ORIGINAL PAPER

IMPACT OF SPLINTING CHARACTERISTICS ON MAXILLARY CENTRAL INCISOR AFTER REPLANTATION – ASSESSED WITH THE FINITE ELEMENT METHOD

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ABSTRACT

Introduction: The study assessed the correlation between mobility and the tensions in the injured tooth after it was splinted using an orthodontic wire and a composite with the number of splinted teeth and the wire diameter.

Material and methods: Simplified geometric models of the alveolar crest of the maxilla and teeth (with avulsed and splinted left central incisor) were constructed using computer software. The tooth displacement and mechanical stress were assessed for different wire diameters (0.4-1.0 mm) for both three and five splinted teeth.

Results: With three immobilised teeth, the displacement ranged from 83.31 μm for 0.4 mm diameter wire to 81.78 μm for 1 mm wire; with five immobilised teeth from 83.36 μm for a 0.4 mm wire to 81.93 μm for a 1 mm one. Stress on the injured teeth was around 14.28 MPa for a 1 mm wire and 14.52 MPa for a 0.8 mm wire for three splinted teeth.

Conclusions: According to the finite element method, the use of a different diameter (0.4-1.0 mm) of stainless steel orthodontic wire after replantation of the maxillary central incisor did not cause any considerable changes in tooth micromovements or stress. Also, it is enough to splint the injured tooth with two neighbouring teeth since there were no considerable differences with two additionally splinted teeth.

Key words: tooth avulsion, tooth mobility, tooth resorption, finite element analysis.

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INTRODUCTION

An avulsion is the complete displacement of a tooth from its socket leading to a loss of blood supply to the pulp tissue and to exposure of periodontal cells to external factors [9]. Total luxation represents 0.5-3.0% of all dental injuries in permanent teeth. The prognosis depends on how quickly the patient gets medical treatment [1]. Maintaining vitality of periodontal ligament cells, which, similarly to pulp cells, start dying without blood supply and when exposed to external factors, such as a dry environment, is the main objective [6]. Since replanted teeth may fail even 20 years after trauma, it is necessary to prevent complications that could lead to tooth loss [9]. Proper splinting of the traumatically injured teeth is one of the procedures impacting the final treatment result [10].

The objective of splinting is no longer to immobilise the teeth. Micromovements in the zone of traumat-

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ic injury promote collagen production and maturation, ensure proper blood circulation, facilitate revascularisation and accelerate periodontal regeneration. Tooth immobilisation results in poorer periodontal tissue healing by inducing fibroblasts into a catabolic state and therefore reducing the amount of collagen produced [3]. Sufficient elastic splinting reduces the risk of resorption [13]. Therefore, splints are recommended to avoid further injuries and ensure that the patient feels comfortable [2]. Perfect splinting should prevent further injuries and the risk of swallowing the mobile tooth; it should allow the regeneration of the periodontal ligament; and the splint should be easily applied and taken off without traumatically impacting the injured teeth and the neighbouring soft tissues. It should also stabilise the traumatically injured tooth/teeth in the correct position, allowing physiologic tooth mobility to promote periodontal healing. It is also crucial to have the necessary access to assess pulp vitality or start an endodontic treatment. The construction of splints is also very important as they should not impede proper oral hygiene routines [10]. Poor hygiene of the injured regions can lead to gingivitis, even causing alveolar bone resorption [14].

Improper splinting can lead to pulp necrosis, pulp canal obliteration, resorption and atrophy of the alveolar process near the injured tooth [14]. Pulp necrosis is caused by abnormal blood flow in its vessels. Studies on animals established that improper splinting could increase the risk of necrosis, probably because of perturbed creation of new blood vessels as a result of tooth immobilisation. Clinical studies similarly established that pulp canal obliteration occurred more often in cases of improper splinting, most likely because of excessive pressure on the neurovascular bundle near the apex of the splinted tooth [14].

When damage to the periodontal ligament co-occurs with a bacterial pulp superinfection, external inflammatory root resorption can occur. When bacterial toxins reach the periodontal tissues (through both the dentinal canals and apical foramen), resorption-stimulating factors (prostaglandins, macrophage chemotactic factors, and osteoclast activating factors) are released. Periodontal tissues are then destroyed by activating the inflammatory response and the osteoclasts. This process is faster in immature teeth as their dentinal canals are wider [8].

The periodontal ligament heals at two levels: at the root (cementum and Sharpey fibre formation) and at the socket (bone tissue formation). When less than 20% of the root surface is damaged, temporary ankylosis can occur and then resorb if the tooth is stimulated by factors such as its physiologic mobility ensured by the use of proper splinting [8]. More extensive injuries of the periodontal ligament usually lead to permanent ankylosis. The tissues resorbed by osteoclasts are then replaced by bone cells. This leads to tooth infraposition, perturbed growth of the alveolar process and finally to the loss of the ankylosed tooth. The process is much faster in children [8, 14].

Since the splinted tooth needs to have proper mobility, it is crucial to examine what type and extent of splinting would guarantee the best conditions for the periodontium to heal and to reduce the risk of late complications.

OBJECTIVES

The study assessed the correlation between mobility and the stresses in the injured tooth (after it was splinted with an orthodontic wire and a composite), the number of splinted teeth, the wire diameter and the stresses on the surrounding bone.

MATERIAL AND METHODS

Code_Aster Open Source and pre- and post-processor Salome-Meca were used in order to assess tooth mobility and the level of mechanical stress in teeth and in the surrounding bone. These are advanced programs using the finite element method (FEM) and serve to assess the deformations and strains in deformable bodies subjected to mechanical forces. FEM is a numerical method used for solving differential equations describing physical phenomena, such as the deformation of deformable bodies by external forces. It is commonly used for solving problems of engineering and mathematical physics, where the phenomenon can be described with differential or integral equations.

The basic FEM concept is that the analysed 3D object with a complicated shape can be subdivided into numerous simpler domains, unequivocally defined by nodes, i.e. points defining the shape of a line (such as the vertices of a triangle or of a polygon). After dividing the examined domain into a collection of subdomains (the so-called finite elements), the researched physical fields, such as displacements, strains or stresses within the material composing the domain, may be approximately expressed in nodes, calculated by solving a set of balance equations. Recently, more and more FEM studies are used in dentistry [16] and dental traumatology [15].

A simplified geometric model of the alveolar crest of the maxilla together with the teeth (from 16 to 26) and three to five splinted teeth using a flowable composite, which was then divided into finite elements, was constructed using Salome-Meca to calculate the strength of the materials. Between 519570 and 557799 degrees of freedom were used to calculate the models.

The avulsion of the left maxillary central incisor was analysed. The junction of the root to the bone was modelled in a simplified way, assuming that there was a layer of weaker tissue – the periodontal tissue – between the tooth and the bone. The calculations also presupposed that all the materials, i.e. the tooth, bone,

TABLE 1. Selected mechanical parameters in the model

Geometric model	E (MPa)	v
Jaw	14,900	0.3
Teeth	19,890	0.3
Periodontal ligament	1379	0.3
Damaged periodontal ligament	1379	0.3
Composite	20,000	0.3
Orthodontic wire	2500	0.3

TABLE 2. Von Mises' peak displacements and reduced strains with three splinted teeth

Wire diameter (mm)	Displacement (μm)	von Mises (MPa)
0.4	83.31	14.42
0.5	83.10	14.38
0.6	82.92	14.33
0.7	82.68	14.41
0.8	82.42	14.52
0.9	82.11	14.38
1.0	81.78	14.28

TABLE 3. Von Mises' peak displacements and reduced strains with five splinted teeth

Wire diameter (mm)	Displacement (μm)	von Mises (MPa)
0.4	83.36	14.37
0.5	83.21	14.43
0.6	83.00	14.37
0.7	82.81	14.36
0.8	82.58	14.30
0.9	82.30	14.29
1.0	81.93	14.31

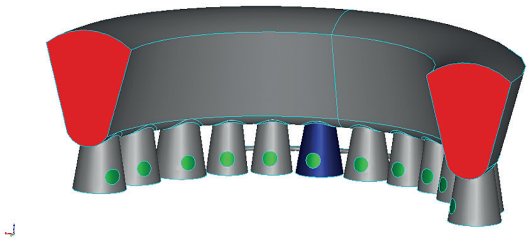

FIGURE 1. Geometric model

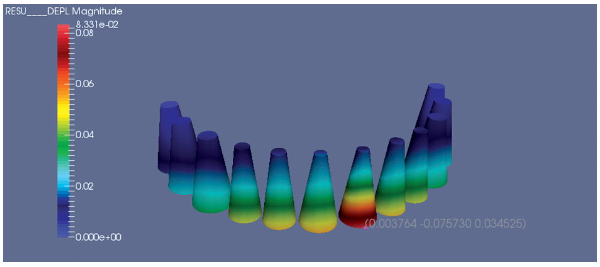

FIGURE 2. Displacement field of magnitude vector for three teeth with 0.4 mm wire

periodontal ligament and composite, had the same linear elasticity. The strength was assessed for different wire diameters (0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 mm) for both three and five splinted teeth.

Young's modulus for stainless steel wire was established based on static extension MTS Insight Electromechanical Testing; Poisson's ratio equalled 0.3 and was the same for all materials. Young's moduli for the other objects were selected based on published data [7, 17, 18] and are presented in Table 1. As data were divergent the mean values were selected.

Young's modulus of the periodontal ligament of the avulsed tooth was presumed to be ten times lower than that of a healthy periodontal ligament. It was assumed that all the elements – the wire and the composite, the composite and the tooth, the healthy tooth and the periodontal ligament, and the periodontal ligament and the bone – were all perfectly joined.

Figure 1 presents the geometric model. The areas in red are those without any degree of freedom; those in green were submitted to a pressure of 6 MPa. The avulsed tooth is dark blue.

RESULTS

With three immobilised teeth, the displacement was most important for a 0.4 mm diameter (83.31 μm) wire, and least important for a 1 mm one (81.78 μm); with five immobilised teeth, the most important displacement was 83.36 μm for a 0.4 mm wire, and the least important was 81.93 μm for a 1 mm one (Tables 2 and 3).

The stresses on the injured teeth varied between 14.28 MPa for a 1 mm wire and three splinted teeth and 14.52 MPa for a 0.8 mm wire and three splinted teeth (Tables 1 and 2).

Analysis of the displacement distribution established that the injured tooth was the most mobile at its incisal edge and the least at its root apex. The injured tooth was always the most mobile; mobility then decreased in the subsequent teeth (Figure 2).

The tooth cervix and the root perimeter from the cervix to the apex were the most strained areas, the incisal edges of the crowns the least. The stress on the bone was the highest at the top of the vestibular lamina of the alveolar process; the stress was the lowest above the apex of the splinted tooth (Figures 3 and 4).

DISCUSSION

To properly heal the splinted tooth, the tooth should be under similar physiological conditions as a healthy one, i.e. the deformation of the periodontal ligament should be around 100-1500 mm and the tooth micro-movements around 50 µm. The micro-strains along the healing tissues were considered to promote the production and maturation of collagen and also the synthesis of procollagen in fibroblasts. Micro-movements guarantee optimal blood flow, which accelerates the reorganisation and reformation of periodontal attachments [3].

In the present study, the micro-strains of the injured tooth were between 14.28-14.52 MPa and the mobility was between 81.78-83.36 µm. The use of a 0.4 mm wire was accompanied by the most important micromovements. The peak mobility was higher for five than for three splinted teeth.

In a finite element study by Isquierdo de Sousa *et al.*, 0.8 mm wires made out of three different materials were selected. The elastic modulus for a steel wire was 200,000 MPa; for a titanium molybdenum wire it was 84,000 MPa; and for a nickel titanium wire it was 52,000 MPa [5]. The conclusions of the aforementioned study established that, based on the selected research model, the biochemical behaviour of the bone and of the periodontium was similar for all the groups [5]. The present study followed a similar method (finite element analysis), but steel wires of different diameters (from 0.4 to 1.0 mm) were used. The mean Young modulus for steel wires, based on strength tests (see Material and methods) and equalling 2,500 MPa, was used for calculations. Despite divergences in the Young moduli in the present and aforementioned studies, i.e. the different wire diameters and numbers of splinted teeth, the conclusions were similar, i.e. the biochemical behaviour of teeth and bones was similar for different splints.

The masticatory forces varied depending on the type of food and methods used. They ranged between 10-20 N (for soft foods) and 100 N (solid foods) [13] up to 675-788 N for meat or nuts [4]. In one of the studies the mean masticatory force was 410 N in patients aged 7-12 years old [12]. In the present study, the teeth were under the pressure of 6 MPa, which corresponded to an exerted force of 350 N.

In a study on human cadavers, Kwan *et al.* established that a stainless steel wire with a diameter over 0.4 mm could considerably increase the stiffness of the splint. They concluded that a 0.4 mm stainless steel wire was the borderline between an elastic and a non-elastic splint. Increasing the diameter from 0.4 to 0.5 mm increased the splinting effect (i.e. the difference between the mobility before and after splinting measured with Periotest M) two-fold, i.e. from 9.1 to 18.6. Such large differences did not occur with nickel titanium wires

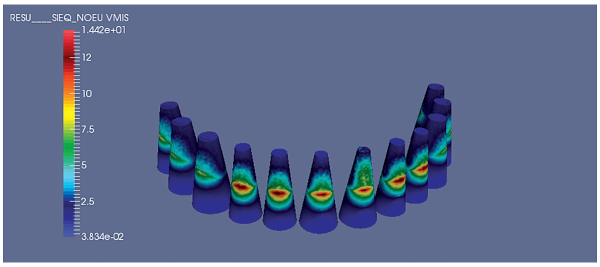

FIGURE 3. Stresses field (von Mises) for three teeth with 0.4 mm wire

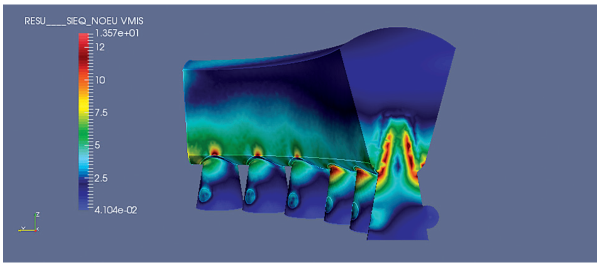

FIGURE 4. Cross-section through the model – stresses field on a traumatic tooth and bone tissue

of different diameters [11]. In the present study, an increase in the diameter of the steel wire by 0.1 mm within 0.4-1.0 mm did not considerably decrease the mobility of the injured tooth – the peak difference was 1.43 µm, i.e. a decrease of 1.7% in its mobility. The difference in the mobility between 0.4-0.5 mm diameter was 0.21 µm, i.e. the mobility decreased by 0.25%. The differences in the present and above-mentioned results could be the consequence of a different study method of the properties of the wire or of an imprecise definition of the mechanical properties of the wire.

Berthold *et al.* compared different types of wire and different numbers of splinted teeth *in vitro*. A 0.45 mm Dentaflex stainless steel wire was considered elastic when compared to a 0.8 × 1.8 mm wire with a rectangular cross-section, both for movements that were horizontal and those vertical to the tooth axis. In the case of a 0.45 mm wire, it was enough to splint the injured tooth and one of the teeth on both sides to properly transmit the functional forces [2]. The present study also established that splinting three teeth (the injured one together with the neighbouring mesial and distal teeth) was adequate as the differences in strains and micromovements with five splinted teeth were minimal.

The selected model was simplified both when it came to its project (simplified geometric jaw model; presupposed uniformity of all elements: bone, tooth, periodontal ligament, wire, and composite) and to the biomechanical conditions when masticating or talking. Furthermore, there were numerous divergences in the publications concerning the mechanical properties of different tissues and materials used in the studies.

CONCLUSIONS

According to the finite element method, the use of a different diameter (0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 mm) stainless steel orthodontic wire after replantation of the maxillary central incisor did not cause any considerable changes in tooth micromovements or stresses. Also, it is enough to splint the injured tooth with two neighbouring teeth since there were no considerable differences in the mobility with two additionally splinted teeth. According to the study, the most strained areas in the traumatised, splinted tooth are the tooth cervix and the root.

CONFLICT OF INTEREST

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

1. Andersson L, Andreasen JO, Day P, Heithersay G, Trope M, Diangelis AJ , et al. International Association of Dental Traumatology guidelines for the management of traumatic dental injuries: 2. Avulsion of permanent teeth. Dent Traumatol 2012; 28: 88-96.
2. Berthold C, Auer FJ, Potapov S, Petschelt A. Influence of wire extension and type on splint rigidity - evaluation by a dynamic and a static measuring method. Dent Traumatol 2011; 27: 422-431.
3. Burcak Cengiz S, Stephan Atac A, Cehreli ZC. Biomechanical effects of splint types on traumatized tooth: a photoelastic stress analysis. Dent Traumatol 2006; 22: 133-138.
4. Casas EB de L, de Almeida AF, Cimini CA, Gomes P de TV, Cornacchia TPM, Saffar JME. Determination of tangential and normal components of oral forces. JAppl Oral Sci 2007; 15: 70-76.
5. De Souza FI, Poi WR, da Silva VF, Martini AP, Melo RA, Panzarini SR, et al. Stress distribution in delayed replanted teeth splinted with different orthodontic wires: a three-dimensional finite element analysis. Dent Traumatol 2015; 31: 190-195.
6. Donaldson M, Kinirons MJ. Factors affecting the onset of resorption in avulsed and replanted incisor teeth in children. Dent Traumatol 2001; 17: 205-209.
7. Fill TS, Carey JP, Toogood RW, Major PW. Experimentally determined mechanical properties of, and models for, the periodontal ligament: critical review of current literature. J Dent Biomech 2011; 2011: 312980.
8. Finucane D, Kinirons MJ. External inflammatory and replacement resorption of luxated, and avulsed replanted permanent incisors: a review and case presentation. Dent Traumatol 2003; 19: 170-174.
9. Hinckfuss S , Messer LB. Splinting duration and periodontal outcomes for replanted avulsed teeth: a systematic review. Dent Traumatol 2009; 25: 150-157.
10. Kahler B, Hu JY, Marriot-Smith CS, Heithersay GS. Splinting of teeth following trauma: a review and a new splinting recommendation. Aust Dent J 2011; 56: 10-15.
11. Kwan SC, Johnson JD, Cohenca N. The effect of splint material and thickness on tooth mobility after extraction and replantation using a human cadaveric model. Dent Traumatol 2012; 28: 277-281.
12. Lemos AD, Gambareli FR, Serra MD, Pocztaruk RL, Duarte Gavião MB. Chewing performance and bite force in children. Braz J Oral Sci 2006; 18: 1101-1108.
13. Mazzoleni S, Meschia G, Cortesi R, Bressan E, Tomasi C, Ferro R, et al. In vitro comparison of the flexibility of different splint systems used in dental traumatology. Dent Traumatol 2010; 26: 30-36.
14. Oikarinen K. Tooth splinting: a review of the literature and consideration of the versatility of a wire-composite splint. Endod Dent Traumatol 1990; 6: 237-250.
15. Oskui IZ, Hashemi A, Jafarzadeh H, Kato A. Finite element investigation of human maxillary incisor under traumatic loading: Static vs dynamic analysis. Comput Methods Programs Biomed 2018; 155: 121-125.
16. Piccioni MA, Campos EA, Saad JRC, de Andrade MF, Galvão MR, Rached AA.Application of the finite element method in dentistry. RSBO Revista Sul-Brasileira de Odontologia 2013; 10: 369-377.
17. Qingzong S, Xiaoli A, Zhenguo W, Mingxi L, Baopin Z, Bin L. Microstructures and Mechanical Characteristics of Enamel and Dentin of Primary and Permanent Teeth. Advanced Materials Research 2013; 658: 67-72.
18. Seong WJ, Kim UK, Swift JQ, Heo YC, Hodges JS, Ching-Chang K. Elastic properties and apparent density of human edentulous maxilla and mandible. Int J Oral Maxillofac Surg 2009; 38: 1088-1093.