Role of occlusal forces in the development of non-carious cervical lesions

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Abstract. The aim of this study is to clarify and analyze the stress on the undamaged premolars, as a result of their exposure to different types of occlusal forces. Experiments were carried out on extracted premolars subjected to axial and para-axial loading ranging from 50 N to 1200 N. An axial load was applied on vestibular cusp tip, whereas the para-axial load was applied obliquely on the long tooth axis. The silicone elastomer was used as a periodontal ligament simulator, while poly(methyl methacrylate) was used as a bone simulator. The teeth withstand a higher force transmitted along the long tooth axis rather than a small para-axial force. Changing the force transmission axis led to non-carious lesion occurrence on tooth cervix.

Key Words: abfraction, functional load, non-functional load

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Introduction

Non-carious cervical lesion (NCCL) can be defined as the loss of tooth structure at the cement-enamel junction that is unrelated to dental caries (Kolak et al 2018). Although it is accepted that NCCL have a multifactorial aetiology, the relative contributions of the various aetiological factors remain unclear (Michael & Kaidonis 2010; Nascimento et al 2016).

A number of causal factors have been identified in the formation of NCCL, namely: the corrosive (chemical and biological) effects due to intrinsic and extrinsic acids; the abrasive and erosive actions of brushing and of toothpaste use; occlusal stress generated by parafunctions and high occlusal load (Bartlett & Shah, 2006; Madani & Ahmadian- Yazdi, 2004).

Although the toothbrush was believed to be the main cause of the third cervical tooth lesions, many cases have been identified where, in spite of the toothbrush not having been used at all, these lesions were present; thus, the unexpected brushing could not be considered a causal factor. Moreover, in many studies, no connection was found between the occurrence of these cervical lesions and the brushing technique, the brushing frequency, the types of toothpaste and toothbrush used, or the salivary pH. Similarly, the prevalence of cervical lesions could not be correlated to either the speed or the skill in carrying out the dental brushing (Miller et al 2003; Lambert & Lindenmuth 1994). Following the corroboration of the results from the studies carried out in this regard, a hypothesis was proposed on the fact that these lesions would be caused by the occlusal forces occurring during the functional or eccentric movements of the mandible (Lambert & Lindenmuth 19947; Litonjua et al 2004; Silva et al 2013).

The types of occlusal loading could be: axial and paraaxial. Axial loading of the tooth causes cusps' bending in the vertical plane resulting in generation of tensile strains in the cervical region. On the other hand, lateral loading of the tooth takes place naturally as a patient moves the lower jaw from side to side, inducing lateral forces during the functional or parafunctional masticatory cycle. In this case, a flexion at the cusp level is generated, causing extensive pressure areas in the tooth cervical region (Rees 2006). Moreover, the persistent cyclic loading in this region causes breakdown of the bonds between the hydroxyl apatite crystals forming the enamel bulk (Grippo et al 2012). In time, these cracks coalesce, resulting in enamel bulk loss, process that has been termed abfraction by Grippo (1991). The aim of this study is to clarify and to analyze the stress on the undamaged premolars in the cervical region, as a result of their exposure to different types of occlusal forces.

Materials and methods

This study was carried out on 4 sound premolars extracted (Fig. 1) for orthodontic purposes, from patients aged between 15 and 22 years. The roots of the premolars were straight and conical. The teeth were water-rinsed, their periodontal ligaments were removed and then the teeth were properly preserved.

The roots of the premolars were wrapped in wax (Elaflex Tauchwachs, Bredent, Germany) and silicone elastomer (AD special vinyl polysiloxane for duplication in the dental laboratory Fegura Sil, Germany) (see Fig. 2), and then fixed into an self-polymerizable acrylic resin (Duracryl Plus, Spofadental, Czech Republic), which is a poly(methyl methacrylate) (PMMA) (Fig. 3).

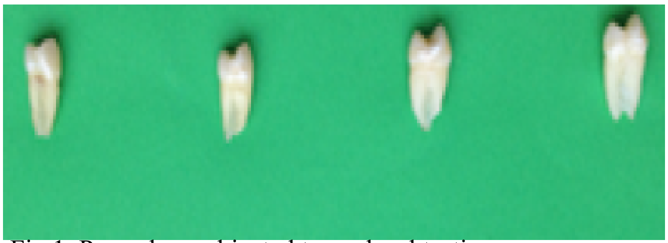

Fig 1. Premolars subjected to occlusal testing

Fig. 2. Premolars wrapped in wax

Fig. 3. Teeth embedded in self-polymerizable acrylic resin

The silicone elastomer acts as periodontal ligament simulator, while PMMA simulates the bone. It provides the polymer with good self-assembly properties and the ability to form highly organized structures (Bărar et al 2018). PMMA, a thermoplastic polymer, has been widely used in many commercial applications due to its high impact-resistance, ease of fabrication, low density, and cost-effective technologies. In addition, PMMA has been one of the most popular substrate materials in making polymer-based micro fluidic devices to perform chemical and biological assays due to its excellent chemical, physical, biological, mechanical, optical, and thermal properties (El-Swie et al 2017). PMMA is an eco-friendly and stable material with excellent optical properties being used also in optoelectronic applications (Guo et al 2016; Cakar et al 2016).The elastomer used in this study simulates the periodontal ligaments that connect the tooth and the alveolar bone, acting as a 'shock absorber' for the tooth.

Half of the teeth used in the present study were positioned in the longitudinal axis of the tooth and the other half was applied in a horizontal position. The teeth were placed at the level of the testing machine in order to apply axial and para-axial forces. The experimental tooth-loading equipment used in our studies consists of a Zwick/ Roell Z005 type test system (Fig. 4)

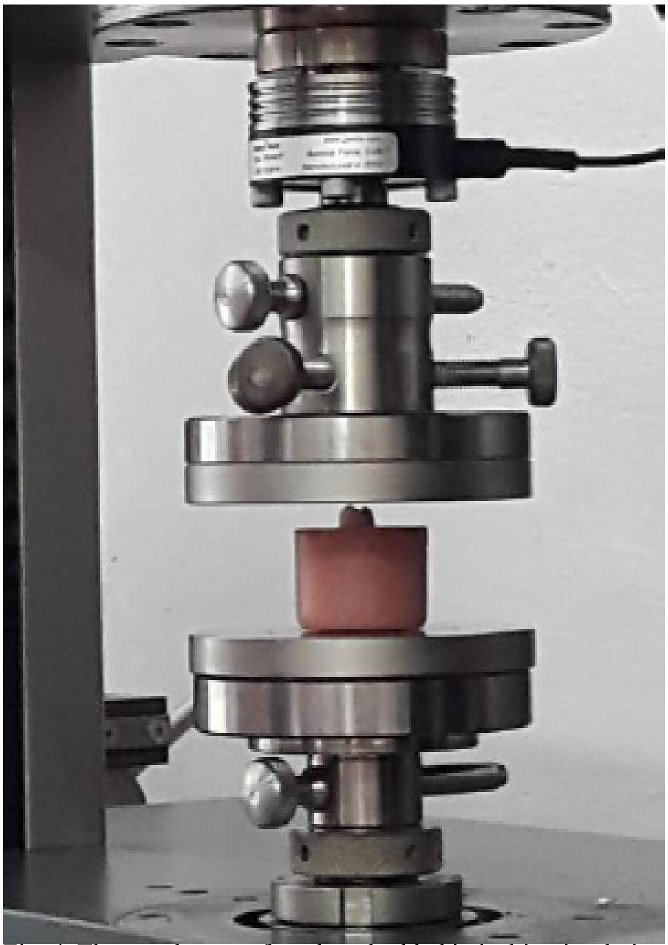

Fig. 4. The attachment of tooth embedded in its bio-simulating support, on Zwick/ Roell Z005 testing system

provided with Test Expert software program, and an Olympus Gx51 optical microscope.

The axial forces applied to the vestibular cusp of the premolars, in the study, ranged from 50 to 1200 N. The force was applied to the tooth continuously on 4 levels, namely: 300 N, 600 N, 900 N, and 1200 N, while maintaining the force for an average of 7 seconds on each level. The force was increased progressively in order to identify the correlation between its magnitude and the initiation of NCCL, both for axial and para-axial forces.

The para-axial force was applied to the internal side of the premolar vestibular cusp, with a 45 - degree inclination, relative to the vertical axis.

In order to identify the changes in the dental structure occurring in time, photographs of the teeth to which both axial and para-axial forces were applied, were taken by microscopic stereoscopy with a digital camera. Our observations focused on the vestibular, lingual, medial, and distal areas. The amelocemental junction on each side of the tooth was a point of reference for taking photos at a magnification of 50x and 100x. The length and extension of the cracks were measured on calibrated images of Olympus GX51 optical microscope at two magnitude factors of 50x and 100x.

Results

In this study, the teeth were extracted for orthodontic purposes from patients aged 15-22 years with a history reflecting the

Fig. 5. Load distribution diagram

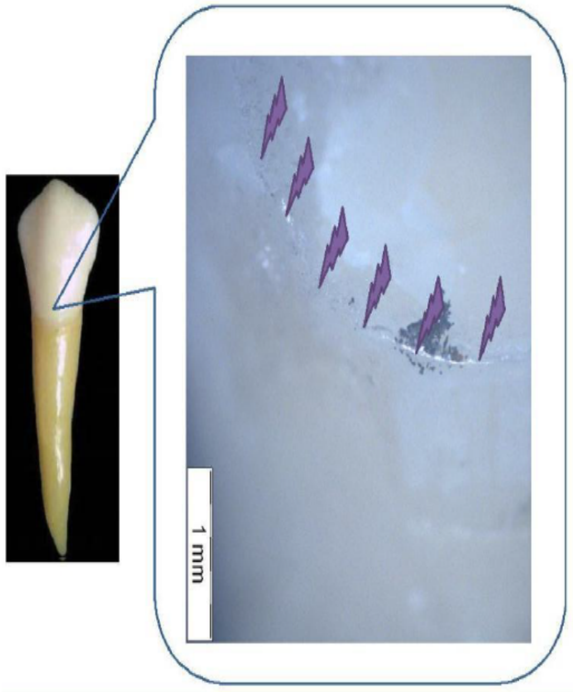

Fig. 6. Initiation of lesion following axial force applied (Magnitude 50x)

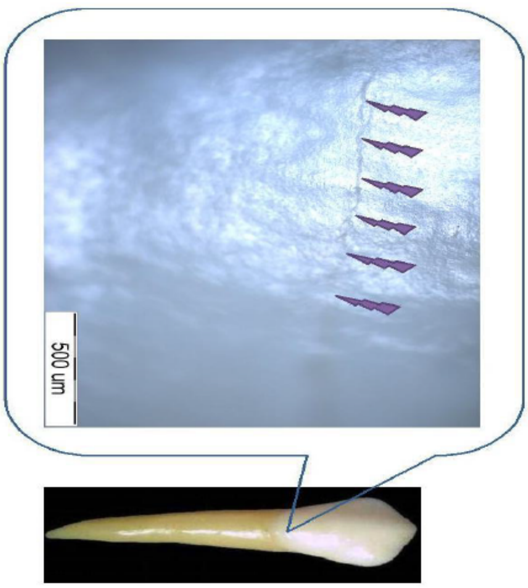

Fig. 7. Initiation of lesion following para-axial force applied (Magnitude 100x)

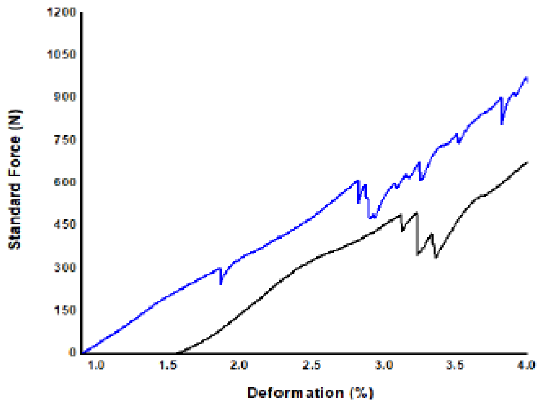

Fig. 8. The mechanical behaviour of tooth exposed to axial (—) and para-axial (—) occlusal forces

low incidence of occlusal stress. Two types of occlusal forces were applied, namely: an axial force acting on the vestibular cusp of the premolars simulating maximum intercuspation, and an oblique force applied to the internal side of the premolar vestibular cusp, simulating a lateral movement.

Occlusal forces lead to deformation of teeth, which can ultimately compromise their durability over time. As known, the main component of tooth is the hydroxyapatite (Jumanca 2018), an inorganic constituent with highly organized crystalline structure providing extraordinary bioactivity and osteoconductivity (Rogojan 2016), but unfortunately it possesses low mechanical strength (Ichim 2016). Therefore, tooth enamel is a brittle glass-like material, being highly vulnerable to fracture, but it possesses a remarkable resilience, surviving millions of functional contacts over a lifetime (Chai 2009).

The diagram (Fig. 5) shows that, when an axial force of 470 N is applied, there is an accidental deformation of the fixing material in the support. Thus, when an axial force of 683 N is applied, NCCL initiation occurs. With a 1300 N load, a decrease in force occurs, most likely because of a bubble of air in the support.

The tooth exposed to such a load was examined under the optical microscope in those areas in which the probability of NCCL occurrence was at its peak. This was found to occur in the cervical region of the tooth, having a curved shape, covering a length of about 3.5 mm (Fig. 6).

The same experiment was carried out on the teeth exposed to para-axial forces (non-functional load) with a 45 -degree tilting, relative to the vertical axis of the tooth. In this case, it was found that the initiation of the non-carious lesion occurred when a force of 532 N was applied. The microscopic surface image of the tooth revealed a small rectilinear lesion of approximately 1.5 mm (Fig. 7).

Figure 8 displays the tooth reactions to occlusal forces (axial — and para-axial —). In these situations, different responses were recorded. Thus, an axial force induced less deformation than a para-axial load.

Discussion

The pattern of tension distribution in the tooth and in its supporting tissues is influenced by the implantation of tooth, its position, the intensity and direction of the forces (Ispas et al 2016). Thus, this study confirms the hypothesis that the type of force could cause the appearance of non-carious lesions. The vertical forces were found to be less harmful and were transmitted down the long axis of the tooth. In this case, the lesion appeared when a force of 683 N was applied to the tooth. Contrarily, subsequently para-axial forces were found to cause the occurrence of non-carious lesions in the cervical area when the tooth was exposed to a lower intensity (532 N).

This behaviour is due to the direction of the force, which favours the flexion of the dental crown because of the 45-degree tilting relative to the long axis of the tooth. The oblique forces simulated in this study tend to produce both compressive stress on the vestibular surfaces of the premolars and traction on the oral surfaces. The results showed that non-carious lesions occurred in the amelocemental junction. Our results are in agreement with those obtained by other authors by photoelasticity tests, tensiometry, approaches with finite elements, all of them indicating a concentration of the occlusal stress on the third cervical (Rees 2006; Spranger 1995).

The studies of dental biodynamics conducted by Goel and coworkers (Goel et al 1990; Goel et al 1991; Khera 1988) developed three-dimensional models of the upper premolar. They showed that the contour of the amelocemental junction and the enamel thickness were significantly affected by the magnitude of the tension and displacement stress, which were present in the cervical region. The accumulation of stress at this level was responsible for producing abfractions. They reported that the displacement stress at the vestibular level was more frequent than at the oral level, which could explain the less frequent lingual localization of dental abfractions.

The research group of Rees (Rees et al 2003; Rees & Hammadeh 2004) reported that a vertical force of 500 N applied at the level of the cusp peaks induced less tensions than in the case of oblique occlusal forces that surpassed known levels of enamel fracture. The overloading shown at this level would be responsible for breaking down the bonds between the hydroxyapatite crystals that compose the enamel and consequently, a loss of volume in the dental enamel occurred. The shape and magnitude of the lesions were determined by the direction, magnitude, frequency, duration and location of the forces applied to the tooth (Lee et al 2002; Grippo 1992; Grippo 1996).

In this respect, our study analysed the effect of various types of forces applied to the teeth and their intensity. The stress caused by the oblique forces, especially those acting on the internal sides of the cuspids, was far over the enamel breaking tension, while the axial forces were below the fracture tension of the enamel.

Conclusions

The experimentally produced abfraction, was the result of the forces applied to the teeth that differ both in intensity and direction. It was shown that the teeth withstand a higher force transmitted along the long axis of the tooth rather than a small para-axial force. Changing the force transmission axis led to the occurrence of the non-carious lesion on the tooth cervix.

This study provides a biomechanical explanation of abfraction: the more oblique the force acts onto the tooth, the faster the enamel fracture occurs at its cervical level.

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