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Evaluation of cyclic and linear mechanical resistance of prebent and manually-bent plates used for maxillary advancement in orthognathic surgery

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Abstract

The aim of the present study was to compare prebent and manually-bent plates used in maxillary advancement. The prebent plates were fixed in polyurethane blocks for the linear test and aluminium blocks for the cyclic test, and the manually-bent plates were fixed in polyurethane and aluminium blocks. The linear load tests were done using an Instron® 4411 mechanical testing machine and the cyclic test with an Instron® E3000 testing machine. The linear mechanical test showed that there was no significant difference between the plates. In the cyclic test the prebent plates reached the limit of 500 000 cycles without fracturing whereas the manually-bent plate group fractured before reaching the limit of cycles ($p = 0.008$). The decision to use prebent or manually-bent plates during operations should be influenced by the production of the bends and their consequent brittleness.

Keywords: Bone plates; Mechanical stress; Fatigue; Maxillary osteotomy

Introduction

Prebent plates come in different sizes and can be selected based on the planned extent of maxillary advancement. These plates are used to eliminate the need to bend and contour titanium plates during orthognathic surgery, particularly in the area around the pyriform rims.[1] Biomechanical studies have shown their elastic properties are greater than those of other types of fixation for maxillary osteotomy.[2]

The decreased need for bending reduces the degradation of material and presumably helps to maintain resistance during the cyclic load.[3] Studies associated with facial trauma and mandibular resection have reported that the creation of excessive bends in reconstructive plates when they are being adjusting for bony morphology can lead to tension and microfissures in the material, which cause fragile points and fractures associated with fatigue.[4,5] In conventional orthognathic surgery, Lye et al[1] reported that this could be a potential problem in cases of major maxillary advancement.

It is assumed therefore that during the adaptation and manual bending of plates for bone tissue, the material becomes more fragile and less resistant as a result of bending, and ceases to function. We know of no published studies that have proved this in orthognathic surgery, and it is purely a clinical observation. To assess the possible decrease in resistance of manually-bent fixation plates used for maxillary advancement, we aimed to compare the linear and cyclic mechanical resistance of prebent and manually-bent plates for maxillary advancement.

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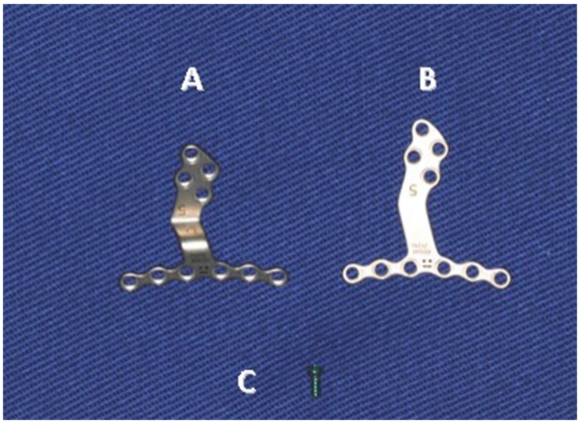

Fig. 1. Fixation material—Tóride® brand: (A) Prebent plate for 5 mm maxillary advancement. (B) Straight plate for 5 mm maxillary advancement. (C) Screw 5 × 1.5 mm.

Material and methods

A total of 13 prebent titanium maxillary plates/5 mm right advancement (10 holes and a 1.5 mm system) and 13 straight titanium maxillary plates/5 mm right advancement (10 holes and a 1.5 mm system) were used (Tóride Indústria e Comércio Ltda., Mogi Mirim, São Paulo, Brazil). The straight (unbent) plates were specifically requested for the present study, as the manufacturer does not usually make this type of plate. In addition, we used 260 × 5 mm screws (1.5 mm system).

According to the specifications of the manufacturer, the plates were made of grade II commercially pure titanium (ASTM-F67) and the screws were titanium-aluminium-vanadium alloy (Ti-6Al-4V) (Fig. 1).

Polyurethane and aluminium blocks

Sixteen blocks of rigid resin prototyping 75 Shore D (variation of polyurethane), which are manufactured by the company Nacional® (Nacional Ossos Ltda., Jaú, São Paulo, Brazil), and eight aluminium blocks designed by the company Tóride® were used. The blocks were designed in different sizes so that the larger block could be adapted for the support used in the test, and the thinner block could simulate the planned maxillary advance. According to the manufacturer (Tóride®) the blocks were composed of aluminium 5052-F (ASTM B-209-M-AA) and were perforated with the thread pitch of the system to enable the insertion of the screws (1.5 × 5 mm).

To standardise the sites of the perforations in which to insert the screws in the polyurethane blocks, a chemically-activated colourless acrylic resin guide was designed for each block (Dental Vipi Ltda, Pirassununga, São Paulo, SP, Brazil). Each guide was inserted into its respective block and the perforations made. After fixation, the guides were removed and the correct fixation of the segments confirmed. In addition, a channel 5 mm deep was made in the central area of the smaller block to permit the positioning of the device used to apply the vertical load.

Samples

The first group comprised eight prebent maxillary plates/5 mm advancement, 10 titanium screws 1.5 × 5 mm, and eight polyurethane blocks in the linear mechanical test. For the cyclic test, we used five similar plates and four aluminium blocks.

The second group comprised eight manually bent plates/5 mm advancement, 10 titanium screws 1.5 × 5 mm, and eight polyurethane blocks in the linear mechanical test. For the cyclic test, five similar plates and four aluminium blocks were used.

To bend the straight plates in a similar fashion, one prebent plate was used as a template. Marks were made with a pencil in the areas where the plates would be bent and excessive bends or manipulations (or both) were avoided. One operator bent all the plates.

Linear and cyclic mechanical tests

For the linear mechanical test, the Instron® model 4411 (Instron Corp, Norwood, MA) of the Department of Dental Material in the Piracicaba Dental School of the State University of Campinas (FOP-UNICAMP) was used for the mechanical trial. A speed of 1 mm/minute placed a progressive load on the system and obtained a peak load (N) and a peak displacement (mm) in each group.

The Instron® model E3000 (Instron Corp, Norwood, MA) of the Nacional Service of Industrial Training (SENAI) in Rio Claro, San Paulo, was used for the universal trial in the cyclic test. A metallic load application device and a support device for the blocks were designed to adapt the samples to the machine. The samples were submitted to a cyclic load of 12–120 N, with a load cell of 5 kN and a frequency of 3 Hz, until a plate or screw fractured. The maximal number of cycles was 500 000 (Fig. 2).

The values of the linear test were analysed using SPSS for Windows software (version 18, SPSS, Chicago, IL, USA). The Shapiro-Wilk test and Levene's test were used to confirm the distribution of normality and the homogeneity of variance, and the significance of differences between groups were assessed with the aid of Student's t test and the Mann-Whitney U test. Probabilities of less than 0.05 were accepted as significant. For the clinical test, the Mann-Whitney test was used to assess the significance of differences between the groups.

Results

The peak load values during the linear load tests were measured in N and the peak displacement values in mm. The

Fig. 2. Cyclic mechanical test until the material failed.

Fig. 3. Prebent plate fractured after cyclic test.

Table 1
Mean (SD) values for peak load (N) and peak displacement (mm) in the two groups.

	Mean (SD)	Range
Peak load (N):		
Prebent	262.68 (30.96)	214.67-299.20
Manually-bent	227.52 (46.22)	180-83-323.42
Peak displacement (mm):		
Prebent	4.19 (0.59)	3.32-5.31
Manually-bent	4.21 (1.47)	2.60-6.24

The prebent group comprised 8 prebent maxillary plates/5 mm advancement, 10 titanium screws 1.5 × 5 mm, and 8 polyurethane blocks. The manually-bent group comprised 8 manually-bent plates/5 mm advancement, 10 titanium screws 1.5 × 5 mm and 8 polyurethane blocks.

Table 2
Number of cycles of each sample during the cyclic test.

Samples	Manually-bent plate
1	94.737
2	144.903
3	52.526
4	74.208
5	341.076

The prebent plates (5 plates and 4 aluminium blocks) achieved the limit of 500 000 cycles in all cases. The manually-bent group comprised 5 plates and 4 aluminium blocks.

distribution of the data was normal, and the variance heterogeneous ($p = 0.008$) in relation to peak load.

Table 1 shows the mean (SD) for the peak load and peak displacement. There were no significant differences between the groups, as confirmed for peak load ($p = 0.09$) and peak displacement ($U = 25.5$; $p = 0.63$).

Table 2 shows the number of cycles in the two groups, and these differed significantly ($U = 0.00$; $p = 0.008$). All the prebent plates reached the limit of 500 000 cycles without fracture. All the manually-bent plates fractured before reaching the limit of cycles and were fractured in the areas in which the bends had been produced (Fig. 3), with the exception of one plate, which had a fracture of the first link on the upper part of the plate.

Discussion

We know of few studies that have sought to assess the association between bending and shaping of plates and early failure of the material. Loukota and Shelton[6] reported that bending plates that are used in the maxillofacial region more than five times, simulating clinical practice, reduces their rigidity to flexion. During an assessment of defects in fixation materials used for mandibular reconstruction, Martola et al[5] reported that the act of bending to adapt plates could be a cause of fracture of plates as a result of the residual tension generated, which can affect the mean tension during the cyclic load.

Using a scanning electron microscope, Katakura et al[4] observed fractures in four fractured mandibular reconstruction plates caused by fatigue, but the areas of plastic deformation were not the point of origin of the fractures. Although reports have confirmed that the fracture is caused by degradation of the metal while folding or adjusting plates, the results of Katakura et al did not indicate degradation caused by bending in any of the four cases. They concluded that excessive bending was not exclusively responsible for the fracture of the reconstruction plates used. We did not make any microstructural assessments of the plates tested to look for possible alterations in the material or other variables that could have clarified more precisely the association between the fracture and the manually-bent plates. These results do not completely explain what happened to the plates used in orthognathic surgery, because they are thinner and smaller than reconstruction plates, and easier to manipulate during the operation.

Evaluation of mechanical properties, as well as the performance of the metals, is made using a number of mechanical trials.[7] With dynamic forces, metal can break with a lower (or even much lower) load than the mean maximal load that is reached in static trials.[7,8] Our load values for the cyclic test were between 10% and 60% of the mean value of resistance during the static test: 12–120 N. Doty et al[9] studied linear and cyclic loading in polyurethane mandibles with segmental defects fixed with reconstruction plates, and the values used to assess the cyclic load ranged from 8% to 80%, with a frequency of 2 Hz. According to them, these rates were fast enough to mimic typical bite speeds, but they were not fast enough to adversely affect the clinical relevance of the system as a result of undesired heating by frictional forces.

Blocks of polyurethane and aluminium were used for the tests of linear and cyclic loading, respectively. We decided not to design a structure that was the shape of a maxilla because, despite its similarity to human anatomy, the three-dimensional structure would probably cause more extensive contact between the cut segments, which would affect the tests and hinder the failure of the material. Two blocks were used to simulate the clinical advance of 5 mm between the segments and to avoid contact between the blocks, which provided a real test for the plate. In the cyclic test, aluminium blocks were selected because, according to Medeiros et al[10] the resistance of plates and screws should be assessed without interference from the substrate, which avoids a failure of the system caused by a loss of contact in the substrate/screw interface during the cyclic test. Despite the fact that the substrate and the screw were not found during the linear test in blocks of polyurethane, there are several published reports of failures at this interface when polyurethane was used in both linear and cyclic studies.[11,12]

The results of the study showed that the two groups had similar mechanical properties in the uniaxial test, although there was a significant difference in the cyclic test—all the prebent plates reached the limit of 500 000 cycles without a fracture, whereas the manually-bent plates fractured after reaching the limit of cycles ($p = 0.008$). This probably occurred because the material was more fragile as a result of being bent, which decreased its resistance.

There are other aspects of the use of prebent plates in orthognathic surgery. During the procedure, manual bending of fixation plates can considerably increase operating time (depending on the experience of the surgeon) and may weaken the material during its adaptation to bony tissue. The use of prebent plates is therefore advantageous, as only two plates are required, they are preformed, and require few modifications. However, these plates are more expensive than conventional plates, and consequently their use in clinical practice is limited.

Questions remain about the quantity of fixation that is really required to stabilise the maxilla. Several clinical studies have described the use of different methods with low indices of postoperative relapse in the medium and long term,[13–15] even when only two conventional plates are used in the pyriform rim.[16,17] In terms of prebent plates, their use with two conventional plates in the zygomatic pillars of the maxilla may be unnecessary. In addition, as other less expensive methods can be equally effective from a clinical point of view, their use could be reserved for operations such as maxillary advancement of greater magnitude[18] or for patients with a cleft lip or palate, or both.[19] In cases with a higher index of relapse the rigidity of the system could be more important.

Further studies are required to assess the microstructure of the fractured plates and provide data about their fragility. In addition, mechanical studies with different methods of fixation, including the use of prebent plates, conventional plates, and absorbable material at different ranges of maxillary advancement, are required to prove their superiority as a method of fixation.

We conclude that the in vitro mechanical resistance between the groups of prebent and manually-bent plates did not alter in the linear load test. However, the design of the bends could have caused microfractures and fragile points that led to premature fracture of the manually-bent plates in the cyclic test. The decision to use prebent or manually-bent plates during operations should be influenced by the production of the bends and their consequent brittleness, but it may not be clinically critical, as bone does repair during the period before the material fractures.

Conflict of interest

We have no conflicts of interest.

Ethics statement/confirmation of patient's permission

Not applicable.

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