Research, Society and Development, v. 11, n. 11, e14111133206, 2022
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v11i11.33206

Assessment of forces exerted by Haas and Hyrax palatal expanders using fiber optic sensors

Avaliação das forças exercidas por expansores palatinos Haas e Hyrax usando sensores de fibra óptica

Evaluación de las fuerzas ejercidas por los expansores palatinos Haas y Hyrax utilizando sensores de fibra óptica

Received: 07/21/2022 | Reviewed: 08/03/2022 | Accept: 08/04/2022 | Published: 08/13/2022

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Abstract
Objective: To evaluate the initial forces generated by two types of palatal expansion appliances, through fiber optic sensors, in elastomeric models. *Materials and Methods*: An elastomeric model simulating the upper dental arch was fabricated. The sensors were placed adjacent to the first premolars and the first molars roots (apical, cervical, vestibular, palatal). Hyrax and Haas palatal expanders were fitted onto the dental arch. Activation of the screw was performed 4 times. The variations in wavelengths of each sensor during the activations were recorded. ANOVA and Games-Howell were used (P <.05). *Results*: In the first premolars, the force generated by Hyrax was higher than that generated by Haas in the cervical and apical regions of the palatal and vestibular surfaces, respectively; in the first molars, the force was higher in the cervical vestibular region than that in the cervical palatal region for both the appliances; in Hyrax, the force was higher in the apical vestibular than in the apical palatine in tooth 14 (P <.05). There was no difference between the devices for each activation; the total force generated by Hyrax was equal to that of Haas (P <.05). *Conclusions*: The fiber optic sensors were effective in measuring the initial forces generated by the studied palatal expanders. Hyrax and Haas palatal expanders produced similar forces. Greater force was recorded on the vestibular surfaces.
Keywords: Optical fibers; Orthodontics; Palatal expansion technique.

Resumo
Objetivo: Avaliar as forças iniciais geradas por dois tipos de aparelhos de expansão palatina, através de sensores de fibra óptica, em modelos elastoméricos. *Materiais e Métodos*: Foi confeccionado um modelo elastomérico simulando a arcada dentária superior. Os sensores foram colocados adjacentes aos primeiros pré-molares e às raízes dos primeiros molares (apical, cervical, vestibular, palatal). Os expansores palatinos Hyrax e Haas foram instalados na arcada dentária. A ativação do parafuso foi realizada 4 vezes. As variações nos comprimentos de onda de cada sensor durante as ativações foram registradas. ANOVA e Games-Howell foram usados (P <0,05). *Resultados*: Nos primeiros pré-molares, a força gerada pelo Hyrax foi maior do que a gerada pelo Haas nas regiões cervical e apical das superfícies palatina e vestibular, respectivamente; nos primeiros molares, a força foi maior na região cervical vestibular do que na região cervical palatina para ambos os aparelhos; em Hyrax, a força foi maior no vestibular apical do que no palatino apical no dente 14 (P <0,05). Não houve diferença entre os dispositivos para cada ativação; a força total gerada por Hyrax foi igual à de Haas (P <0,05). *Conclusões*: Os sensores de fibra óptica foram eficazes na medição das forças iniciais geradas pelos expansores palatinos estudados. Os expansores palatinos Hyrax e Haas produziram forças semelhantes. Maior força foi registrada nas superfícies vestibulares.
Palavras-chave: Fibra óptica; Ortodontia; Técnica de expansão palatina.

Resumen
Objetivo: Evaluar las fuerzas iniciales generadas por dos tipos de aparatología de expansión palatina, a través de sensores de fibra óptica, en modelos elastoméricos. *Materiales y Métodos*: Se fabricó un modelo elastomérico simulando la arcada dentaria superior. Los sensores se colocaron junto a los primeros premolares y las raíces de los primeros molares (apical, cervical, vestibular, palatino). Se colocaron expansores palatinos Hyrax y Haas en la arcada dentaria. La activación del tornillo se realizó 4 veces. Se registraron las variaciones en las longitudes de onda de cada sensor durante las activaciones. Se utilizaron ANOVA y Games-Howell (p < 0,05). *Resultados*: En los primeros premolares, la fuerza generada por Hyrax fue mayor que la generada por Haas en las regiones cervical y apical de las superficies palatina y vestibular, respectivamente; en los primeros molares, la fuerza fue mayor en la región cervical vestibular que en la región cervical palatina para ambos aparatos; en Hyrax, la fuerza fue mayor en el vestibular apical que en el palatino apical en el diente 14 (P <.05). No hubo diferencia entre los dispositivos para cada activación; la fuerza total generada por Hyrax fue igual a la de Haas (P <.05). *Conclusiones*: Los sensores de fibra óptica fueron efectivos para medir las fuerzas iniciales generadas por los expansores palatinos estudiados. Los expansores palatinos Hyrax y Haas produjeron fuerzas similares. Se registró una mayor fuerza en las superficies vestibulares.
Palabras clave: Fibras ópticas; Ortodoncia; Técnica de expansión palatina.

1. Introduction

Maxillary atresia is a dentofacial deformity in which the maxilla is discrepant in the transverse plane, as compared to the mandible, and the patient might have uni- or bi-lateral posterior crossbite. This causes narrowing of the upper arch, which is usually followed by dental crowding, oval palate, and sucking habits, and respiratory and phonetic problems. (Pedreira, et al., 2010).

The treatment for maxillary atresia involves a rapid maxillary expansion procedure using Haas (Haas, 2001) or Hyrax (Biederman, 1973) expanders or MARPE (Kapetanović, et al., 2021), for example. Such devices, when attached to the upper dental arch and activated, release high magnitude forces to overcome the resistance of the medial palatine and adjacent sutures. (Isaacson, et al., 1964; Haas, 1965) Other orthopedic and dental effects, such as development of a diastema between the maxillary central incisors, (Zimring, Isaacson, 1965) inclination of the posterior teeth and consequent reduction of the buccal bone tables, (Garib, et al., 2005) which occur during palatal disjunction, have been described in the literature.

The high magnitude forces generated by the palatal expansion devices are immediately transferred to the teeth, which then act as a unit along with the bone structures, offering resistance to the expansion movement. (Zimring, Isaacson, 1965) The total force generated during palatal disjunction has already been studied. (Isaacson, and Ingram, 1964; Chaconas and Caputo, 1982) However, forces generated in specific areas have not been studied yet.

Some methods have been proposed to evaluate the forces generated by these devices. A clinical study used a dynamometer welded to the expander screw to evaluate the total force generated by the modified palatal expanders during activations.4 Holographic lasers were used to evaluate the tension in a palatal expansion appliance in an acrylic model adapted to the human skull. (Pavlin, Vukicevic, 1984) In vitro evaluation was performed through a compression test, with the aid of a universal testing machine. This was done to verify the force generated by the two types of expander screws. (Chaconas & Caputo, 1982) A study performed using a photoelastic model reported the effects of five types of expanders on the craniofacial structures, evaluated by a transmission polariscope. (Chaconas & Caputo, 1982) Similarly, evaluation of the biomechanical effects of palatal disjunction on the teeth, (Işeri, et al., 1998; Lee, et al., 2009) bones, (Işeri, et al., 1998; Holberg, et al., 2007) and craniofacial sutures(Lee, et al., 2009; Holberg, et al., 2007) has also been performed using finite element analysis.

As an alternative for the measurement of stresses and pressures, fiber-based sensors have been used in dental models and human occlusion. (Milczeswki et al., 2006) These sensors offer advantages such as immunity to electromagnetic interference, extreme precision, light weight, small size, and supersensibility.(Kalinowski, 2008) They also have the ability to measure chemical, mechanical, and temperature parameters. (Lee, 2003) Moreover, they are safer than electrical sensors, since they do not require electrical connection to the patient. (Ciocchetti, et al., 2015) The fiber optic sensor is easy to embed in composites (Afromowitz, 1988; Lam, Afromowitz, 1995) and elastomeric models, (Glickman, et al., 1970) without changing any of its characteristics.

Fiber optic sensors have been used to measure forces applied to the surfaces of the teeth and the consequent displacement caused by orthodontic systems. Milczewski et al., (Milczeswki et al., 2006) used this technology to investigate the forces applied to the surface of an incisor in an artificial maxilla, with an orthodontic system. A similar approach was applied by Milczewski (Milczewski et al., 2011) in an in vitro study of the magnitude and location of forces at the roots of the teeth and maxillary bone during force application by orthodontic appliance. In the study by Tiwari et al., (Tiwari et al., 2011) fiber optic sensors were used to monitor the impact-absorbing capacity of mouth guards. Carvalho et al.,(Carvalho et al., 2006) evaluated, in vitro, the impact of a dental implant on the mandibular surface using fiber optic sensors.

Therefore, fiber optic sensors can be used to study orthodontic forces in regions that are difficult to access. These sensors have not yet been used to measure the forces generated by the activation of expansion screws. Therefore, this study had the objective of evaluating the initial forces generated by two types of palatal expansion appliances, through fiber optic sensors, in elastomeric models.

2. Methodology

Fabricating the elastomeric model

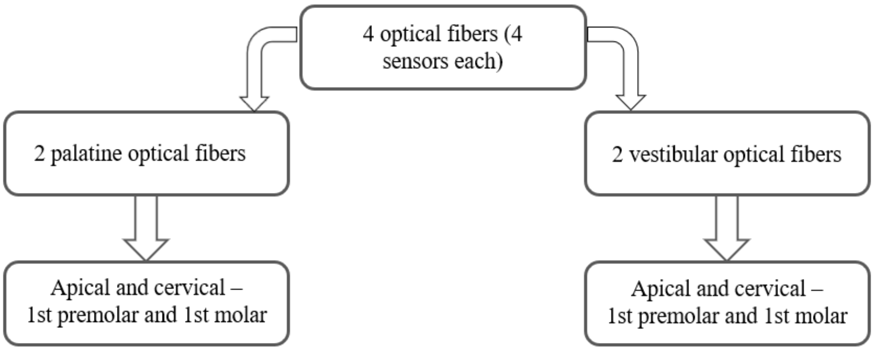
Inicially fiber optic sensors were written on Laboratório de Fotônica (UTFPR, Brasil), using excimer laser ArF (Xantos 500 XS, Coherent), energy 5 mJ/pulse, frequency 250 Hz and 2 minutes exhibiting time. The fiber optic sensors were made using the written technique by direct exhibition under fase mask, standard telecommunications Monomode fiber (G-652), Draktel SSMF with ~3 mm length.

A model was fabricated using artificial teeth (MOM - Marília, Brazil) and elastomeric material (Epoxy, flexible GIII, Polipox - Curitiba, Brazil) to allow the reproduction of properties such as resilience and resistance of the periodontium and to facilitate visibility by transparency. The model represented a maxilla with permanent dentition.

Thereafter, a 3-mm acetate plate (Bio-Art - São Carlos, Brazil) was fabricated on the upper dental arch of the manikin, with the aid of a vacuum plasticizer (Bio-Art - São Carlos, Brazil). The teeth of the manikin were adapted in their respective positions in this plate, following which, it was filled with wax 07 (Asfer - São Caetano do Sul, Brazil). In this wax model, bands were adapted on teeth 16 and 26 and transfer molding was performed for later confection of the Haas and Hyrax palatal expanders.

The wax model was glued with cyanoacrylate (Superbonder Gel - Loctite - Dusseldorf, Germany) in a polyvinyl polychloride (PVC) cylinder (Tigre - Joinville, Brazil) with 20-cm diameter. A silicone (CS - Curitiba, Brazil; in the ratio of 200 ml of base to 15 ml of catalyst) was slowly inserted for duplication. After fixing the material, the teeth were positioned in the mold. Two fibers optic were positioned on the palatal surface and two on the buccal surface of the dental roots in the apical and cervical regions, according to the following scheme (Figure 1).

Figure 1. Explanatory diagram on the position of fiber optic sensors.

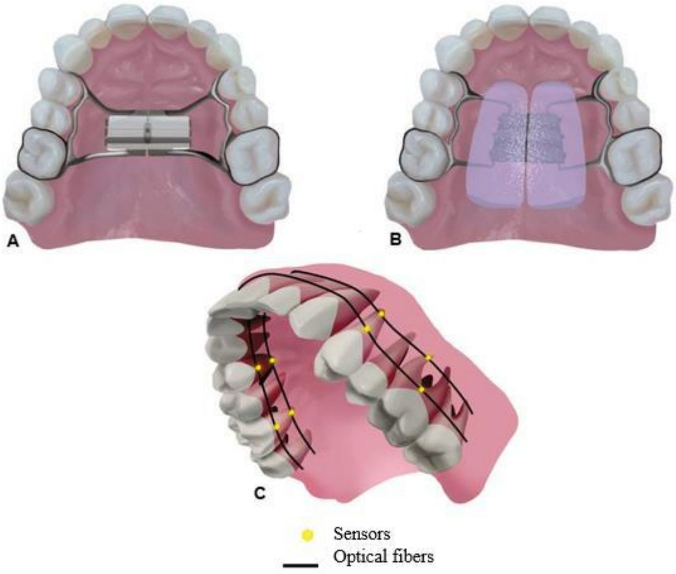


Source: Authors.

The sensors were named according to their location: tooth numbers followed by the position of the sensor, such as 26VA (sensor on the 1st molar, located on the vestibular surface of the root, in the apical region), 26PC (sensor on the 1st molar, located on the palatal surface of the root, in the cervical region).

The optical fiber was bonded to the teeth with light-cured resins (Top Comfort; FGM, Joinville, Brazil). The photoelastic resin (Epoxy, flexible GIII, Polipox - Curitiba, Brazil) was manipulated in a ratio of 2: 1 (76 ml of base and 38 ml of catalyst), and inserted into the silicone mold containing the teeth and the fibers. After the final resin fixation (72 hours), the elastomeric model was obtained. The same elastomeric model was used for the test with the two appliances (Figure 2).

Figure 2. Illustration of the Hyrax and Haas devices adapted to the elastomeric model.



Source: Authors.

Acquisition of data

The Hyrax and Haas expanders were adapted to the elastomeric model and activated 4 times (1/4 of a turn at each activation). During the activations, the optical fibers were coupled to the Optical Spectrum Analyzer (OSA, Yokogawa 6345 - Tokyo, Japan) and the Optical Interrogator (Micron Optics - Atlanta, GA), which recorded the wavelength offset from the 16 sensors before (T0) and during each activation (T1, T2, T3, and T4). The tests were performed in the same elastomeric model, at different times for each type of apparatus.

The data were analyzed using the Origin 8® program, which generates the variation in wavelength of each sensor in nanometers. To convert these values to grams-force, they were divided by a coefficient (1,54 pm/gF). This coefficient was found experimentally by sensor stretching analysis for different masses connected to it.

Statistical analysis

Statistical analysis was performed using SPSS 23.0 for Windows (SPSS, Inc., Chicago, IL) and Statistica 7 (Statsoft, Inc., Tulsa, OK). The significance level adopted for all statistical tests was .05.

The verification of variances in normality and homogeneity between sensor X appliance and appliance X activation was performed with the Kolmogorov-Smirnov normality test and Levene's test, respectively.

Normal distributions and homogenous variances were further subjected to three-way ANOVA followed by the Games-Howell multiple comparison test for heterogeneous variances.

3. Results and Discussion

During the experiment, two sensors broke (26PC and 24PC); thus, the remaining 14 sensors were analyzed. ANOVA showed no statistically significant difference between the appliances, sensors, and activations ($P > .05$).

In the interaction sensor x appliance evaluation, it was observed that force exerted by Hyrax was greater than that exerted by Haas in the 14PC and 14VA sensors ($P < .05$). In all other sensors, there was no difference between the appliances ($P > .05$) (Table 1).

Table 1. Means and standard deviations of the force (gf) in each sensor in Hyrax and Haas appliances

Appliance Sensor	(n)	Hyrax (average ± SD)	Haas (average ± SD)	Comparisons - Games - Howell Test Hyrax X Hass (p)	Power test
26 PA	5	32.26 ± 11.02	33.85 ± 12.55	1	
26 PC	5				
26 VA	5	2.67 ± 0.60	6.43 ± 5.45	0,1071	
26 VC	5	38.89 ± 6.71	39.74 ± 7.19	0,9850	
24 PA	5	15.70 ± 7.07	18.99 ± 8.11	0,9999	
24 PC	5				
24 VA	5	8.82 ± 3.04	9.47 ± 2.10	0,9999	
24 VC	5	38.21 ± 4.28	44.37 ± 4.24	0,8038	0,9999
16 PA	5	33.84 ± 5.77	32.81 ± 9.28	1	
16 PC	5	39.85 ± 12.41	9.37 ± 7.09	0,1030	
16 VA	5	16.10 ± 10.52	9.06 ± 4.79	0,9939	
16 VC	5	90.75 ± 7.66	74.07 ± 14.08	0,7768	
14 PA	5	11.88 ± 7.09	16.95 ± 5.59	0,9985	
14 PC	5	52.58 ± 5.14	26.32 ± 3.85	0.0018*	
14 VA	5	34.79 ± 2.21	7.93 ± 1.32	0.0000*	
14 VC	5	8.00 ± 6.75	23.65 ± 5.31	0,1699	

Significance level for Games-Howell test: $P < 0.05$*

Source: IBM SPSS Statistics 25.0 and authors.

The Hyrax expander exerted a greater force in 16VC than in 16PC; however, the Hass expander exerted a greater tension in 16VC than in 16PC (P<.05). Comparing apical sensors with one another, Hyrax was found to exert a greater force in 14VA than in 14PA (P<.05). In other comparisons, no statistically significant differences were observed (P>.05) (Table 2).

Table 2. Force (gf) average and standard deviation in sensors at apical (A) and cervical (C) regions for Hyrax and Hass appliances. Palatine (P) and vestibular (V) comparison

Appliance/Tooth	n	Sensor				Comparison - Games-Howell Test		
		PA (Avg. ± SD)	VA (Avg. ± SD)	PC (Avg. ± SD)	VC (Avg. ± SD)	PA X VA (p)	PC X VC (p)	Observation Power
Hyrax								
26	5	32.26 ± 11.02	2.67 ± 0.60	-	38.89 ± 6.71	0,0831	-	
24	5	15.70 ± 7.07	8.82 ± 3.04	-	38.21 ± 4.28	0,2586	-	1
16	5	33.84 ± 5.77	16.10 ± 10.52		90.75 ± 7.66	0,3865	0.0076*	
14	5	11.88 ± 7.09	34.79 ±2.21		8.00 ± 6.75	0,0357	0.0003*	
Hass								
26	5	33.85 ± 12.55	6.43 ± 5.45	-	39.74 ± 7.19	0,1555	-	
24	5	18.99 ± 8.11	9.47 ± 2.10	-	44.37 ± 4.24	0,5410	-	1
16	5	32.81 ± 9.28	9.06 ± 4.79		74.07 ± 14.08	0,0845	0.0048*	
14	5	16.95 ± 5.59	7.93 ± 1.32		23.32 ± 3.85	0,3686	0,9999	

* Statiscally significant difference: $P < 0.05$*

Source: IBM SPSS Statistics 25.0 and authors.

In the present study, optical fiber sensors were positioned in an elastomeric model, which simulated the maxilla and the upper dental arch. This model had resilience and resistance characteristics similar to those of the periodontal ligament and adjacent structures. (Glickman, et al., 1970)

After the adaptation of each device on to the elastomeric model, the first four activations were performed in the expander screw, as the literature recommends. (Haas, 1961) The palatal expanders adapted well and remained fixed in their initial position during the activations. Therefore, they were not cemented in order to minimize the possibility of breaking the fiber during removal, since it is composed of silica. (Haas, 1961; Hill, Meltz, 1997)

In the present work, the means of the total forces generated by the Hyrax and Haas expanders after a full turn of the expansion screws were 30.31 gf (gram-force) and 25.21 gf, respectively. Higher forces were found by Ingram et al, when studying the Hyrax expander. They observed that the initial force of activation of the expansion screw (a full turn) ranged from 1,600 gf to 3,100 gf. This force decreased after a few minutes, from 900 gf to 1,800 gf, respectively. (Isaacson, and Ingram, 1964) These authors used a dynamometer coupled to the expansion screw, to measure the total force generated by screw activation. In the present study, forces generated in specific areas were evaluated, which may explain such differences.

Zimring and Isaacson, (Zimring & Isaacson, 1965) also used a dynamometer and found that the maximum load accumulated after all activations of the expansion screw during palatal expansion ranged from 7,500 gf to 15,800 gf. These forces were completely generated in approximately 6 weeks. (Zimring & Isaacson, 1965) In the present study, it was not possible to evaluate the force generated during the entire palatal expansion procedure, because the fiber optic sensors are composed of silica, which is friable (Haas, 1961; Hill & Meltz, 1997) and could break after several activations. Moreover, the elastomeric material, which was used to simulate the periodontal ligament, has a high yield strength, (Glickman, et al., 1970) and does not return to its initial shape after plastic deformation. This would make the analysis inaccurate and would prevent the test to be performed with the other device.

The observation of greater strength of Hyrax in the 14PC and 14VA sensors is probably due to the fact that the Haas has booth tooth- and mucosal support. Studies have shown that the lack of acrylic in the palatal region not only permits expansion of the bone, but also results in a higher vestibular inclination component of the teeth. (Haas, 2001; Lam & Afromowitz, 1995; Weissheimer et al., 2011) Garib et al., (Garib et al., 2006) evaluated the dento-skeletal effects of rapid maxillary expansion by Hyrax and Haas devices using a CT scan and verified that the teeth that were not banded had a higher vestibular inclination of their crowns. (Garib et al., 2005; Garib et al., 2006; Odenrick et al., 1991) In order to minimize inclination and to obtain linear opening of the median palatine suture, the appliance must be stiffer (greater gauge of the wire should be used and the acrylic should occupy a larger area). (Chung & Font, 2004) Besides the composition of the appliance, the amount of dental inclination depends on factors such as the mode of activation and the age of the patient. (Kılıç, et al., 2008; Braun et al., 2000)

In both appliances, greater force was recorded by the cervical vestibular sensors compared to the cervical palatal sensors, for the tooth 16. The same was found for the apical region of the tooth 14 (Table 2). No studies evaluating the strength of the palatal expander specifically generated on the teeth and the periodontal ligament were found in the literature. However, studies evaluating the Hyrax and Haas palatal expanders using computed tomography have been reported. These observed that there is a decrease in the thickness of the bone on the vestibular surfaces of posterior teeth after palatal expansion. (Garib et al., 2005; Garib et al., 2006) This effect may be related to the high magnitude forces generated by the screws that compress the posterior teeth against the cortical alveolar bone of the vestibular surfaces, (Weissheimer et al., 2011) and may lead to bone dehiscence and consequent periodontal retraction in this region. (Garib et al., 2005)

Fiber optic sensors, because of their size and accuracy, have proven to be effective in assessing forces in regions that previously could not be evaluated. The initial forces generated by the two types of palatal expanders were similar; however, they do not represent the real situation due to the limitations imposed by the elastomeric model. It is therefore suggested that additional studies using fiber optics in vivo should be conducted, to allow evaluation of the real forces generated on the external surfaces of the teeth.

4. Conclusions

- The fiber optic sensors were effective in measuring the initial forces generated by the studied palatal expanders.
- Hyrax and Haas palatal expanders produced similar forces.

- Greater force was recorded on the vestibular surfaces, as compared to the palatal surfaces.

Acknowledgments

We thank CAPES (Higher Education Improvement Coordination - Brazil), for the scholarship provided to one of the contributing researchers in this work.

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