Journal of the Mechanical Behavior of Biomedical Materials xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of the Mechanical Behavior of Biomedical Materials

journal homepage: www.elsevier.com/locate/jmbbm

Extensiometric analysis of strain in craniofacial bones during implant-supported palatal expansion

Carlos Nelson Elias[a,*], Daniel Jogaib Fernandes[a], Denis Souza Zanivan[b], Yuri Resende Fonseca[a]

[a] Materials Science Department, Instituto Militar de Engenharia, Pr Gen Tiburcio 80, 22290-270, Rio de Janeiro, RJ, Brazil
[b] Private clinic, Brazil

ARTICLE INFO

Keywords:
Extensometer
Bone strain
Palatal expansion

ABSTRACT

Palatal expansion has several orthodontic and orthopedic applications, such as increasing maxillary transverse dimensions and correcting maxillary atresia, oral breathing, and skeletal cross-bites. Little is known about the strain to which craniofacial bones are submitted when a palatal expander is loaded. The objectives of the present work were to propose a new palatal bone-borne titanium device (expansion screw), to determine patterns of strain distribution in craniofacial bones during palatal expansion and to show the clinical results of a new palatal expander supported by implants. For *in vitro* testing, the palatal expander supported by two commercially pure titanium (cp Ti) implants was inserted parallel to the median palatine suture of four dry adult human skulls. Uniaxial and triaxial strain gauges were attached to craniofacial bones and connected to a signal acquisition system. An expansion screw was turned and strain data were collected during palatal expansion. The results showed that the bone strain distribution in craniofacial bones loaded by the palatal bone-borne titanium device was complex: the strain was tensile in the palatine cortical bone and compressive in pterygopalatine processes, nasal bones, and orbital floor. The maximum compressive strain occurs in the upper portion of the pterygopalatine processes and the strain changes from compressive to tensile in the zygomatic process. The experimental results suggest that the bone strain due to the palatal expander is distributed over all craniofacial bones and that the upper portions of pterygopalatine processes are the main sites of resistance to palatal expansion. The new palatal expander supported by two cp Ti implants proposed was employed on adult patient as an illustrative report, where adequate palatal expansion was achieved. The new protocol proposed was less invasive, risky, painful and costless for the correction of moderate maxillary transverse deficiency.

1. Introduction

The main current clinical treatment to increase the mandibular width involves the use of tooth-borne devices (Mommaerts, 1999; Zimring, Isaacson, 1965). However, dental fixation entails a number of drawbacks such as loss of anchorage, skeletal relapse during and after the expansion period, cortical fenestration and apical root resorption. The force applied by the expander compresses the periodontal ligament of the supporting teeth and alveolar bone resorption leads to tooth movement in the same direction. Tooth-borne expanders concentrate the force on the dentoalveolar area, being more iatrogenic and causing more root resorption than bone-borne expanders, which distribute the force over the palatal surfaces (Mommaerts, 1999).

Several studies analyzed the use of implants as anchors for the application of orthodontic forces (Bernhart et al., 2000; Henriksen et al., 2003; Kyung et al., 2004; Morais, et al. 2007; Baumgaertel et al., 2016). Other studies (Bernhart et al., 2001; Schlegel et al., 2002) have shown that the paramedian region of the palate is adequate for implant placement. Mommaerts (1999) introduced the first bone-borne device (distractor), which delivers the expansion force directly to the maxillary bone, thus avoiding harmful periodontal effects. Application of forces on implants inserted parallel to the median palatine suture in order to promote its opening may eliminate the need for osteotomies. This method speeds up the orthodontic treatment, reduces morbidity, and increases the probability of achieving a successful orthodontic/orthopedic therapy using mechanical forces.

In the present work, a new bone-borne palatal expander was developed and tested. This device has two Ti alloy grade 5 implants inserted parallel to the median palatine suture. The implant-supported palatal expander device (ISPE) was designed to promote transverse expansion of maxillary bone by opening the median palatine suture. The forces are generated by an expansive screw supported onto implants for bone anchorage (IBAs). These implants are inserted next to the right and left surfaces of the median palatine suture.

Although the ISPE is inserted in the palatal area, its effect is not limited to the maxillary alveolus and midpalatal suture but is expected

---

[*] Corresponding author.

http://dx.doi.org/10.1016/j.jmbbm.2017.05.028
Received 17 January 2017; Received in revised form 24 April 2017; Accepted 20 May 2017

Please cite this article as: Elias, C.N., Journal of the Mechanical Behavior of Biomedical Materials (2017), http://dx.doi.org/10.1016/j.jmbbm.2017.05.028

to affect several other adjacent structures in the face and the cranium. The maxilla articulates with other skull bones through the cranial and circummaxillary sutures and the force applied by the ISPE is transmitted to different bones and induces stresses and strains at different craniofacial bones. The strain distribution in craniofacial bones during activation of an ISPE device can be measured with the help of a strain gauge.

Strain gauges are devices designed to convert mechanical motions into electrical signals. The strain gauge-based extensometric method is a technique used to quantify strains and to validate the results obtained through computer simulations such as the finite element method (FEM). Some researchers analyzed the displacement and stress distribution by different bone-borne palatal expanders using finite element analysis (Bessho et al., 2007; Akça et al., 2002; Lee et al., 2014). Park et showed the highest stresses at the infraorbital margin, anterior and posterior nasal spines, maxillary tuberosity, and pterygoid plate (Park et al., 2017). Eser et al. (Eser et al., 2009) analysed bone strain using strain gage during dental implant loading. Cehreli et al. calculated the stress distribution in the maxilla during maxillary expansion followed by protraction using bone-borne and conventional tooth-borne palatal expanders and a facemask via 3-dimensional finite element analysis. (Cehreli 2002). They used strain gauge and compared the in vitro strains on dental implants supporting cement-retained fixed partial dentures under axial and off-axial loading conditions.

The experimental results are expressed in terms of a dimensionless quantity known as strain (ε) that represents the relative change in cortical bone dimension ($\Delta L/L$). Typical values for strain are less than 0.001 mm/mm and are often expressed in micro-strain ($\mu\varepsilon$) units. Tensile strains are expressed by positive numbers and compressive strains by negative numbers.

Measurement of strains using strain gauges requires the use of an adequate methodology to obtain reliable results. The electrical resistance of an ideal strain gauge is only sensitive to deformation of the surface to which the sensor is attached. In practice, however, the resistance depends on temperature, on the adhesive that bonds the gauge to the surface and on the properties of the material whose strain is being measured.

Strain gauges have been used to measure the stress in craniofacial bones due to insertion of dental implants into dried human skulls (Milgrom et al., 2004; Yacoub et al., 2002). In the present work, they were used to investigate the distribution of bone strain and stress in craniofacial bones during implant-supported palatal expansion.

2. Materials and methods

Four dried human adult skulls (45–64 years old) were used, all presenting no deformity or trauma. Bone rigidity (Peterson et al., 2006) was estimated as 15 GPa.

Two parallel holes were drilled to a depth of 8 mm, 3 mm away from the median palatine suture, in the paramedian region corresponding to the first premolars, using a 2.2 mm surgical drill. Ti alloy grade 5 implants for bone anchorage (IBA) measuring 2.5 mm in diameter were inserted in each hole. The prototype of the bone-borne palatal expansion device, made of stainless steel, was attached onto the IBA heads.

The proposed ISPE device has an anti-rotational system (Fig. 1) for attaching the IBA head to the support base, which eliminates rotation during expansion and prevents interference with the resulting translational movement. The pitch (distance between adjacent threads) of the expansive screw was measured using a scanning electron microscope (SEM) (JEOL, JSM 5800LV, Japan) at 20 kV. The average value of the pitch was 0.40 mm. Each 1/4 turn of the screw corresponded to a palatal expansion of approximately 0.10 mm, a small value in comparison with conventional expanders.

The expansive screw and supports were made of stainless steel according to ASTM F-138 specification with yield strength of 190 MPa and an ultimate tensile strength of 550 MPa (ASTM F 138). The implants for bone anchorage were made of titanium alloy (ASTM grade 5) according to ASTM F-136 specification. Titanium dental implant should receive a surface treatment to improve osseointegration, but this requirement is not relevant in the case of IBAs, since the implant is removed after palatal expansion.

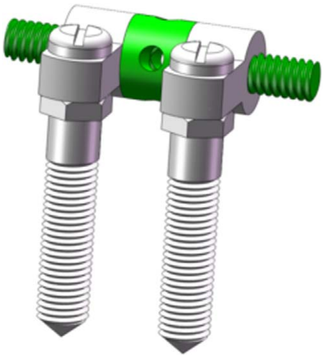

Fig. 1. Proposed bone-borne palatal expander.

In order to determine the bone strain induced by the ISPE device during palatal expansion, *in vitro* extensometric testing was performed using uniaxial and triaxial strain gauges. The strain gauges were attached to the maxillary bones of four dried human skulls. They were bonded in pairs at bone sites considered as resistant to palatal expansion. The screw was turned and the bone microstrain corresponding to each 1/4 turn was recorded. Two 600 Hz Spider 8 devices (HBM, Germany) were used for acquisition of strain gauge signals. The uniaxial strain gauges were type PA-06-125BA-120L (Kyowa, Electronic Instruments, Japan), with a resistivity of 120 Ω and a gauge factor of 2.09. The triaxial strain gauges were type KFC 5-D16-11 (5 mm) (Kyowa, Electronic Instruments, Japan), with a resistivity of 120 Ω and a gauge factor of 2.11, and were used in the 45° configuration. As shown in Fig. 2, the strain gauges were attached to five craniofacial bone sites in each side of the median palatine suture. The following sites were chosen to attach the strain gauge based on resistance to palatal expansion:

- Two uniaxial strain gauges were attached to the back part of maxillary palatine process, next to the transversal palatine suture and perpendicular to the median palatine suture;
- Two uniaxial strain gauges were attached to the upper part of the nasal bone, next to the nasofrontal suture;
- Two uniaxial strain gauges were attached to the zygomatic process, perpendicular to the median palatine suture;
- Two uniaxial strain gauges were attached to the orbital floor, perpendicular to the median palatine suture;
- Two triaxial strain gauges (Rosetta type) were attached to the inner surface of the large wing of pterygoid processes of the sphenoid.

Before bonding the strain gauge to the bone, the bone surface was ground with a drill coupled to an electric motor spinning at 400 rpm. After leveling, the bone was polished with sandpaper (200, 300, and 400 grit) and cleaned with ether.

Copper wires were welded to the ends of the strain gauges and connected to a signal acquisition device (Spider 8). The strain gauges were bonded by applying a small amount of cyanoacrylate-based adhesive (Loctite, Super Bonder) to the bone surface.

As an illustrative report of the approach described above, a male patient with 33 years old with a bilateral posterior crossbite was submitted to treatment. The main objective was orthopedic correction of the posterior crossbite, which was complemented by a followed orthodontic treatment with fixed appliance to achieve adequate dental and skeletal relationships. Improvements in symmetry and facial profile were also considered.