has to be applauded.

- Implication on clinicians and patient care

The study has highlighted inadequacies within current orthodontic specialist training. Many specialists as well as consultants lacked confidence, experience and training in dental trauma. This has a negative impact on patient clinical care on various levels. Looking at the current orthodontic specialist training curriculum, the training of orthodontists is under 'Module 31 – Orthodontics and Restorative dentistry'. Many orthodontists, I suspect, would have had insufficient training in trauma from undergraduate level and this lack of confidence, experience has continued throughout their clinical journey as general dental practitioners and throughout specialist training. The fall out effect of this could be specialist's lack of experience to diagnose various forms of dental trauma, may not have the diagnostic knowledge to treatment plan trauma cases through the correct use of sensibility testing and radiographic imaging and thus lack of overall management of traumatic dental injuries. The need for orthodontic management further adds to this lack of experience, meaning many specialists would rather refer these cases for a second opinion and in some cases not treat such cases at all.

These all have implications on patient care, namely, knowing when to treat versus how long to monitor the tooth/ teeth prior to any orthodontic movement, knowing how to consent patients who have had trauma and needing orthodontic care, knowing the complications their orthodontic treatment will have on the prognosis of the tooth. This lack of training translates into potential failure of orthodontic treatment or increased risk of complications, frustrated patients, lack of trust in orthodontic provision and the dental profession.

A notable trend in dentistry is the rise of orthodontic treatment in adult patients using 'Short term' orthodontic devices. The lack of orthodontic knowledge in this field may have a knock on effect on adult patients as well as GDPs confidence in orthodontists, who may ask for a second opinion or advice before carrying out similar treatment in primary care settings.

One measurement that can help reduce some of this confusion and ambiguity is to create dedicated trauma clinics for orthodontists within their specialist training. This can be in the form of shadowing or the treatment of cases seen in paediatrics or restorative clinics. A dedicated trauma clinic may give orthodontists greater first-hand experience with trauma, its diagnosis and treatment planning and dealing with complications that may result from this. This experience can be strengthened by studying dental trauma and the literature surrounding trauma in more depth and not only looking at its implications to orthodontic therapy but knowing the implications of trauma in general would give greater foundations going forward. This can all be integrated into a modernised curriculum for orthodontic specialist training which meets the demands of the patients of today. For qualified clinicians, CPD events updating orthodontists on trauma, its complications and implications to orthodontic provision may help reduce some of the anxiety surrounding this subject manner.

Another implication to patients, as seen in the studies, is a lack of dedicated trauma centres, this like many other services in the NHS are based on the postcode lottery. A lack of services means reliance on general practitioners and other specialists to manage dental trauma. These clinicians, like orthodontists may share a similar lack of confidence to deal with trauma and its sequalae. The rise of litigation within the dental industry has meant that many clinicians, with the lack of confidence, competence and training in dental trauma, alongside lack of local services, refer patients to consultants in secondary and tertiary care setting. This will overburden an already stretched, underfunded and understaffed NHS service. The outcome of which is longer waiting lists, disgruntled patients and parents and possibly detrimental effect on teeth which have had dental trauma, which could have been treated sooner with better or more predictable outcomes. Further to that,

endodontists are not seen by many orthodontists as a first call of referral following trauma. Endodontists, are on the whole, the most well trained clinicians when dealing with pulpal disease and its complications, they need to be more involved in dental trauma and its treatment, either through trauma clinics or 'Managing Clinical Networks (MCNs) set up by local NHS trusts. These networks will allow dentists, orthodontists and endodontists to liaise with one another and be able to follow up patients within primary care setting, thus reducing the stress on secondary and tertiary care, as well as, reducing waiting lists and allowing patients to see the right clinicians at the right stages of treatment.

5.3 Future research

In order to investigate the clinical significance of orthodontic therapy on traumatised teeth, further research is required to evaluate the true extent and effect of orthodontics, with it variability in treatment, on teeth with a history of dental trauma and the array of injuries and complications within a clinical setting, as well as, long term outcomes for the tooth and the individual it affects.

Current literature on the effect of orthodontic treatment on traumatised teeth is extremely limited. Most studies on this subject are record linked and retrospective in nature. Moreover, these studies are based on small sample sizes involving a wide presentation of dental trauma, on a wide spectrum of dental age groups and malocclusions. Furthermore, the orthodontic treatment varies across studies and usually carried out by one examiner in a private practice setting rather than a multicentre setting. This leads to possible misdiagnosis, mistreatment, subjectivity on differing views on the management of dental trauma within various settings and various countries and their help belief on the best way to manage and stabilise trauma as well as, the orthodontic treatment of the teeth in the future. All of this may result to a lack of definitive conclusions to be drawn. In addition, it is very difficult, if not impossible to conduct future studies involving dental trauma subjects due to the sensitive nature of the injury and age groups of paediatric patients, thus ethical approval within these parameters may never been granted and the cultivation of which is reflected in literature by the lack of current

evidence based approach to this matter. Kindelan et al 2008, to date is the only published review which discusses dental trauma and its influence on orthodontic management. This published work is perceived by many orthodontists as the best evidence within orthodontics (Kindelan et al. 2008).

Future research is required to study the effect of orthodontic treatment on traumatised teeth, one suggestion could come from the development of the 'Core Outcome Sets (COS)' for traumatic dental injuries in children and adults as set out by the International Association of Dental Traumatology (IADT)(Day 4 July 2014). The aim of the COS is to define what outcomes are collected, how they are measured and at what time intervals with patients who have suffered from dental trauma. COS will help collate data for evidence based comparisons of dental trauma treatment and interventions, which at present is challenging due to the diversity of outcomes reported in clinical studies based on a variety of different interventions and treatment modalities. Furthermore, many clinical studies favour the publications of interventions with a positive outcomes which adds bias in outcome reporting (Williamson et al. 2012; Sinha, Smyth, and Williamson 2011).

To address many of the current challenges in clinical traumatology research COS can be utilised to an agreed standardised collection of outcomes. This would allow researchers and clinicians to compare similar outcomes of various interventions over a larger population sample to compare effectiveness of interventions and promote changes in guidelines in the treatment of dental trauma and orthodontic treatment of traumatised teeth (Sinha, Smyth, and Williamson 2011; Williamson et al. 2012).

Appendix 1: Electronic database search results

Electronic Databases	Date searched	No. retrieved
Cochrane Database of Systematic Reviews – CDSR (Cochrane) and Cochrane Central Database of Controlled Trials – CENTRAL (Cochrane)	23/07/2019 (2017-2019)	8
Database of Abstracts of Reviews of Effect	23/07/2019 (2017-2019)	0
MEDLINE (Ovid), Epub ahead of print and MEDLINE In-Process (Ovid)	23/07/2019 (2017-2019)	184
EMBASE (Ovid)	23/07/2019 (2017-2019)	114
Web of Science	23/07/2019 (2017-2019)	35

Electronic Databases	Date searched	No. retrieved
Cochrane Database of Systematic Reviews – CDSR (Cochrane) and Cochrane Central Database of Controlled Trials – CENTRAL (Cochrane)	24/07/2017	139
Database of Abstracts of Reviews of Effect	24/07/2017	5
MEDLINE (Ovid), Epub ahead of print and MEDLINE In-Process (Ovid)	24/07/2017	2297
EMBASE (Ovid)	24/07/2017	2348
Web of Science	24/07/2017	250

Appendix 2: CDSR/ CENTRAL Database search

CDSR/ CENTRAL Database	
#1 MeSH descriptor: [Tooth Movement Techniques] explode all trees	190
#2 MeSH descriptor: [Malocclusion] explode all trees	686
#3 MeSH descriptor: [Orthodontics] explode all trees	2457
#4 ((tooth* or teeth*) near/4 (depress* or intrus* or move* or upright*)):ti	90
#5 (malocclus* or orthodontic*):ti	1381
#6 #1 or #2 or #3 or #4 or #5	3177
#7 MeSH descriptor: [Tooth Injuries] explode all trees	243
#8 MeSH descriptor: [Tooth Fractures] explode all trees	188
#9 ((tooth* or teeth* or root* or alveolar or dento-alveolar) near/4 (fractur* or injur* or trauma*)):ti	111
#10 MeSH descriptor: [Root Resorption] explode all trees	104
#11 MeSH descriptor: [Dental Pulp Diseases] explode all trees	517
#12 MeSH descriptor: [Dental Pulp Necrosis] explode all trees	103
#13 MeSH descriptor: [Tooth, Nonvital] explode all trees	172
#14 MeSH descriptor: [Root Canal Therapy] explode all trees	998
#15 MeSH descriptor: [Apexification] explode all trees	10
#16 MeSH descriptor: [Dental Pulp Devitalization] explode all trees	2
#17 MeSH descriptor: [Tooth Root] explode all trees	725
#18 Root* canal* Therapy*:ti	81
#19 ((tooth* or teeth*) near/4 (non vital or nonvital or root* or apex*)):ti	125
#20 (dental near/3 pulp near/3 (disease* or necrosis or devitali?at*)):ti	1
#21 MeSH descriptor: [Tooth Apex] explode all trees	275
#22 apexificat*	23
#23 MeSH descriptor: [Tooth Avulsion] explode all trees	23
#24 ((tooth* or teeth*) near/4 (concuss* or subluxat* or extrus* or lateral luxat* or intrus* or avuls*)):ti	16
#25 MeSH descriptor: [Endodontics] explode all trees	1251
#26 Endodon*:ti	483
#27 #7 or #8 or #9 or #10 or #11 or #12 or #13 or #14 or #15 or #16 or #17 or #18 or #19 or #20 or #21 or #22 or #23 or #24 or #25 or #26	2286
#28 #6 and #27 Publication Year from 1980 to 2017	144

Appendix 3: Medline Searches

Medline	
1 Tooth Movement Techniques/	8042
2 malocclusion/	23243
3 exp Orthodontics/	49801
4 ((tooth* or teeth*) adj4 (depress* or intrus* or move* or upright*)).ti.	1918
5 (malocclus* or orthodontic*).ti.	23995
6 or/1-5	65164
7 tooth injuries/ or tooth fractures/	7986
8 ((tooth* or teeth* or root* or alveolar or dento-alveolar) adj4 (fractur* or injur* or trauma*)).ti.	3699
9 "Root Resorption"/	3196
10 dental pulp diseases/ or dental pulp necrosis/ or tooth, nonvital/	6475
11 "root canal therapy"/ or apexification/ or dental pulp devitalization/	12710
12 "Tooth Root"/	12499
13 Root* canal* Therapy*.ti.	616
14 ((tooth* or teeth*) adj4 (non vital or nonvital or root* or apex*)).ti.	1992
15 (dental adj3 pulp adj3 (disease* or necrosis or devitali?at*)).ti.	81
16 Tooth Apex/	2560
17 apexificat*.tw.	399
18 Tooth Avulsion/	2254
19 ((tooth* or teeth*) adj4 (concuss* or subluxat* or extrus* or lateral luxat* or intrus* or avuls*)).ti.	548
20 Endodontics/	1959
21 Endodon*.ti.	9446
22 or/7-21	43237
23 6 and 22	3379
24 limit 23 to english language	2848
25 limit 24 to yr="1980 -Current"	2615
26 animals/ not humans	4405525
27 25 not 26	2332
28 remove duplicates from 27	2297

Appendix 4: EMBASE searches

EMBASE	
1 Tooth Movement Techniques/	259
2 malocclusion/	28009
3 exp Orthodontics/	31970
4 ((tooth* or teeth*) adj4 (depress* or intrus* or move* or upright*)).ti.	1731
5 (malocclus* or orthodontic*).ti.	21551
6 or/1-5	54033
7 tooth injuries/ or tooth fractures/	5881
8 ((tooth* or teeth* or root* or alveolar or dento-alveolar) adj4 (fractur* or injur* or trauma*)).ti.	3446
9 "Root Resorption"/	19641
10 dental pulp diseases/ or dental pulp necrosis/ or tooth, nonvital/	7114
11 "root canal therapy"/ or apexification/ or dental pulp devitalization/	434
12 "Tooth Root"/	13935
13 Root* canal* Therapy*.ti.	435
14 ((tooth* or teeth*) adj4 (non vital or nonvital or root* or apex*)).ti.	1741
15 (dental adj3 pulp adj3 (disease* or necrosis or devitali?at*)).ti.	59
16 Tooth Apex/	321
17 apexificat*.tw.	334
18 Tooth Avulsion/	3450
19 ((tooth* or teeth*) adj4 (concuss* or subluxat* or extrus* or lateral luxat* or intrus* or avuls*)).ti.	496
20 Endodontics/	26679
21 Endodon*.ti.	8370
22 or/7-21	63733
23 6 and 22	4289
24 limit 23 to english language	3265
25 limit 24 to yr="1980 -Current"	2920
26 animals/ not humans	4021302
27 25 not 26	2862
28 remove duplicates from 27	2348

Appendix 5: Web of Science Searches

Web of Science		
# 15	250	#14 AND #3
# 14	10,396	#13 OR #12 OR #11 OR #10 OR #9 OR #8 OR #7 OR #6 OR #5 OR #4
# 13	289	TI=((tooth* or teeth*) near/4 (intrus* or avuls*))
# 12	3	TI=((tooth* or teeth*) near/4 lateral luxat*)
# 11	48	TI=((tooth* or teeth*) near/4 extrus*)
# 10	4	TI=((tooth* or teeth*) near/4 (concuss* or subluxat*))
# 9	5,789	TI=(apexificat* or Endodon*)
# 8	17	TI=(dental near/3 pulp near/3 (disease* or necrosis or devitali?at*))
# 7	1,531	TI=((tooth* or teeth*) near/4 (nonvital or root* or apex*))
# 6	61	TI=((tooth* or teeth*) near/4 non vital)
# 5	189	TI=Root* canal* Therapy*
# 4	3,040	TI=((tooth* or teeth* or root* or alveolar or dento-alveolar) near/4 (fractur* or injur* or trauma*))
# 3	14,123	#2 OR #1
# 2	13,300	TI=(malocclus* or orthodontic*)
# 1	1,525	TI=((tooth* or teeth*) near/4 (depress* or intrus* or move* or upright*))

Appendix 6: Table of excluded studies

Study	Year	Country	Reason for exclusion
Owtad	2015	USA	Case report
Duggal	2015	UK	Literature review
Gutmann	2014	USA	Literature reviews
Costi	2014	USA	Literature review
Beck	2013	New Zealand	Literature review
Fields	2013	USA	Literature review
Kupar	2013	India	Case report
Mendoza	2010	Spain	Case report
Tondelli	2010	Brazil	Literature review
Bauss	2008	Germany	Research did not evaluate the association between of orthodontics and trauma
Kindelan & Day (a)	2008	UK	Literature review
Kindelan & Day (b)	2008	UK	Literature review
Healey	2006	New Zealand	Case report
Duggan	2005	Ireland	Case report
Kugel	2005	Germany	Research did not evaluate the association of orthodontic and trauma
Erdemir	2005	Turkey	Case report
Bauss	2004	Germany	Research did not evaluate the association between of orthodontics and trauma
Atack	1999	UK	Literature reviews
Linge & Linge	1991	Norway	Research did not evaluate the association between of orthodontics and trauma
Turley	1984	USA	Animal study
Hovland	1983	USA	Case report
Hines	1979	USA	Research did not evaluate the association between of orthodontics and trauma
Zachrisson	1974	Norway	Case report

Appendix 7: Inclusion and exclusion criteria

Study	Inclusion criteria
Bauss 2008 (a) (Bauss et al. 2008 (a))	**OT and O group** 1. Class 2 Div 1 with a deep bite 2. Orthodontic treatment with molar and incisor banding with utility arch wire to intrude maxillary incisors 3. No extraction of maxillary teeth 4. No additional lateral movement of maxillary incisors **Additional criteria OT group** 1. Complete dental records with initial classification of dental trauma. If more than one injury to the tooth, the most serious injury was used. 2. Positive sensitivity testing prior to orthodontic treatment. 3. Pre-and Post-treatment IOPA with results of post treatment sensitivity testing. **T Group** 1. Positive sensitivity testing after trauma 2. Minimum follow up for 3 years after trauma
Bauss 2008 (b) (Bauss et al. 2008)	**OT Group** 1. Class 2 Div 1 2. Increased overjet and overbite 3. Orthodontic intrusion of maxillary incisors 4. Traumatised teeth with positive sensitivity test 5. No history of multiple dental trauma 6. Hard tissue injury 3-month healing period prior to orthodontic treatment 7. Periodontal injury, 12 months of healing period prior to orthodontic treatment **C group** 1. IOPA after initial trauma and during final follow up 2. No pulp obliteration on initial PA 3. Positive sensitivity testing during the first 6 months after trauma 4. Minimum 3 year follow up after trauma 5. No orthodontic treatment 6. No grinding habit or restorative therapy on the traumatised tooth
Bauss 2009 (Bauss et al. 2009)	1. Maxillary Incisors 2. Complete dental records with initial classification of dental trauma. If more than one injury to the tooth, the most serious injury was used. **OT Group** 1. Positive sensibility testing of the traumatized teeth before resumption of orthodontic treatment 2. No clinical or radiologic signs and no history of dental trauma before onset of orthodontic treatment 3. A minimum treatment period of 6 months after trauma 4. Exchange of at least two archwires prior to termination of orthodontic treatment 5. No extreme intrusive, extrusive, or lateral tooth Movements 6. A follow-up period of at least 6 months after termination of active orthodontic treatment **O Group** 1. no clinical or radiologic signs and no history of dental trauma before, during, or after orthodontic treatment. 2. positive sensibility testing before onset of orthodontic treatment 3. A follow up period of at least 6 months after termination of orthodontic treatment. **T Group** 1. positive sensibility testing during the first 6 months after dental trauma. 2. minimum follow-up period of 3 years after dental trauma. 3. no subsequent grinding or filling therapy after trauma. 4. no history of multiple dental trauma

Bauss 2010 (Bauss et al. 2010)	**OT group** 1. Complete dental records with initial classification of dental trauma. If more than one injury to the tooth, the most serious injury was used. 2. Positive sensitivity testing prior to orthodontic treatment. 3. Pre-and Post-treatment 4. Post treatment sensitivity testing. **T Group** 1. Positive sensitivity testing after trauma 2. Minimum follow up for 3 years after trauma
Brin 1991 (Brin et al. 1991)	**OT, T, O groups** 1. Records which included history of injury and/ or orthodontic treatment. 2. Clinical examination including electric pulp test 3. Periapical radiographs of maxillary teeth with evaluated: I. Arrest of root formation II. Pulp Obliteration III. Root resorption
Malmgren 1982 (Malmgren et al. 1982)	Patients who had complete records from the time of the injury and during an observation period before and after orthodontic treatment including: 1. Radiographs taken at the time of injury and after following up period. 2. Type of dental injury recorded. 3. Root-fractured teeth were excluded **C group** Extraction of 4 first premolars and fixed appliance.

C (Control), Class 2 Div 1, (Class 2 division 1 incisal relationship), Enamel # (Enamel fracture), Enamel-dentine # (Enamel and dentine fracture), IOPA (Intra-oral periapical radiograph), O (Orthodontic treatment on teeth with no history of dental trauma), Ortho (Orthodontics), OT/ TO (Orthodontic treatment on teeth with dental trauma), Ortho tx (orthodontic treatment), PA (periapical), PO (Pulp obliteration), PCO (pulp canal obliteration), RCT (root canal treatment), RR (root resorption), SS (statistically significant), T (trauma without orthodontic treatment), Tx (treatment), TDI (traumatic dental injuries)

Appendix 8: Definition and measurements of outcome

Study	Definition		Measurement of outcome
Bauss 2008 (a) (Bauss et al. 2008 (a))	**Pulp necrosis** defined by Andreasen and Andreasen is: 1. Loss of sensitivity plus 1 other clinical or radiographic sign of: i. Grey discolouration of the crown ii. Periapical radiolucency		**Pulp necrosis** 1. sensitivity testing with cryogenic spray 2. Discolouration of the crown 3. IOPA for traumatised teeth 4. OPT for non-traumatised teeth
Bauss 2008 (b) (Bauss et al. 2008)	**Pulp obliteration** according to Jacobson and Kerekes Classification 1. traumatised teeth without pulp obliteration 2. traumatised teeth with partial pulp obliteration 3. Traumatised teeth with total pulp obliteration. **Pulp Necrosis** As per Bauss 2008 (a)		**Pulp obliteration** Jacobson & Kerekes classification 1. sensibility testing with Cryogenic spray 2. Discolouration of the crown 3. IOPA
Bauss 2009 (Bauss et al. 2009)	**Pulp necrosis** As per Bauss 2008 (a)	**Pulp obliteration** As per Bauss 2008 (b)	**Pulp vitality and Pulp obliteration** As per Bauss 2008 (b)
Bauss 2010 (Bauss et al. 2010)	**Pulp necrosis** As per Bauss 2008 (a)		**Pulp Necrosis** As per Bauss 2008 (a)
Brin 1991 (Brin et al. 1991)	**Root Resorption Classification** As per Malmgren 1982		Pulp Vitality Root resorption Pulp obliteration Root development Radiographic evaluation only
Malmgren 1982 (Malmgren et al. 1982)	**Root Resorption Classification, Malmgren 1982** **Grade 1:** irregular root, slight resorption. **Grade 2:** resorption of less than 2 mm of the root length when compared with the intact antimere. **Grade 3:** resorption of more than 2 mm, but less than one-third of the root length; **Grade 4:** resorption of more than one-third of the root length.		Root resorption Radiographic analysis only

C (Control), Class 2 Div 1, (Class 2 division 1 incisal relationship), Enamel # (Enamel fracture), Enamel-dentine # (Enamel and dentine fracture), IOPA (Intra-oral periapical radiograph), O (Orthodontic treatment on teeth with no history of dental trauma), Ortho (Orthodontics), OT/ TO (Orthodontic treatment on teeth with dental trauma), Ortho tx (orthodontic treatment), PA (periapical), PO (Pulp obliteration), PCO (pulp canal obliteration), RCT (root canal treatment), RR (root resorption), SS (statistically significant), T (trauma without orthodontic treatment), Tx (treatment), TDI (traumatic dental injuries)

Appendix 9: Vignette survey cover letter

Ammar Al Hourani
Doctoral student in Endodontology
University of Liverpool, School of Dentistry
Pembroke Place, Liverpool, L3 5PS
T 0151 706 5231
E ammar.alhourani@nhs.net

Dear Orthodontic Specialist

As part of my DDSc program at the University of Liverpool, School of Dentistry, I am undertaking a study primarily investigating UK Orthodontic Specialist's experience in dealing with traumatic dental injuries and their subsequent treatment planning of orthodontic cases with patients with a history of dental trauma.

Consecutive Child Dental Healthy Surveys have shown a rise in the number of children sustaining dental trauma within the United Kingdom, some of whom will require orthodontic treatment as part of their emergency management, whilst many will undergo orthodontic treatment to correct malocclusion.

Within the parameters of my study, my aims are:

A. To gain an understanding of Orthodontists experience of dental trauma within their working day to day environment and exposure to dental trauma management within their respective specialist training programme.
B. To gain an understanding of orthodontist's treatment planning of patients with dental trauma prior to orthodontic treatment or patients who undergo trauma during active orthodontic treatment with the help of written clinical scenarios

In order to gain reliable information, it is essential to receive responses from as many specialists as possible. All Orthodontic who are members of the British Orthodontic Society have been invited to participate. Your reply is, therefore, very important to this research. However, your participation in this study is voluntary and you are free to withdraw your participation at any time.

This study has received Research Ethics approval from the University of Liverpool ethics committee. There are no risks associated with participating in this study. Responses will be anonymised, summarised and disseminated in a peer reviewed dental journal. All information identity coding will be destroyed once data has been collected so that you cannot be identified as a participant.

If you would like to discuss the questionnaire with the research team, please telephone (telephone number to be added) or email ammar.alhourani@nhs.net

Many thanks for your time.

Yours sincerely,

Appendix 10: Vignette survey ethical approval

UNIVERSITY OF LIVERPOOL

Health and Life Sciences Research Ethics Committee (Human participants, tissues and databases)

8 March 2018

Dear Dr Albadri

I am pleased to inform you that your application for research ethics approval has been approved. Application details and conditions of approval can be found below. Appendix A contains a list of documents approved by the Committee.

Application Details

Reference:	3002
Project Title:	Orthodontic treatment and traumatised teeth, a specialist Orthodontists perspective
Principal Investigator/Supervisor:	Dr Sondos Albadri
Co-Investigator(s):	~~Mr~~ Ammar Al Hourani, ~~Dr Fadi Jarad~~
Lead Student Investigator:	-
Department:	School of Dentistry
Approval Date:	08/03/2018
Approval Expiry Date:	Five years from the approval date listed above

The application was **APPROVED** subject to the following conditions:

Conditions of approval

- All serious adverse events must be reported via the Research Integrity and Ethics Team (ethics@liverpool.ac.uk) within 24 hours of their occurrence.
- If you wish to extend the duration of the study beyond the research ethics approval expiry date listed above, a new application should be submitted.
- If you wish to make an amendment to the research, please create and submit an amendment form using the research ethics system.
- If the named Principal Investigator or Supervisor leaves the employment of the University during the course of this approval, the approval will lapse. Therefore it will be necessary to create and submit an amendment form using the research ethics system.
- It is the responsibility of the Principal Investigator/Supervisor to inform all the investigators of the terms of the approval.

Kind regards,

D Prescott

Health and Life Sciences Research Ethics Committee (Human participants, tissues and databases)

edreseth@liverpool.ac.uk

0151 795 4358

Appendix 11: The vignette survey

Vignette Sample Questionnaire

Part 1

Professional Background

1. What is your gender?

Male Female

2. How many years have you been a GDC registered Orthodontist

less than 5 years
between 5 and 10 years
between 11 and 20 years
between 21 and 30 years
Over 30 years

3. As an Orthodontist, what would you describe as being your primary role?

Consultant

Specialist

Honorary Consultant

Academic specialist

Post CCST Trainee

Other…

4. In which setting do you mainly practice? (Tick one box)

Dental Teaching Hospital
District General Hospital
NHS Specialist Practice
Private Specialist Practice
Mixed Practice
Other …..

5. In which part of the UK do you currently practice orthodontics?

England

Scotland

Wales

Northern Ireland

6. Are you currently involved in Orthodontic teaching and supervision?

Yes No

If yes…. Which institute and which grade of dentists do you train or supervise?

- Orthodontic StRs
- Post CCST's
- Orthodontic Therapists
- Other

(Tick one or more boxes)

Part 2

Dental Traumatology Experience

1. Within your Orthodontic Specialist Training programme, do you feel you gained sufficient experience in the management of dental trauma?

Yes No Don't remember

As a Post CCST Trainee, do you feel you gained sufficient experience in the management of dental trauma?

Yes No Don't remember

2. Did you feel confident in your role, as an Orthodontist, in dealing with dental trauma?

Not at all confident		Somewhat confident		Very confident
1	2	3	4	5

3. Within a 12-month calendar, how often do you examine or treat patients with an acute and/or recent trauma in the permanent dentition?

- Weekly
- Monthly
- Every three months
- Every six months
- Every year
- Never

4. How many patients currently under your care have experienced a dental trauma in their permanent dentition?

- None that I know off
- Less than 5%
- Between 5% and 10%
- Between 11% and 20%
- Between 21% and 30%
- Between 31% and 40%
- More than 40%

5. If you suspect a patient has had previous dental trauma, would you regularly take radiographs prior to orthodontic treatment, if so which radiographs would you take? (Tick all that applies)

- Periapicals
- Occlusal Oblique
- Periapical and Occlusal Oblique
- OPT
- CBCT
- No radiographs

6. Do you routinely perform sensibility testing prior to orthodontic treatment? (Tick one choice)

Cold Testing

Electric Pulp Testing

Both

No sensibility testing

7. Which form of trauma have you most encountered within your current post? (Tick one choice)

Crown fracture

Root fracture

Luxation injuries

Avulsion

None

8. In your local area, is there a dedicated trauma service?

Yes

No

9. Are you aware of any guidelines or any other resources relating to the orthodontic treatment of traumatised teeth?

Yes

No

Don't know

10. If you ticked yes for Q9, could you name the guidelines or resources that you currently use to help you in the treatment management of orthodontic patients with a history of dental trauma?

Case 1

A 12-year-old boy, fit and well with no known medical problems, attends the Orthodontist with his parents having fallen onto the handle bars of his scooter 2 weeks ago; He is suffering from tenderness and bleeding around the gingiva of the UR1 and UL1, he has tenderness on tapping his teeth with some mobility on both teeth. The patient is due to start orthodontic treatment for moderate upper arch crowding. On taking a Periapical radiograph, you suspect a mid-root fracture to the UL1 and UR1 respectively.

What other radiograph would you ask for other than a PA in this instance? (Tick one or more choice)

- A second PA at 45 degrees
- Occlusal Oblique
- OPT
- CBCT
- None
- All the above

When would you start the orthodontic treatment?

- Start immediate orthodontic treatment
- Monitor for 3 months
- Monitor for 6 months
- Monitor for 12- 24 months
- Would never attempt treatment in this case
- Refer the case for MDT opinion/ treatment

Would you give the patient and parents any specific warning or advice prior to starting orthodontic treatment?

Case 2

A 13-year-old boy, fit and well with no known allergies, accidentally traumatised his tooth whilst playing sport 3 years ago. He presents to your orthodontic clinic with discolouration of the UL1. The patient has a Class 2 Div 1incisor relationship with an 8mm overjet. The patient's mother is concerned with the yellow discolouration of this tooth. Otherwise, the tooth is asymptomatic. A periapical radiograph of the UL1 shows a completely obliterated canal. The patient is about to start orthodontic course of treatment.

What sensibility testing would you carry out on this tooth?

- Cold testing
- Electric Pulp Testing
- Both
- No sensibility testing

Orthodontic treatment is planned for this patient, how would this change your management? Would you do anything differently and what warnings would you give the patient?

(written answer)

Having discussed the findings with the patient and his parents, when would you start the orthodontic treatment for this patient?

- Start immediate orthodontic treatment
- Monitor for 3 months
- Monitor for 6 months
- Monitor for 12- 24 months
- Would never attempt treatment in this case
- Refer the case for MDT opinion/ treatment

Case 3

A 12-year-old patient, otherwise fit and well, had a fall whilst playing with her friends in the playground 4 years ago. The patient's mother is concerned about the gradual discolouration associated with the UR1. The patient has no other symptoms. The tooth is not mobile and has no localised deep pocketing. She is due to start orthodontic treatment and on taking a periapical radiograph, you diagnose an immature UR1 with open apex

Sensibility testing of the UR1 was deemed unreliable, would you consider root canal treat for this tooth or wait for further root development? And why?

If you feel root end closure is required for the UR1, who would you refer this patient for further treatment? (Tick one or more choices)

GDP

Specialist Paediatric Dentist

Hospital based Orthodontic Consultant

Specialist Endodontist

Restorative Dentist

Other

Could you explain your choice? (written Text)

How soon, following root end closure, would you begin orthodontic treatment?

- Start immediate orthodontic treatment
- Monitor for 3 months
- Monitor for 6 months
- Monitor for 12- 24 months
- Would never attempt treatment in this case
- Refer the case for MDT opinion/ treatment

Would this injury and subsequent treatment affect your orthodontic management of the case? If so, how would it affect it?

Written text

Do you feel experienced/ confident to treat this case?

(written answer)

Are then guidelines for the orthodontic treatment of MTA root end closured teeth? If so can you name it?

Appendix 12: IADR Poster abstract

Orthodontic Treatment on Dentally Traumatised Teeth: A Systematic Review

A. Al-Hourani, A. Bowland, J. Greenhalgh, S. Al Badri, Prof F Jarad

Background

Traumatic dental injuries are a preventable oral condition which is often overlooked, despite its relatively high prevalence and its significant impact on the individual, their family and society. Various published studies have shown that increased overjet with protrusion of upper anterior incisors and insufficient lip closure are significant predisposing factors to traumatic dental injuries.

These features frequently co-occur in many patients with an orthodontic treatment need. Some studies have suggested that 1 in 10 patients referred for orthodontic treatment have had previous dental trauma prior to active orthodontic treatment, with infraction, enamel and enamel – dentine fractures being present in 80% of cases.

Objectives

To determine if orthodontic treatment on teeth with a history of dental trauma increases the risk of pulp necrosis, root resorption, pulp obliteration and root fracture.

Methods

The systematic review was conducted according to internationally recognised methodology. A specific question was constructed according to PICO principles. Electronic databases were searched (MEDLINE, EMBASE, Web of Science, the Cochrane Library) from 1970 to 2017. Different combinations of keywords were used for searching e.g., 'Orthodontics', 'tooth movement', 'dental pulp', 'dental trauma', 'pulp necrosis', 'root resorption', 'pulp obliteration' and 'root fracture'. Inclusion criteria included clinical studies (any design) of people (aged >7 years) who had undergone orthodontic treatment using any orthodontic appliance with a history of dental trauma prior to or during orthodontic treatment. Literature reviews, case reports, animal studies, commentaries and letters to editors were excluded.

Results

Searches retrieved 3026 citations. After screening titles and abstracts only, 29 potentially eligible papers were identified; six retrospective cohort studies were retained after the inclusion criteria were applied. Included studies were assessed as having a low risk of bias (using the Newcastle-Ottawa Scale). Evidence from narrative synthesis (participants, n=1897; Incisors, n=3659) showed the following:

I. Orthodontically treated teeth with a history of dental trauma (OT) had statistically significantly higher rate of pulp necrosis than O and T group respectively.
II. Traumatised lateral incisors may have an increased risk of pulp necrosis compared to traumatised central incisors undergoing orthodontic treatment, however, the evidence is inconclusive.
III. There was no correlation between intervention period (intrusion or extrusion) and duration of the orthodontic treatment on pulp necrosis in traumatised teeth undergoing orthodontic intervention.
IV. Teeth that had trauma to the periodontal apparatus and orthodontic treatment had a significantly higher rate of pulp necrosis than teeth that had hard tissue trauma and orthodontic treatment.
V. Traumatised teeth that underwent orthodontic treatment and had radiographic evidence of complete pulp canal obliteration had significantly higher rate of pulp necrosis compared to

teeth that had no pulp canal obliteration or partial pulp canal obliteration. Moreover, orthodontically treated teeth without a history of trauma but exhibited complete pulp canal obliteration had higher rate of pulp necrosis in intrusion phase of orthodontic treatment.

VI. In the OT group, there appears to be no correlation between root resorption, relapse or type of injury, furthermore, in intra-individual comparisons, there seems to be no difference in the degree of root resorption between traumatised and non-traumatised teeth.

VII. Traumatised teeth with mild – moderate root resorption does not have a greater tendency to root resorb during orthodontic treatment in comparison to non-traumatised teeth.

Conclusion

There is insufficient scientific evidence regarding orthodontic treatment of traumatised teeth. A history of dental trauma may be considered a risk factor for loss of pulp vitality, increased pulp canal obliteration and root resorption during orthodontic treatment. Orthodontists should be aware of this risk and the pulpal condition of the traumatised teeth should be monitored frequently throughout orthodontic treatment and retention period.

More high-quality research evidence is required within this field of dentistry

Conflicting interest

The author declares no conflict of interest

Ethical approval

No ethical approval was required for this systematic review

Appendix 13: IADR Poster

Orthodontic Treatment on Dentally Traumatised Teeth: A Systematic Review

A. Al-Hourani, A. Boland, J. Greenhalgh, S. Al Badri, F. Jarad

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No. 1587

Background

The findings from the UK child Health Survey 2013 showed that the prevalence of dental trauma to permanent incisors of children in all age groups was 9.1%. Increased overjet with protrusion of upper anterior incisors and insufficient lip closure are significant predisposing factors to traumatic dental injuries.
These features frequently co-occur in many patients with an orthodontic treatment need, with some studies suggesting as many as 1 in 10 patients referred for orthodontic treatment have had previous dental trauma prior to active orthodontic treatment.

The true effect of orthodontics in post trauma cases is unestablished in current literature. Orthodontic forces can lead to complications including pulp necrosis, pulp canal obliteration (PCO) and root resorption which can affect the long term prognosis of teeth that have suffered from dental trauma.

Aims

The aim of this study is to systematically review the current literature to determine whether orthodontic treatment on teeth with a history of dental trauma increases the risk of pulp necrosis, root resorption, pulp canal obliteration and root fracture.

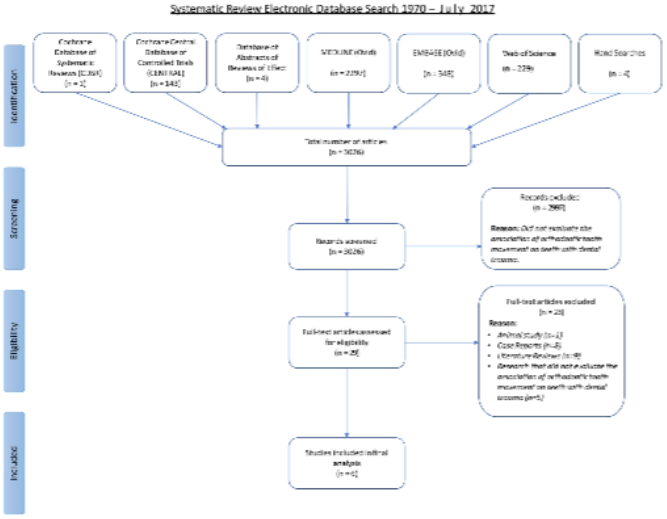
Methods

The systematic review was conducted by One researcher (AAH) and two systematic supervisors conducted the study (AB & JG) according to internationally recognised **PRISMA** methodology.

A specific question was constructed according to PICO principles as follows

(P) Participants: patients aged 7 years and older with a history of dental trauma prior to orthodontic treatment or trauma during orthodontic treatment.

(I) Types of Interventions: orthodontic treatment on teeth with a history of dental



A systematic search of electronic databases was carried. Relevant **keywords** were used to search for relevant English language published literature. Searches were conducted in **MEDLINE (OvidSP), EMBASE (OvidSP), Web of Science (Thompson Reuters), Cochrane Database of Systematic Reviews (Wiley) and the Cochrane Central Register of Controlled Trials (CENTRAL) from 1970 –**

Appendix 14: European Society of Endodontology (ESE) Abstract

Do orthodontists consider endodontic complications in their orthodontic management of teeth with a history of dental trauma?

Aim

To evaluate whether orthodontists consider the endodontic implications associated with the orthodontic treatment of teeth with a history of dental trauma

Summary

Method: A mixed methods vignette survey was designed, and distributed to UK registered specialist orthodontists electronically over a 4 month period from May–Sept 2019. GDPs, orthodontic trainees and incomplete surveys were excluded from the study. The survey was split into two parts. Part 1 explored the orthodontist's professional background and experience in dental trauma. Part two consisted of three vignette clinical scenarios with open/closed questions to explore the orthodontist's understanding of endodontic risk with the provision of orthodontic treatment of three cases, which were a mid-root fracture, pulp canal obliteration and an immature open apex.

Results: 76 orthodontists responded from the UK. Following quantative analysis of the data and thematic analysis of the transcripts, the following was identified; with regards to diagnosing dental trauma, 46% of orthodontists utilised an OPT and 53% did not carry out pre-treatment sensibility tests. 46% of orthodontists felt they had insufficient training in dental trauma and 42% lacked confidence in the treatment of traumatic injuries. In addition, 32% of clinician's felt there is lack of guidance in the orthodontic treatment of traumatised teeth and pulpal Sequalae. Qualitative themes identified were: Non-standardised pre-treatment examination, dental trauma experience, dental trauma training and lack of literature guidance on the orthodontic treatment of traumatised teeth.

Conclusion: There is no standardised protocol to examine teeth with a history of trauma prior to orthodontic movement, however, the majority of orthodontists were happy to request the support/ second opinion from their paediatric/ endodontic colleagues in the management of complex traumatic cases requiring orthodontic treatment.

Key learning points

- There is no standardised pretreatment method in the examination of teeth with a history of dental trauma prior orthodontic treatment
- There is a lack of dental trauma training within orthodontic specialist training and possible misdiagnosis of pulpal complications and management.
- Orthodontists lack confidence in the treatment of previously traumatised teeth and its management, the majority asking for a second opinion by paediatric/endodontic specialists
- There is insufficient literature guidelines within orthodontics in the management of traumatised teeth

Message to editor

I am happy to accept a general endodontic poster should this oral presentation fail acceptance.

Submission details

Submitted to: Oral Presentations
Topic: Treatment planning

Appendix 15: European Society of Endodontology Oral Presentation

Do orthodontists consider endodontic complications in their orthodontic management of teeth with a history of dental trauma?

European Society of Endodontology, Vienna 2019

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Vignette Survey Results

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