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Evaluation of the performance of orthodontic devices using FBG sensors

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Abstract. Cross-bite, as a malocclusion effect, is defined as a transversal changing of the upper dental arch, in relation to the lower arch, and may be classified as skeletal, dental or functional. As a consequence, the expansion of maxilla is an effective clinical treatment used to correct transversal maxillary discrepancy. The maxillary expansion is an ancient method used in orthodontics, for the correction of the maxillary athresia with posterior crossbite, through the opening of the midpalatal suture (disjunction), using orthodontic- orthopaedic devices. Same controversial discussion arises among the clinicians, about the effects of each orthodontic devices as also about the technique to be employed. The objective of this study was to compare the strain field induced by two different orthodontic devices, named disjunctor with and without a connecting bar, in an acrylic model jaw, using fiber Bragg grating sensors to measure the strain patterns. The orthodontic device disjunctor with the bar, in general, transmits higher forces and strain to teeth and maxillae, than with the disjunctor without bar. It was verified that the strain patterns were not symmetric between the left and the right sides as also between the posterior and anterior regions of the maxillae. For the two devices is also found that in addition a displacement in the horizontal plane, particularly in posterior teeth, also occurs a rotation corresponding to a vestibularization of the posterior teeth and their alveolar processes.

1. Introduction

Cross-bite, as a malocclusion effect, is defined as a transversal changing of the upper dental arch, in relation to the lower arch, and may be classified as skeletal, dental or functional. This type of malocclusion is frequent in some populations, appearing in early stage development of teenagers and does not present self-correction. As a consequence, the expansion of maxilla is an effective clinical treatment used to correct transversal maxillary discrepancy, in children and teenagers that present maxillary atrophy, until the final phase of puberty (end of the active growth). The maxillary expansion is an ancient method used in orthodontics, for the correction of the maxillary athresia with posterior crossbite, through the opening of the midpalatal suture (disjunction), using orthodontic- orthopaedic devices [1-3]. The expansion is achieved when a force is applied to the dental-alveolar structures, through a removable or fixed device, by exceeding the necessary limits for the expansion, anticipating the cellular reaction of the periodontal ligament and favouring the dissipation of the forces through the

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maxilla sutures[4-6]. According to de Assis et al [7] several studies have confirmed that the activation of the tooth-borne (Hyrax) or tooth-tissue-borne (Haas) expanders after osteotomies dissipates tensions responsible for the lateral movement of the maxilla and all adjacent structures, such as the teeth and the bones of the face and skull, which affects the nasal cavity, nasal septum, lateral walls and floor of the nose and nasal area, as well as the upper lip, alar base, gingiva and facial soft tissues.
Due to anatomic characteristics of the jaw and its resistance of several cranial-facial sutures (pterigo-palatal, to fronto-maxillary, to naso-maxillary and to zigomatic-maxillary), the expansion occurs in the horizontal plane with a pyramidal form, where the base is directed to the anterior inter-incisive region (anterior nasal spine), and the vertex located posterior, in direction to the posterior nasal socket (posterior nasal spine) (Fig. 1). In the frontal plane the disjunction of the jaw obeys to the same geometric configuration, with the vertex located close to the fronto-nasal suture and with the base at the oclusal plane (figure 1).

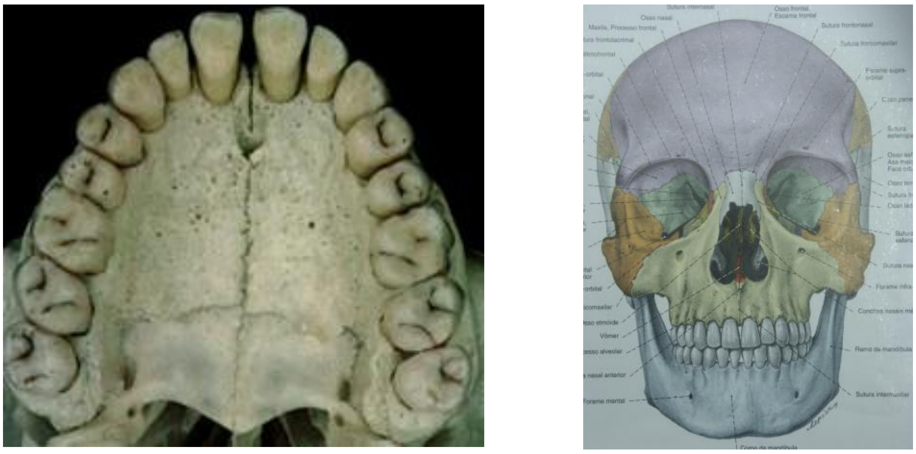

Figure 1. The maxillary expansion in the frontal and horizontal planes.

In clinical practice, after a few weeks of using the orthodontic-orthopaedic devices, the expansion in the horizontal plane induces the appearance of a maxillary midline diastema (figure 2).

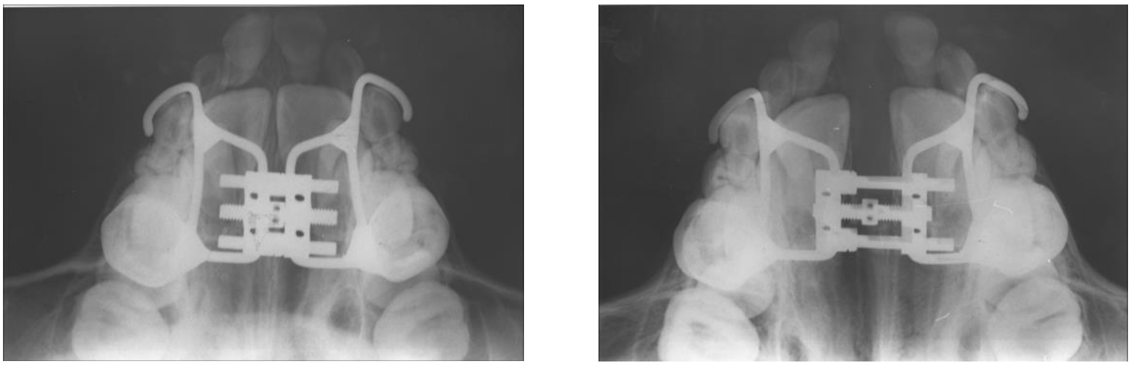

Figure 2. Radiographs showing clinical appearance of a maxillary midline diastema, in the horizontal plane.

Same controversial discussion arises among the clinicians, about the effects of each orthodontic devices as also about the technique to be employed, in order to achieve their goals of treatment, minimizing the negative effects for the patient [8-11]. Some authors [12,13] have reported that short-term rapid maxillary expansion (RME) with conventional appliances (Haas and Hyrax models) promotes the anterior and inferior dislocation of the maxilla, inclination of the alveolar process,

extrusion and buccal inclination of the posterior teeth, with a consequent posterior-inferior rotation of the mandible. Awareness of these effects motivated researchers to develop other types of appliances.
The objective of the present study was to compare the strain field induced by two different orthodontic devices, named disjunctor, in an acrylic model jaw.

2. Materials and methods
For this study it was used an acrylic model of a human jaw. The maxillae suture was simulated using a hard silicone at the interface of the two midpalatal parts. Periodontal ligament, who maintains teeth attached into alveolar socket, was simulated with a fine membrane of polyethylene, also to permit natural tooth mobility. The combination of mechanical properties of materials used within the study were taken into account the relationship between naturals ones. The two devices have been manufactured with a Hyrax screw of 10mm from Forestedente®. Two kinds of disjunctor were made, one with a bar connecting the metallic bands around teeth of the same side, and the other one without that bar (figure 3). The metallic bands were putted in pre-molar and molar teeth. Teeth were manufactured in metal alloy, to be rigid as natural teeth are and also to avoid teeth deformation during the experiment. Were used two optical fibers, each one with four Bragg grating sensors, one in the anterior region and the other in the posterior region of the maxilla (figure 3).

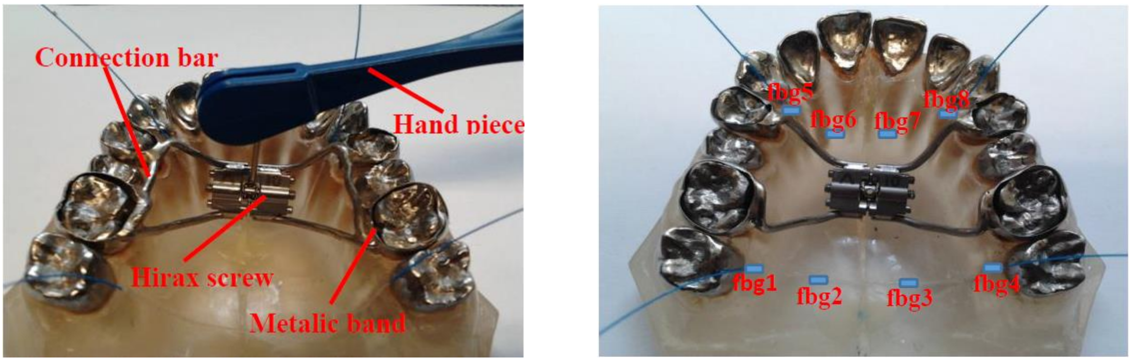

Figure 3. Overall view of the two devices, with the location of 8 FBG sensors.

The applied load was made twirling the screw Hirax one quarter turn, each 5 minutes, with a hand piece, in a total of twelve times. Data acquisition was made at 1sample/2seconds, with BraggMeterTM from FiberSensing.

3. Results and discussion
To make a better evaluation and comparison of the strain pattern, they were grouped for different locations, for the two devices. The term _b in each graph legend, corresponds to the device with the metallic bar connecting teeth in the same side. In figure 4 the strains located near the alveolar sockets, both in left and right sides, are displayed.
The maximum values of strain were not similar in both sides and this is due to the fact that the device was handmade and the technician has to adapt the device to model anatomy/geometry, forcing the arms of hyrax screw to adapt and consequently, sometimes they do not have the same length. For the region near the maxillae suture, there was obtained the same pattern in both sides, as it can be seen in the graphs displayed in figure 5. For that location, it was also observed that the strain difference between the two devices maintains constant during the entire applied load.

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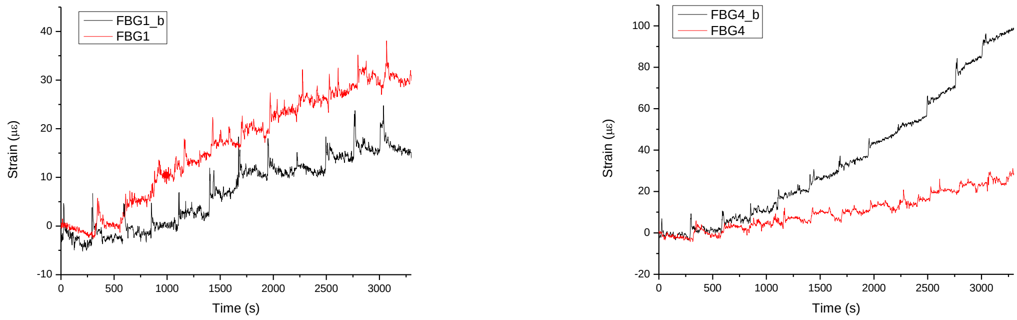
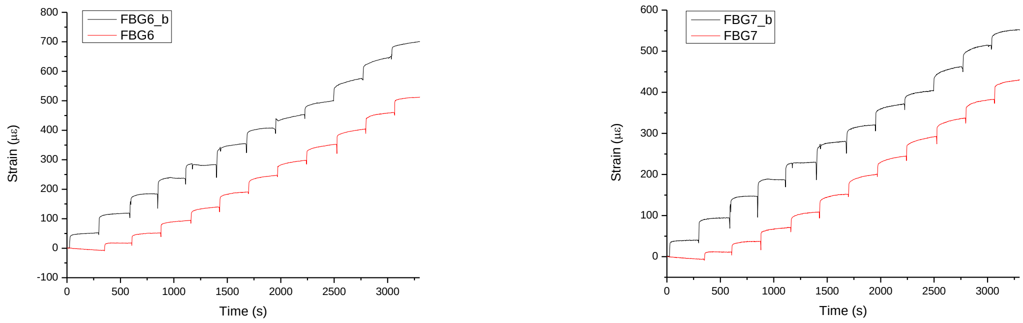


Left side Right side

Figure 4. Comparison of the strains versus time in the posterior region, for the two orthodontic devices.

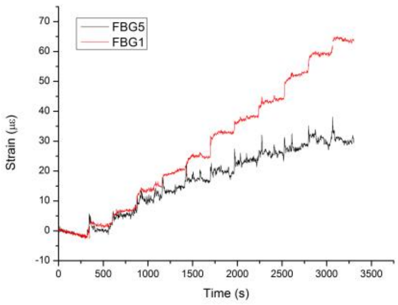


Left side Right side

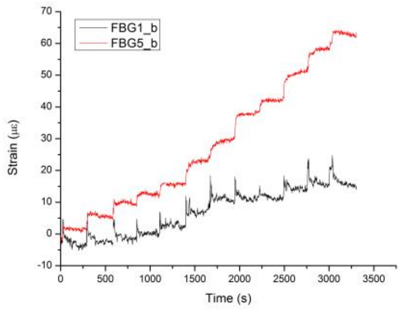
Figure 5. Comparison of the strains versus time in the anterior region, for the two orthodontic devices.

The patterns observed for all measurements reflect the viscoelastic behaviour of the model, as it happens with natural bone. This behaviour is shown by the pic of strain when the screw was twirled, followed by a strain relaxation. The great amount of force produced and transmitted from the devices into the bone were located at the anterior region, what corroborates the appearance of a middle diastema, seen in clinical practice. The observed strains for the device disjunctor with the bar are, in general, greater than with the disjunctor without bar. The observed strains are greater in the middle of the maxilla then near the teeth. The observed strains are greater in the anterior region of the maxilla. At the posterior teeth, in some cases it was observed initially a compression and after an expansion. This was due to the fact that the location of the sensors in that region was near vertical, proving that these devices provoke a rotation for vestibular position of posterior teeth and alveolar process. These results were also observed in others studies [7, 12]. For the two devices it has also been determined that, besides the displacement in the horizontal plane, especially on the posterior teeth, there is also a labial movement of the posterior teeth and alveolar processes, and a back rotation of the anterior section of the jaw, as already was verified by some authors [7, 11-12].

For each device, it was also performed the comparison between anterior and posterior region, for each side of the maxillae in both devices. In figure 6 are displayed the results in the posterior and anterior regions, for the two orthodontic devices, in the left side.



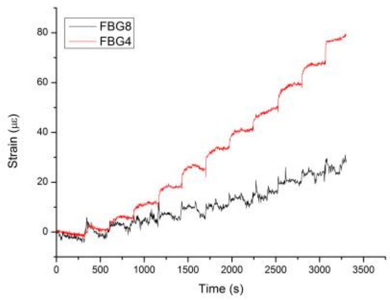
Disjunctor without bar



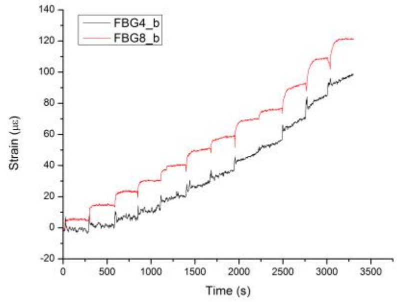
Disjunctor with bar

Figure 6. Comparison of the strains versus time in the posterior and anterior regions, for the two orthodontic devices, in the left side

In figure 7 are displayed the results for the right side of the maxillae, in anterior and posterior regions. As it can be seen, only in the case of the disjunctor with bar, the strain difference maintains constant, during the applied load. For the other cases, there is a greater increase in strain at the posterior region than at the anterior region.



Disjunctor without bar



Disjunctor with bar

Figure 7. Comparison of the strains versus time in the posterior and anterior regions, for the two orthodontic devices, in the right side

In order to compare quantitatively the induced strains by the two orthodontic devices, the results were organized in two tables and represent the strain measured at the maximum amount of applied load, corresponding to twelve turns of the Hyrax screw. In table 1 are displayed the results for the disjunctor with the bar and in table 2 are displayed for the disjunctor without the bar.

Table 1. Strains in the anterior region, for the dijunctor with bar.

	Left	Centre-Left	Centre-Right	Right
Anterior region	63.4 (με)	701.2 (με)	553.0 (με)	121.6 (με)
Posterior region	15.0 (με)	902.0 (με)	1423.3 (με)	98.5 (με)

Table 2. Strains in the anterior region, for the dijunctor without bar.

	Left	Centre-Left	Centre-Right	Right
Anterior region	63.8 (με)	512.8 (με)	430.0 (με)	78.9 (με)
Posterior region	29.4 (με)	785.4 (με)	1276.7 (με)	29.2 (με)

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For both types of disjunctors, the highest values are measured in posterior region, in the middle of maxillae, in the right side of the suture. Comparing the two devices at the same location, higher strains are obtained with the disjunctor with bar varying between 112% and 154%, except in left posterior region, around 51%, and in the anterior region was almost the same value. The greatest difference was achieved at the right posterior region, reaching almost 334%.

4. Conclusions

FBG sensors were able to measure the strain field pattern in an acrylic model of a maxillae and it was possible to compare the performance of two orthodontic devices. The orthodontic device disjunctor with the bar, in general, transmits higher forces and strain to teeth and maxillae, than with the disjunctor without bar. It was verified that the strain patterns were not symmetric between the left and the right sides as also between the posterior and anterior regions of the maxillae. For the two devices is also found that in addition a displacement in the horizontal plane, particularly in posterior teeth, also occurs a rotation corresponding to a vestibularization of the posterior teeth and their alveolar processes.

Acknowledgments

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