Current Science International Volume : 4 | Issue : 01 | Jan-Mar. | 2015
ISSN 2077-4435 Pages: 19-26

Three Dimensional Finite Element Analysis of a Traumatized Avulsed Maxillary Permanent Central Incisor in Children

[1]Abou El Yazeed, [2]M. El Zawahry, [3]M. El Anwar, M., and [4]Abou Zeid, W.

[1]*Orthodontics and Pediatric Dentistry Department, National Research Centre, Cairo, Egypt.*
[2]*Prosthodontics Department, National Research Centre, Cairo, Egypt.*
[3]*Mechanical Engineering Department, National Research Centre, Cairo, Egypt.*
[4]*Basic Dental Sciences Department, National Research Centre, Cairo, Egypt.*

ABSTRACT

The maxillary central incisor is the most frequently involved tooth in frontal impact in children. Theoretically force direction plays an important role in the propagation of fracture lines or even complete avulsion of the traumatized tooth but still exact relationship between angle of impact and the resultant action on the tooth remain unclear and without experimental evidence. With the rapid advancement and development of computer technology, finite element analysis is now widely used as an effective method for dental trauma analysis. Aim: The idea of this study emerged to assess the avulsion patterns occurring when a human maxillary central incisor in children is subjected to sudden impact forces. Methodology: A three dimensional finite element model of the maxillary central incisor and its surrounding tissues was established. The geometrical models were designed using commercial three dimension modeling package, Inventor version 8 (Autodesk Inc., San Rafael, CA, USA). The meshing element was 8-nodes Brick element (SOLID 185), which has three degrees of freedom. The highest area of the maxillary cortical bone (outer cylinder base) was considered as fixed in all directions as a boundary condition. Linear static analysis of the models was performed on Server HP ProLaint ML150, with Intel Xeon 3.2 GHz processors (with 1MB L2 cache), 10 GB RAM, and that each run takes about three hours. Results: A total deformation, maximum tensile stress value of 108 MPa, and maximum Von Mises stress of about 37 MPa occurs to the periodontal ligament respectively which indicated complete avulsion of the tooth that moves down words by about 16mm at 300 Newton with 10 degrees angle in relation to longitudinal axis of the tooth and directed downwards and outside the oral cavity. Conclusion: the surrounding periodontal tissues of the maxillary central incisor provide protective effects for the tooth during traumatic injury by dispersing the concentrated stress over a longer period beyond it the tooth avulsed. Recommendation: more finite element research based on epidemiological studies from representative populations using standardized trauma classifications are needed in order to understand the complexities of dental trauma and to ultimately help reduce the increasing frequency of dental trauma in children as well as examining the effect of mouth guard in avulsion prevention.

Key words: Finite element, avulsion, maxillary incisor

Introduction

Facial trauma - that results in fractured, displaced, or even lost teeth - have significant negative functional, esthetic, and psychological effects on children (Traebert *et al.,* 2012). The greatest incidence of trauma to the primary teeth occurs at 2 to 3 years of age, when motor coordination is developing. The most common injuries to permanent teeth occur secondary to falls, followed by traffic accidents, violence and sports (Tapias *et al.,* 2003). All sporting activities have an associated risk of orofacial injuries due to falls, collisions, and contact with hard surfaces. The American Academy of Pediatric Dentistry encourages the use of protective gear, including mouth guards, which help distribute forces of impact, thereby reducing the risk of severe injury (AAPD, 2010). Traumatic dental injuries (TDIs) occur with great frequency in preschool, school age children and young adults comprising 5% of all injuries for which people seek treatment (Andreasen *et al.,* 2007). About 25% of school children experience dental trauma and 33% of adults have experienced trauma to the permanent dentition with the majority of injuries occurring before age 19 (Glendor, 2008). Luxation injuries are the most common TDIs in the primary dentition, whereas crown fractures are more commonly reported for the permanent dentition. As TDIs present a challenge to clinicians worldwide so dentists and physicians should collaborate to educate the public about prevention and treatment of traumatic injuries to the oral and maxillofacial region. Consequently, proper diagnosis, treatment planning and follow up are critical to assure a favorable outcome (Kramer *et al.,* 2003). One of the most severe dento-alveolar injuries is avulsion, where the tooth or teeth are completely knocked out of the mouth. This injury accounts for between 0.5 to 3% of dento-alveolar trauma to

Corresponding Author: Abou El Yazeed, M., Orthodontics and Pediatric Dentistry Department, National Research Centre, Cairo, Egypt
E-mail: mohamedabouelyazied@yahoo.com

permanent teeth. In the most severe scenarios, the tooth or teeth are lost, e.g. not replanted, or extracted due to failure replantation (Chadwick *et al.,* 2006). It is particularly surprising that the percentage of articles focusing on TDIs in pediatric dental journals has remained around only 3% over the past few decades (Andreasen *et al.,* 2009). It is a well-established claim that mechanical testing is of paramount importance, not only in aerospace, civil engineering and the automotive industry, but also in health care. The field of biomedical research raises specific problems due to the fact that today's research may prove extremely expensive and ethically questionable when performed on live subjects (Satava, 2005). To limit the costs and risks involved in live experiments, virtual models and simulation approaches have become unavoidable. Yet dental research seems to make very little use of virtual models, such approaches representing a minor part of the scientific publication volume (Pascal, 2007). Using the traditional biomechanical knowledge database in a rational validation process and the finite element analysis in dental research has been significantly refined during the last decade. They allow the researcher to reduce the time and cost required to bring a new idea from concept to clinical application, to increase their confidence in the final concept/project by virtually testing it under all conceivable loading conditions (Vasconcellos *et al.,* 2008). The finite element method is a highly approved method to simulate biomechanical phenomena in computerized models of teeth and their periodontium. The finite element method is based on a mathematical model, which approximates the geometry, loading and constraint conditions of a structure to be analyzed. Deformations and stresses at any point within the model can be evaluated and highly stressed regions can be analyzed (Li *et al.,* 2008). Nowadays, experimental numerical approaches undoubtedly represent the most comprehensive in-vitro investigation methods in dentistry (Tantbirojn *et al.,* 2004). The upper central incisor is the most frequently involved tooth in frontal impact. Clinical findings demonstrate that the outcomes for frontal tooth impacts typically involve crown, oblique root, oblique crown-root, or neck fractures. Theoretically force direction plays an important role in the propagation of fracture lines or even the complete avulsion of the impacted tooth but still the exact relationship between the angle of impact and the resultant action on the maxillary incisors remain unclear and without experimental evidence. With the rapid advancement and development of computer technology, finite element analysis is now widely used as an effective method for dental trauma analysis. Therefore, the idea of this study emerged to examine the finite element analysis related to the avulsion of traumatized maxillary central incisors in children.

Aim of the study:

Three dimensional finite element analyses related to the avulsion of traumatized maxillary central incisors in children.

Materials and Methods

The present study applies three dimensional finite element analyses to determine the stress distribution in traumatized maxillary central incisor subjected to sudden impact force of about 300 Newton on the lingual side of the crown and directed by 10 degrees angle to the long axis of the tooth from inside to the outer side of the oral cavity. The geometrical models were designed using commercial three dimension modeling package, Inventor version 8 (Autodesk Inc., San Rafael, CA, USA). While, values of material properties were based on previously published data (Ash *et al.,* 2003; Xiao *et al.,* 2008; Daniela *et al.,* 2010; and Flávio *et al.,* 2012) and listed in Table 1. All materials were assumed to be isotropic, homogenous and linearly elastic. After construction of all of the components of the model, they were exported to the ANSYS version 12 ® (ANSYS Inc., Canonsburg, PA, USA) as IGES files (El Anwar, 2009) and were assembled together to obtain a finite element model after set of Boolean operations between the imported components. The meshing element was 8-nodes Brick element (SOLID 185), which has three degrees of freedom (translations in the global directions). Table 2 lists number of nodes and elements of the components of the meshed model. The highest area of maxillary cortical bone (outer cylinder base) was considered as a fixed in all directions as a boundary condition. Linear static analysis of the models was performed on Server HP ProLaint ML150, with Intel Xeon 3.2 GHz processors (with 1MB L2 cache), 10 GB RAM, and that each run takes about three hours. Figure 1 illustrates Ansys screen shots of the components of the studied system. While Figure 2 and 3, represent the assembled and meshed model respectively before analysis.

Table 1: Material properties used in the finite element model construction

Structure	Young's Modulus (GPa)	Density (g/cm^3)	Poisson's Ratio
Enamel	77.90	3.00	0.33
Dentin	16.60	2.20	0.31
Pulp	0.00689	1.00	0.45
Cementum	13.70	2.39	0.30
Periodontal ligament (PDL)	0.05	1.10	0.45
Alveolar Bone	3.50	1.40	0.33
Cortical Bone	10.00	1.40	0.26
Cancellous Bone	0.50	1.40	0.38

Table 2: Mesh density

	Number of elements	Number of nodes
Enamel	120.046	163.263
Dentin	231.117	413.252
Pulp	166.485	231.763
Cementum	180.482	301.936
Periodontal ligament (PDL)	8.165	14.275
Cancellous Bone	12.422	17.743
Cortical Bone	2.830	6.628

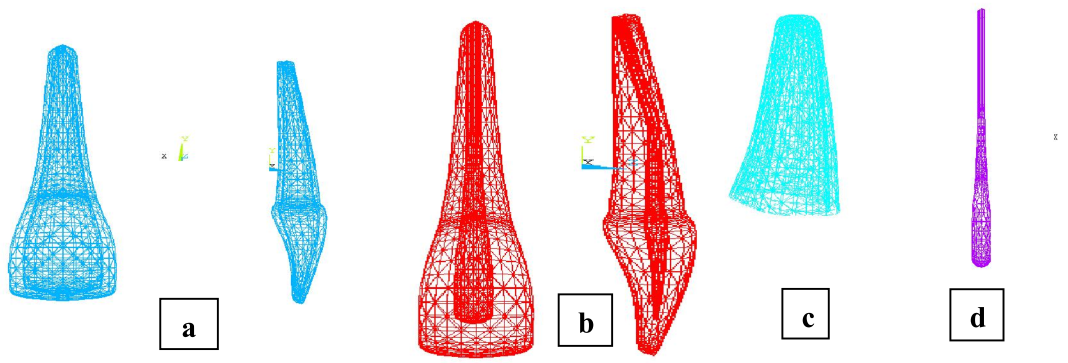

Fig. 1: Components of the studied model; (a) enamel, (b) dentine, (c) periodontal ligament and (d) pulp

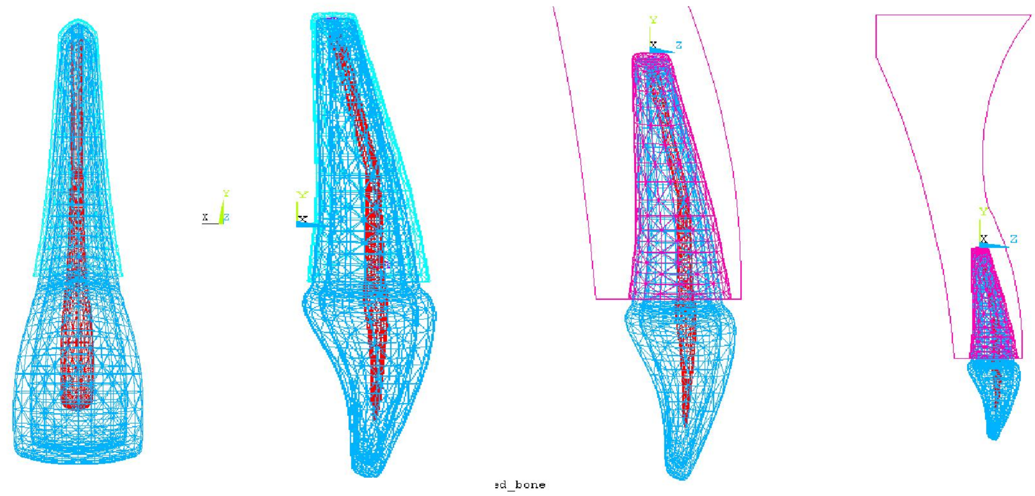

Fig. 2: Assembled maxillary incisor finite model

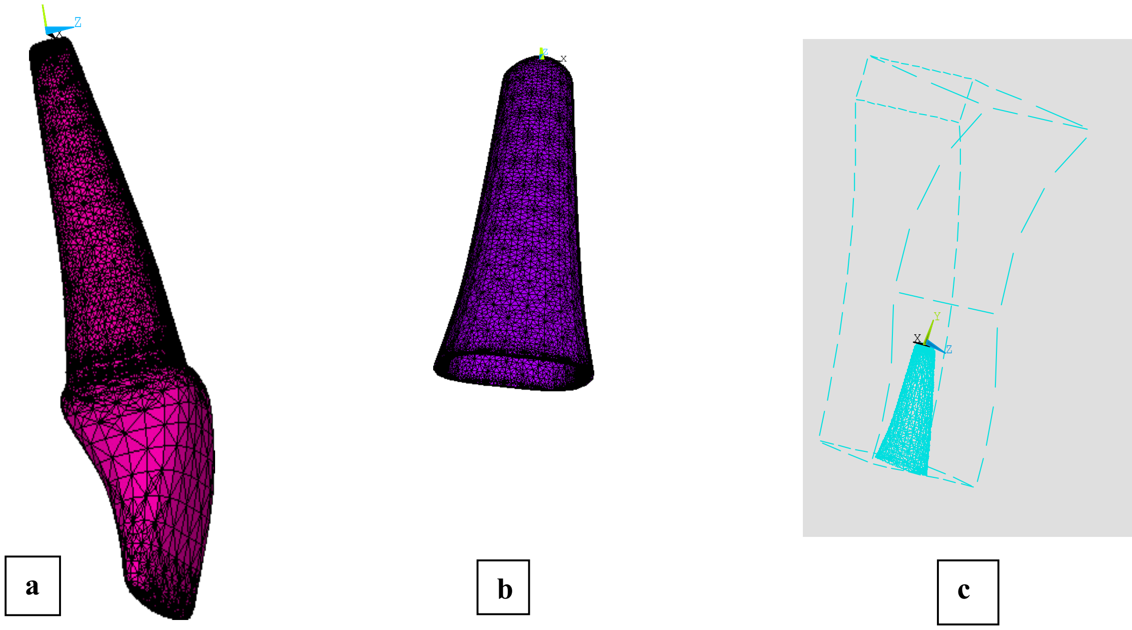

Fig. 3: Meshed model components (Tooth, periodontal ligament, and bone with periodontal space)

Results

In the present study the periodontal ligament results are the indicators for incisor avulsion. Figure 4 represent the Von Mises stress distribution on bone and tooth taken from Ansys screen. The values of Von Mises stress are moderate, indicating safe mode away from failure (i.e. no fracture of the tooth or bone).

Figures 5,6 and 7, illustrate the periodontal ligament results as total deformation, maximum tensile, and Von Mises stresses distribution respectively from the all four aspects of the root (buccal, palatal, mesial and distal). Total deformation of the periodontal ligament and movement of the tooth down words by about 16mm occurred (Figure 5). Maximum tensile stress distribution in Figure 6 showed maximum value of 108 MPa. While the maximum Von Mises stress of about 37 MPa (Figure 7).

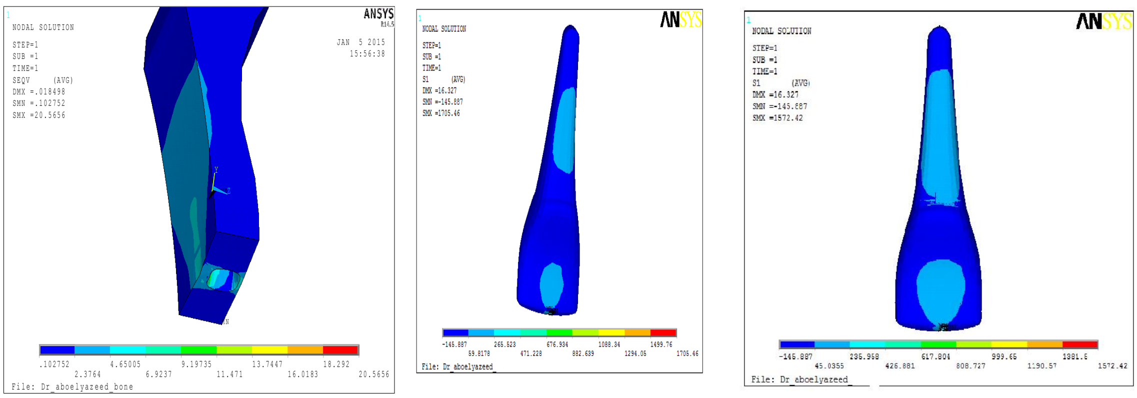

Fig. 4: Von Mises stress distribution on bone and maxillary central incisor (Ansys screen shot)

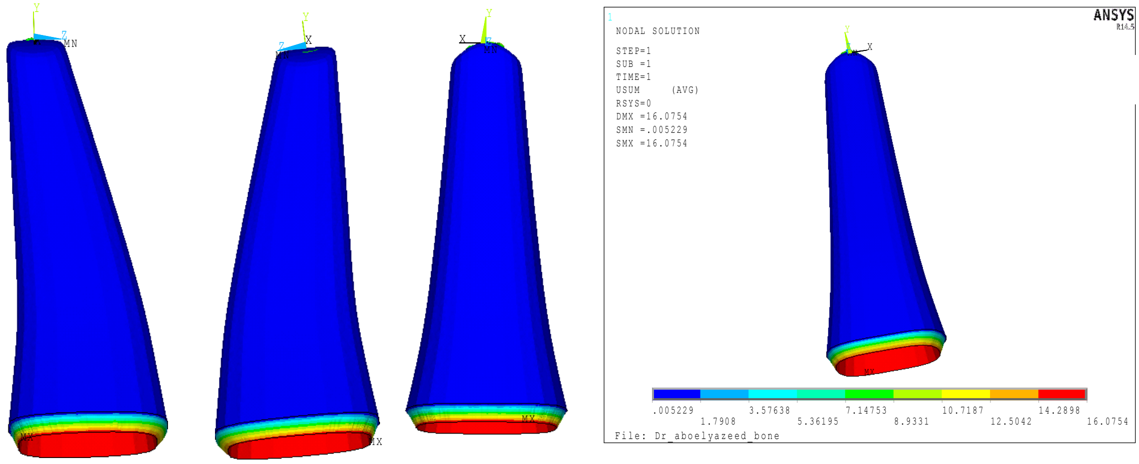

Fig. 5: Periodontal ligament total deformation distribution

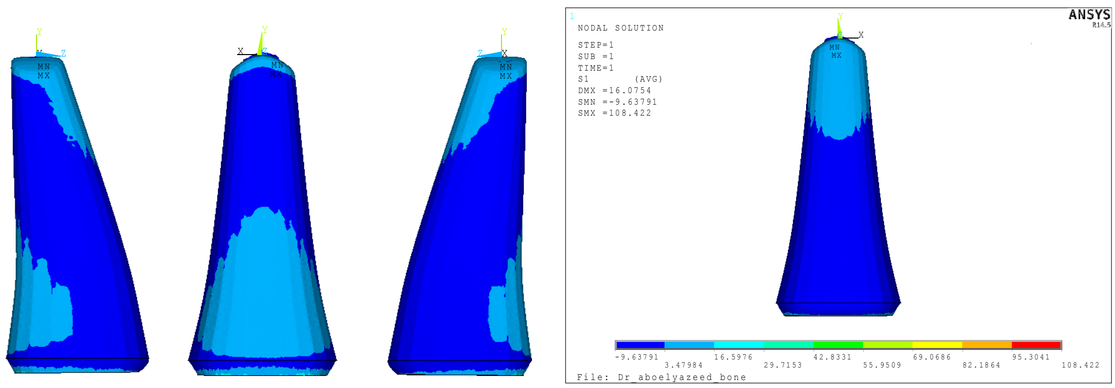

Fig. 6: Periodontal ligament maximum tensile stress distribution

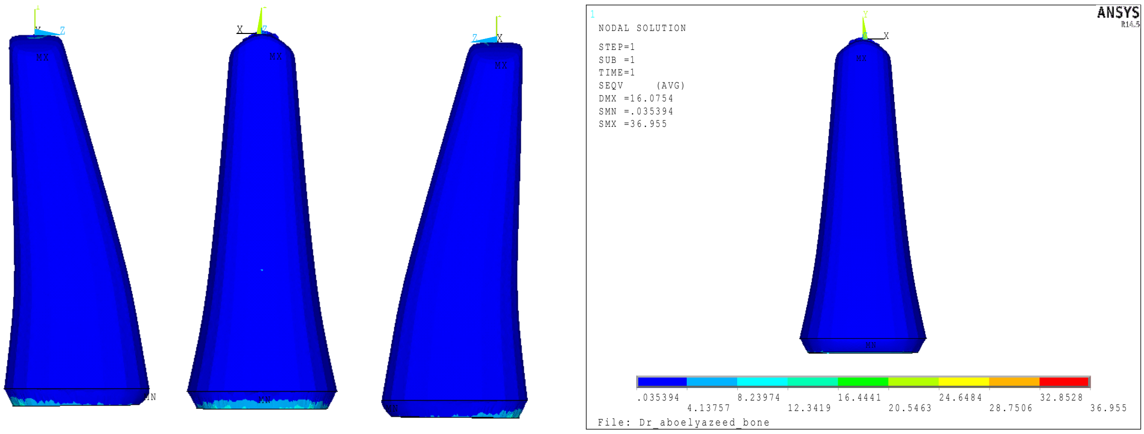

Fig. 7: Periodontal ligament Von Mises stress distribution

Discussion

In the present violent world our children are exposed to trauma of different types and origins especially nowadays with the social and political circumstances our children are subjected to new approaches of violence wish risen the prevalence of tooth avulsion. Tooth fracture has been described as a major problem in dentistry and is the third most common cause of tooth loss after dental caries and periodontal disease (Ellis *et al.,* 2009). Dental trauma in children and adolescents is a serious public health problem that may have an impact on children's quality of life not only physically, but also psychologically as well as a source of distress for the parents of those children (Alessandro *et al.,* 2009). The majority of dental injuries involved the anterior teeth which may lead to restriction in biting, difficulty of speaking clearly, and feeling embarrassed to show the teeth. Traumatic dental injuries are widespread in the population and the prevalence of traumatic dental injuries among school children in different parts of the world varies from a low of 2.6% (Macko *et al.,* 1979), to a high of 43.8 % (Marcenes *et al.,* 2001). Trauma to the anterior teeth is very common during childhood (Wilson *et al.,* 2007). Additionally it has also been demonstrated that about 80% of dental trauma occurs before the age of 12 years, with incisors the teeth most frequently traumatized (Skaare *et al.,* 2003). Frequencies of traumatic dental injuries in the permanent dentition in children and adolescents have been reported in different parts of the world and the prevalence of injured teeth varies in different populations and at various ages. Boys experience more dental injuries than girls. There is agreement that traumatic injuries occur more often to the maxillary than the mandibular incisors and that the central incisors are affected more often than the lateral incisors. Furthermore, the risk of injury to the maxillary incisors has been shown to increase with incisal overjet and inadequate lip coverage (Prajna, 2013). The costs for the treatment of avulsed tooth or even the replacement of the avulsed tooth are often more than treating dental carries among children. Huang *et al.,* 2006 stated that the periodontal ligament, which connects the tooth root and the underlying bone, plays an important role in the mechanisms of tooth trauma and tooth mobility. Traditionally, biomechanical experiments which conducted to determine the impact resistances of intact tooth have tended to focus on the strength of the tooth (Sedgley *et al.,* 2002). The finite element method which was introduced as one of the numerical analyses has become a useful technique for stress analysis in biological systems.

The problem of tooth stresses is very complicated because of the non-homogeneous character of tooth material and the irregularity of tooth contours (Senka *et al.,* 2003). As the tooth structure consists of enamel, dentin, pulp, cementum, periodontal ligament and surrounded by the alveolar bone and each of these has widely varying properties so the problem is further complicated by large variations (both in magnitude and direction of impact forces). In this study the majority of periodontal ligament volume did not exceed 16 MPa. Other researchers indicated that periodontal ligament cut at lower stress than these values (Komatsu, 2010), i.e. tooth avulsion is confirmed. Maximum Von Mises stress of about 37 MPa (as in Figure 7), is another proof for tooth avulsion under the applied estimated 300 Newton force which is directed downwards lingually from inside to outside by 10 degrees angle to the long axis of the permanent central incisor to mimic some scenarios of tooth trauma . This force initiates a group of internal strengths upon all the different complex parts of the model leading to tearing of the periodontal ligament all around the root and hence the movement of the tooth by about 16 mm away from its socket which means complete avulsion of the tooth without its fracture. It was found that high stresses concentrated at some specific areas, which obeyed engineering principles. These areas are the labial and lingual incisor edges, cervical ridge and the area around the root apex. When connecting lines between these high stresses areas, complete avulsion similar to that described by Andreasen *et al.,* 2007 was found. The finding of similar qualitative results from clinical observation and the numerical simulation demonstrates that the finite element model used in this study is a reliable model for dental trauma analysis. However, when tracing the stress growth process it was found that high stresses in each concentrated area occurred independently. These phenomena explain why the complete avulsion caused by impacts reveals specific directions and positions; this is coinciding with Huang *et al.,* 2006.

Conclusion

The surrounding periodontal tissues of the maxillary central incisors provide protective effects for teeth during traumatic injury by dispersing the concentrated stress over a longer period beyond it the tooth either fractured or avulsed.

Recommendations

1- Further studies concerning the protection of maxillary incisors using protective mouth guard should be approached especially with hyperactive kids and those at high risk of trauma (Bicycle riding, travelling, school bus or during other violent activities).

2- More finite element research and epidemiological studies from representative populations using standardized trauma classifications are needed in order to understand the complexities of dental trauma and to ultimately help reduce the increasing frequency of dental trauma in children.
3- Health promotion policies should aim to create an appropriate and safe environment that protect against traumatic dental injuries.

Ethical approval

This research doesn't require ethical approval and followed the Helsinki declaration.
The authors declare that they have no conflict of interest.

References

Alessandro L., K. Priscilla, R. Catarina and M. Cristiano, 2009. Traumatic anterior dental injuries in 7 to 12 year old Brazilian children. Dental Traumatology, 25: 198–202.

American Academy of Pediatric Dentistry, 2010. Policy on prevention of sports related orofacial injuries. Pediatr Dent., 32:55-58.

Anand K., S. Suhail, V. Krishna, B. Satheesha, M. Rajesh, A. Meera and K. Anand, 2014. Finite Element Analysis in Dentistry. International Journal of Engineering and Technical Research, 2(8): 17-22.

Andreasen J., F. Andreasen and L. Andersson, 2007. Textbook and Color Atlas of Traumatic Injuries to the Teeth. 4th ed. Oxford, England, Wiley-Blackwell, Munksgaard, Copenhagen, pp. 444-488.

Andreasen J., E. Lauridsen and J. Daugaard, 2009. Dental traumatology: an orphan in pediatric dentistry. Ped Dent., 31:153–163.

Ash, M. and S. Nelson, 2003. Wheeler's Dental Anatomy, Physiology and Occlusion. Chapt.1 Introduction to Dental Anatomy pp 18, 8th. ed., Saunders Company.

Chadwick B., D. White, A. Morris, D. Evans, and N. Pitts, 2006. Non-carious tooth conditions in children in the UK, British Dental Journal, 379-384.

Daniela G., S. Marlia, O. Terumi and G. Omar, 2010. Alveolar bone morphology under the perspective of the computed tomography: Defining the biological limits of tooth movement. J Orthod., 15(5):192-205.

El Anwer M.I., 2009. Simple Technique to Build Complex 3D Solid Models", 19th International conference on Computer Theory and Applications (ICCTA 2009), Alexandria, Egypt, 10:17– 19.

Ellis S., J. Mc Cord and F. Burke, 2009. Predisposing and contributing factors for complete and incomplete tooth fractures. Dent Update, 26: 150–158.

Flávio V., A. Flávio, A. José and I. Rívea, 2012. Mapping of proximal enamel thickness in permanent teeth. Braz J Oral Sci., 11(4): 25-29.

Glendor U., 2008. Epidemiology of traumatic dental injuries – a 12 year review of the literature. Dental Traumatol., 24:603–611.

Huang H., C. Tsai, H. Lee, T. Lin, W. Yao, W. Chiu and S. Lee, 2006. Damping effects on the response of maxillary incisor subjected to a traumatic impact force: A nonlinear finite element analysis. Journal of Dentistry, 34, 261–268.

Komatsu K., 2010. Mechanical Strength and Viscoelastic Response of the Periodontal Ligament in Relation to Structure. Journal of Dental Biomechanical, 10 :(3), 1-18, 2010

Kramer P., C. Zembruski, S. Ferreira and C. Fedens, 2003. Traumatic dental injuries in Brazilian preschool children. Dent Traumatol., 19(6):299-303.

Li X., Y. Shi, Z.C. Li, C. Song, X. Chen and Z. Guan, 2008. Three dimensional finite element analysis of a maxillary central incisor restored with different post-core materials. Int Chin J Dent., 8:21-27.

Macko D., J. Grasso, E. Powell and N. Doherty, 1979. A study of fractured teeth in a school population. J Dent Child, 46:130-133.

Marcedes W. and S. Murray, 2001. Social deprivation and traumatic dental injuries among 14-year-old schoolchildren. Dent Traumatol, 17(1):17-21.

Pascal M., 2007. Efficient 3D finite element analysis of dental restorative procedures using micro-CT data. Dental Materials, 23: 539–548.

Prajna P., M. Roseline, N. Konark and K. Ramesh, 2013. A finite element analysis for a comparative evaluation of stress with two commonly used esthetic posts. European Journal of Dentistry, 7 (4) 419-420.

Satava R., 2005. The scientific method is dead—long lives the (new) scientific method. Surg Innov., 12:173-176.

Sedgley C. and H. Messer, 2003. Are endodontically treated teeth more brittle? J Endod., 2002: 18: 332–335.

Senka M., Mladen l. and Petra R. Finite element method analysis of the tooth movement induced by orthodontic forces. Coll. Antropol., 27: (2) 17–21.

Skaare, A. and I. Jacobsen, 2003. Dental injuries in Norwegians aged 7-18 years. Dent Traumatol., 19(2) 67-71.
Tantbirojn D., A. Versluis, M. Pintado, R. De Long and W. Douglas, 2004. Tooth deformation patterns in molars after composite restoration. Dent Mater, 2004, 20:535–542.
Tapias M., R. Jiménez-Garcia, F. Lamas and A. Gil, 2003. Prevalence of traumatic crown fractures to permanent incisors in a childhood population: Dental Traumatol., 19(3):119-122.
Traebert J., J. de Lacerda, L. Foster Page, W. Thomson and M. Bortoluzzi, 2012. Impact of traumatic dental injuries on the quality of life of schoolchildren. Dent Traumatol., 28:423–428.
Vasconcellos A., S. Pereira, I. Darwish and A. Camarao,2 008. Virtual analysis of stresses in human teeth restored with esthetic posts. Mater Res., 11:459-463.
Wilson, S., 2007. Epidemiology of dental trauma treated in an urban pediatric emergency department. Pediatr Emerg Care, 13(1) 12-15.
Xiao L., S. Yun, G. Zhen, S. Chao, C. Xiao, G. Zhen, G. Hong and C. Xiang, 2008. Three dimensional finite element analysis of maxillary central incisore restored with different post core materials. Int Chin J Dent., 8:21-27.