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Distribution of forces on supporting teeth in the midpalatal expander during "Hyrax" screw pre-load

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ABSTRACT

Purpose: The aim of the study was to determine forces which are transferred to supporting teeth during the treatment with the midpalatal device with Hyrax screw and to evaluate orthodontic and orthopaedic effects based on displacement analysis.

Design/methodology/approach: The finite element method (FEM) was used to simulation the midpalatal expansion forces activated by the screw pre-loaded during a turn of 180° which corresponds to daily recommended value. Distribution of expansion forces of Hyrax device was calculated as reaction forces on elastic supports with stiffness corresponding to the teeth working on periodontal ligament in alveolar bone.

Findings: On the basis of the displacement analysis was observed the movement of supporting teeth by a value higher than 0.1 mm which corresponds to the recommended daily value. The midpalatal suture splitting forces were determined on the first premolars with a value of 32.8 N and on the first premolars of 44.2 N.

Research limitations/implications: The studies did not take into account the shape of palate other craniofacial bones and their stiffness.

Practical implications: Adjusting the stiffness of the device to degree of ossification midpalatal suture and teeth mobility. Searching for new solutions which eliminate the negative phenomenon of tilting teeth during the expansion of maxilla and recommending a surgically assisted techniques.

Originality/value: The simulation confirmed that treatment with Hyrax screw gives a uniform expansion with values of forces corresponded to stiffness of premolar and molar teeth. The studies have indicated a possibility of tendency to tilting the supporting teeth what is a negative phenomenon.

Keywords: Rapid palatal expansion, Hyrax screw pre-load, Stress, Displacement, Finite elements analysis (FEA)

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BIOMEDICAL AND DENTAL ENGINEERING AND MATERIALS

1. Introduction

A narrow maxilla can be treated by splitting the midpalatal suture which is resulting in expansion of palatal vault and nasal cavity [1-3]. The vital importance has properly selected method of treatment that is related to patient's age, degree of ossification in the craniofacial connections and periodontal condition [4-6]. Rapid palatal expansion (RPE) is commonly used method of treatment for patients with full permanent dentition. Most often, the RPE is supported with Hyrax screw device cemented on first premolars and first molars in upper dental arch [1,2,7]. This type of appliance should transfer appropriate values of forces to teeth in lateral segments to obtain the orthopaedic effect of maxillary expansion. The task of orthodontist before starting treatment is perform additional tests to determine the degree of ossification of the midpalatal suture and mobility of teeth [5,6]. Failure to perform detailed diagnostics may result in incorrect course of treatment, exacerbation of malocclusion, pain complaints and even loss of teeth [1,8]. Some authors indicate the occurrence of teeth tilting in a greater extent than orthopaedic splitting of the midpalatal suture. The purpose of RPE treatment is to increase the lateral dimension of the hard palate which is why the tilting of the dental arch is negative phenomenon. Anatomical factors such as the large area of the sutures surrounding the maxillary complex limit the splitting of sutures and create greater resistance to expansion [2,9].

Supporters of the RPE consider that this method results in minimal mobility (tilting) of teeth and maximum skeletal movement around the midpalatal suture. Expansion forces are delivered by the device to exceed the limit which is required for orthodontic teeth movement and the connections are splitted while the teeth mobility is minimal in relation to the alveolar bone. The device squeezes the ligament of the periodontium, bends the alveolar process, tilts the supporting teeth and gradually opens the midpalatal suture [2].

The device to expand maxilla's narrowing with Hyrax is made of a classic unloaded orthodontic screw which is placed on the midpalatal suture line. Four wire-shaped arms with a diameter of 1.5 mm are connected with screw's slots and accorded to curvature of palate. None of components of the device should contact with mucosal tissue. Various modifications of mounting the expander on the patient's teeth are used. The most common methods are individual or fabricated metal bands and wire loops connected with acrylic resin. The arms of the screw are welded or soldered with metal elements which are placed on the supporting teeth. If metal bands are used on premolar and molar from the same side of dental arch, the wires are connected by a beam with diameter of 0.7-0.9 mm to obtain the stiffness of the construction [1,2,10].

The aim of this study was to determine the distribution of displacements due to activation by half a turn (180°) Hyrax screw in the device cemented on first premolars and first molars in the RPE treatment. On the basis of the finite element method, transferred forces to supporting teeth were determined. The results of analysis were compared with literature data.

2. Methodology

Geometric model (SolidWorks) of the expansion screw was including stabilizing guide-bars, slots (wings of screw) and active element- threaded spindle with central placed perforated cylinder. Four holes in the cylinder are used to activate the device during treatment. Geometric model was constituted the modification of the device with cemented metal bands. High quality finite element mesh was applied on curvature of the model. The smallest size of element was around 0.4 mm and the largest was approximately of 2 mm. Areas where the element is particularly exposed to occurrence of elevated stress levels were defined on the thread surfaces. Figure 1 presents the model of the device with finite element mesh. In the study has been used the following designations: RFP – right first premolar, LFP – left first premolar, RFM – right first molar, LFM – left first molar. Figure 2 shows the defined contact surfaces between threaded spindle, stabilizing guide-bars and slot on which slide was allowed. The rotation of the screw was applied on the perforated cylinder wall. The direction of half a turn activation is presented in Figure 3. Material in all components was used stainless steel 316L with austenitic structure.

Fig. 1. Model of the midpalatal expansion device with Hyrax screw – finite element mesh used in simulation

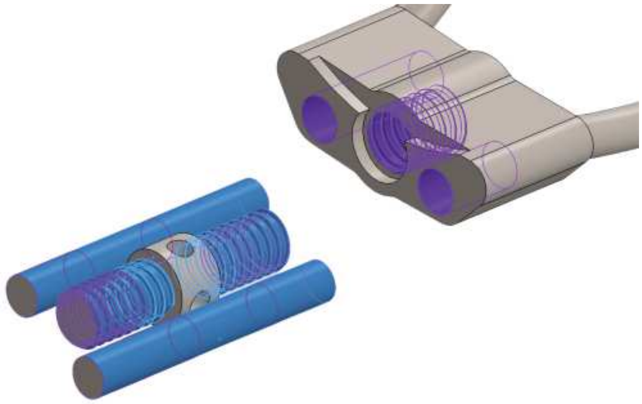

Fig. 2. Contact surfaces of threaded spindle and stabilizing guide-bars with their slot

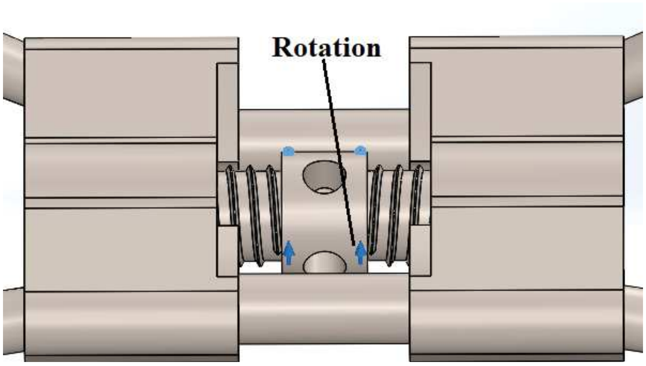

Fig. 3. Active Hyrax screw with the direction of rotation

In order to determine values of forces transferred to supporting teeth and displacements in the model, the elastic support of teeth in periodontium was simulated. The most optimal established value was $93 \cdot 10^8$ MPa/mm which has been checked with results of displacement analysis on the part of model. The values were consistent with physiological mobility of teeth with literature data [6,11].

The studies did not take into account non-linear behaviour and the resistances of other craniofacial sutures and their ossification.

3. Results

3.1. Stress distribution

Based on the equivalent Huber-Mises stress distribution during the screw pre-loading has been observed that materials were working in the safe range (Fig. 4.). Higher stress with values from 175 to 200 MPa was visible on the arms of the device which is related to the lack of support and bending effect. The obtained results are consistent with the tests presented in the literature as the wire arms are also more efforted [12]. Elevated values on the bands were the modelling artifact which resulted from the simplification of teeth. Band at realistic teeth is not bending because is rigidly supported and mobility there are at the alveolar socket. Albeit the finite element mesh was efficient and most interesting reaction forces was achieved at reasonable time of several hours.

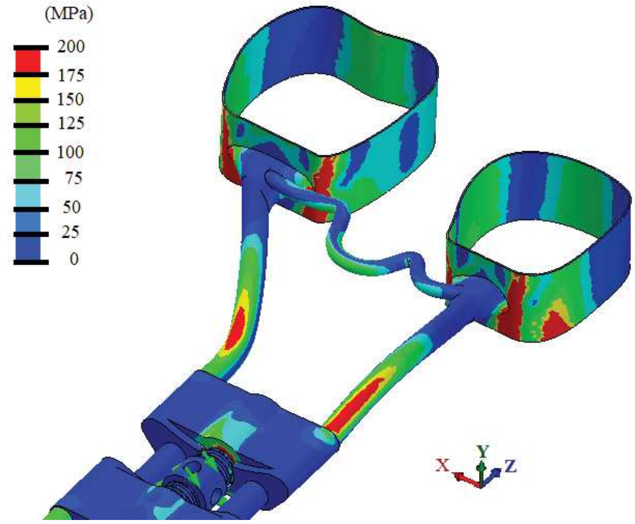

Fig. 4. Equivalent Huber-Mises stress in the half part of the model

3.2. Displacements analysis

The distribution of displacements along the x-axis is shown in Figure 5a, where in the area of slots and screw's arms are presented the values between 0 mm and 0.056 mm, which indicates a slight mobility of the device in this direction. Zones on the bands were significantly displaced anteriorly above of -0.2 mm.

Figure 5b presents the displacements along the y-axis. The values in the area of slots are within 0-0.056 mm in opposite directions. Displacements on the bands from palatal side and their connections with arms are ranged from -0.056 mm to -0.112 mm. The values from vestibular side are lower (from 0 mm to -0.056 mm). These results show that supporting teeth could tilt during screw expansion what should be verified by studies with more advanced model to confirm the literature data [9].

The distribution of displacements along z-axis is illustrated in Figure 5c where the values in the area of slots and arms of the device are according to expansion determined by half a turn activation of the screw (0.225 mm). Larger displacements are seen on cemented bands from palatal side compared to vestibular part. The values are estimated above 0.112 mm. Higher values along z-axis are consistent with the direction of expansion.

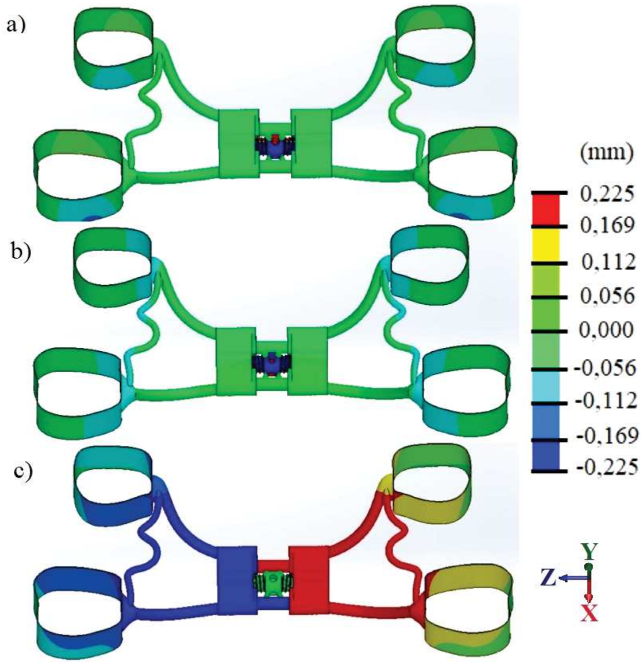

Fig. 5. Displacements of the device after screw pre-load along: a) x-axis, b) y-axis, c) z-axis which presented lateral expansion

3.3. Forces transferred to supports

The forces generated on supporting teeth during pre-loading of Hyrax screw by half a turn are listed in Table 1. The bands cemented on first premolars and molars on the right as well as the left side of the dental arch have shown similar values of resultant reaction forces what means an even expansion. The highest values of forces were along the expansion direction (z-axis) for premolars 31 N, while for molars 41.2 N. Forces oriented parallely to y-axis for the fourth teeth in the dental arch were 11.6 N and for the sixth teeth were 14.02 N. The lowest values of forces were directed towards x axis, which for premolars were 0.317 N while for molars 2.38 N.

Table 1.
Distribution of the values of expansion forces transferred to supporting teeth as reaction forces in the device with Hyrax screw

		Supporting teeth			
		right premolar	left premolar	right molar	left molar
Forces, N	X	-0.215	-0.102	1.23	1.15
	Y	5.72	5.89	7.07	6.95
	Z	15.5	-15.5	20.7	-20.5
	resultant	16.5	16.6	21.9	21.7

4. Discussion

Results of stress analysis below 3 MPa during screw pre-load in the work [12] present a safe stress level, however in simulation description lacks a way to load and support the model. Stress value around 200 MPa was in agreement with works [13-15] albeit to complete an analysis the function during occlusal loads transfer is required in the future not only under vertical direction [15]. Simulation studies [13-15] that take into account the entire skull structure are demanding in regard of computing power. However, in the presented simulations [13-15] there is lack of significant susceptibility in the model, because periodontal ligament was omitted. In this work, the goal was achieved, which was mapping the significant features of biomechanical behaviour and obtaining reaction forces and displacements at individual support points on the teeth depending on their mobility with maximum simplification of the model. At the same time, screw preload was realized in a real way by rotating it. It allowed for the distribution of stress in the screw and around its threaded slot, which was not analysed in previous works.

Displacements of slots, arms and stabilizing wires in expansion directions were obtained with a total value of 0.45 mm during the activation by half turn of the screw on the basis of the simulation using the finite element method. Supporting teeth were moved above 0.1 mm/day which not corresponds to the recommended value [16]. Additionally, on the basis of displacement analysis, the tendency of supporting teeth tilting was observed. This is a negative phenomenon in orthodontic treatment with the RPE method. Therefore the model presented in the studies should be verified with the assembly of the palatine bone and the teeth in periodontium placed inside the bands. This kind of model assembly could precisely define the stiffness of palatine bone with palatal suture for reaction forces during pre-loading of the screw. The simplification described in the article with small differences to proposed assembly could be applied in clinical practice in order to select the stiffness of the arms and the range of rotation of the screw for individual cases.

The studies have proven that teeth with physiological mobility gives a uniform expansion in the RPE treatment expressed by similar values of forces on premolars and molars. The resultant forces generated on the level of premolars was 33 N and for molar teeth 43.6 N. The literature sources indicate that the force of 49-98 N is required to splitting the palate structures [17,18]. Another data from articles describe that forces from 13 N to 44 N are obtained during one activation [19]. Two literature sources also indicate the maximum range needed to splitting the palate suture which was 74-156 N [20,21]. The presented values in article were obtained on the basis of measurements by a dynamometer that connected the bands on opposite sides of the dental arch [21].

5. Conclusions

In this work, the essential features of the biomechanical behaviour of the palatal expander, which are reaction forces and displacements at individual support points on the teeth depending on their mobility, have been mapped with the maximum simplification of the model.

The simulation has proved that treatment with Hyrax screw gives a uniform expansion which is expressed by similar values of forces on premolar and molar teeth.

Although stress value was at the safe level for expander material, the implementation of the screw preload in a real way by rotating it, showed that the highest stress is not only in the bending areas of the arms but also around the screw slot.

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