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EVALUATION OF STABILITY OF ORTHODONTIC MINI-IMPLANTS IN CONNECTION WITH BONE PARAMETERS

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Abstract: *In today's society, patients who turn to the orthodontist want final results in the shortest possible time, with maximum emphasis on smile aesthetics, dental alignment and facial harmony. In this regard, some procedures have emerged to accelerate the movement of teeth through the alveolar bone, thus shortening the duration of active treatment: corticotomy, application of mini-implants etc. Of these methods, bone anchorage on mini- implants is increasingly popular among adult patients, as it is a versatile technique that ensures a stable, bony anchorage and more predictable final results. Mini-implants have recently been widely used as anchoring aids in orthodontics. Their clinical effectiveness lies in their ability to maintain contact with the bone, thus resisting reactive orthodontic forces. Mini-implants are made of stainless steel, commercially pure titanium, or titanium alloy with a diameter of 1 to 2 mm and a length of 8 to 20 mm. They usually do not induce osseointegration due to their small size, short-term presence in the oral cavity and the fact that they do not protrude beyond the cortex. Compared to implantology in prosthodontics, which has a long history, mini- orthodontic implants emerged later in medical practice. In 1998, Shapiro and Kokich described for the first time the possibility of using dental implants for anchorage in orthodontic therapy. In 1997, Kanomi showed that a 1.2 mm diameter titanium mini- implant provides anchorage for the intrusion of the lower front teeth. After 4 months, the mandibular incisors were intruded by 6 mm without root resorption. In 1998, Birte Melsen et al. introduced the use of zygomatic ligatures as anchorage in patients with partial edentulousness. To this they attached nickel-titanium springs for intrusion and retraction of maxillary incisors. Over the past two decades, much research has been done to achieve skeletal anchorage using a variety of titanium mini-implants (micro-screws), palatal implants and plates or mini- plates with screws, which did not require osseointegration. Literature shows showed that microimplants with thread diameter less than 1.5 mm do not resist torsion. They maintain their stability after insertion by mechanical anchorage in the bone. The anchorage capacity depends on the surface of the microimplant, its length and diameter. The diameter determines the optimal retention in the bone. The mini- implants used in our study fall within the sizes recommended by most studies.*

INTRODUCTION

The term temporary anchorage device (TAD) has become extremely used nowadays and it expresses the nature of mini-implants as a non-osseointegrated device of titanium or stainless steel alloy, destined for anchorage purposes during the active tooth movement. Thus, researchers' common concern gravitates around their effectiveness, meaning that the success of mini-implants depends on their stability inside the bone, correlated with the quality of the bone support.

Technically, an anchorage device may be integrated anywhere there is bone tissue, but more frequently there have been used three selection areas: the external cortex of the maxillary bone and the mandibular bone, the inner cortex (lingual) of the mandibular bone and the hard palate.(1)

A series of authors, such as Baumargtael (2), recommends inserting these devices in favourable areas anatomically, for obtaining high success rates. The mini-implants used for orthodontic anchorage are less invasive ("flapless" surgery) (3), have less anatomical limitations, are easy to position and remove, they allow immediate loading, can be also used in children, being limited only by the patient's clinical status and background, and they are generally better tolerated by patients as opposed to a classic anchorage auxiliary (Goshgarian bar, Quad helix, Lip-bumper).

As Kim and Park (4) argue, the mandibular cortex is thicker than the maxillary one, thus being more advantageous with respect to the primary stability of mini-implants. At the same time, the lingual mandibular bone is not favourable to orthodontic implants due to the presence of the tongue which might be constantly injured.

For most patients, the maxillary vestibular alveolar bone, the posterior palatal area and the mandibular vestibular area may offer multiple options for inserting mini-implants for orthodontic anchorage.(5)

The anchorage capacity is influenced by the surface of the micro-implant, its length and diameter, the thread pitch, but also by the quality of the bone tissue: cortical and medullary thickness and density.(6)

AIM

The purpose of this study was to evaluate the optimal qualities of bone tissue on animal bone samples, namely the thickness and density that assure a good primary stability of a mini-implant for a period of 4-5 months from insertion.

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MATERIALS AND METHODS

The evaluation of primary stability of mini-implants for orthodontic anchorage was realized through the measurement of tractive force with a traction device, adjusted for axial traction and at 45°, while the variables were the characteristics of the bone, in the place of mini-implants insertion (cortical thickness and density, medullary thickness and density).

For in vitro studies, we used samples (pork ribs) harvested by a vet from pigs slaughtered for human consumption. The ribs were harvested, the soft tissue was removed, they were washed with water under pressure, disinfected with 96° ethanol and severed with an electric saw in order to be analysed with a CT scan. The rib fragments were kept during transportation from the slaughterhouse to the radiology lab in an isothermal vessel, with ice bags.

32 samples were analysed and the results (cortical and medullary bone thickness, evaluation of different density of the bone) were synthesised in charts for each sample analysed. The SOREDEX CT scan (Tuusula, Finland) was performed with the CRANEX 3D special soft (figure no.1).

Figure no. 1. CRANEX 3D CT – SOREDEX Special soft CT

Four A1.1, A1.2 orthodontic implants (titanium alloy) and A2.1, A2.2 implants (Cr-Co_Mo alloy) were inserted in the samples collected for the study, dependent on the dimensions and shape of the implant thread: radius and angle type (table no. 1, figure no. 2).

Table no. 1. Dimensions and shape of the implant thread

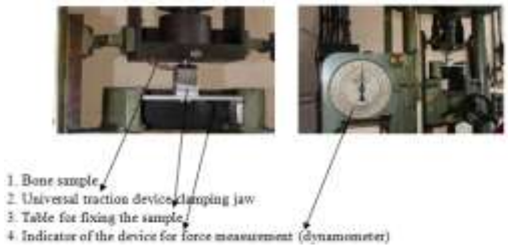
Mini-implant	Dimensional characteristics	Shape of the thread
A1.1 Titanium	Diameter = 1,8 mm, Length= 8 mm	radius
A1.2 Titanium	Diameter = 1,6 mm, Length= 8 mm	angle
A2.1 Cr-Co_Mo	Diameter = 1,6 mm, Length = 7 mm	radius
A2.2 Cr-Co_Mo	Diameter = 1,8 mm, Length = 7 mm	angle

Figure no. 2. Implants inserted in the bone samples

The universal device for mechanical tests is a device for static and dynamic tests on which the weight increases slowly and consistently from zero until the final value. The device is electrically driven and the force is measured with a mechanical pendulum device with three scales of measurement: 0-1000 daN, 0-2500daN, 0-5000 daN.

The bone sample is fixed on the clamp table and the head of the implant is attached to the screw clamping device which is connected through two orifices to the universal traction device clamping jaw. When the traction device electric circuit closes, the lower clamping jaw which holds the clamp table starts to descend in a low, constant speed.

Figure no. 3. Universal traction device



Due to how the implant is clamped into the bone, the force with which the clamp table of the implant descends meets resistance, whose value in N (Newtons) is registered on the dial of the traction device. We analysed:

I. **The variation of cortical bone thickness**: samples no. 1, 2, 3, 4,5,6,7 and 8
II. **The variation of medullary bone thickness:** samples no. 9,10,11,12,13,14,15 and 16
III. **The variation of cortical bone density:** samples no. 17,18,19,20,21,22,23 and 24
IV. **The variation of medullary bone density:** samples no. 25,26,27,28,29 ,30,31 and 32

The samples accepted for study were inserted with four A1.1, A1.2, A2.1, A2.2 orthodontic implants, dependent on the dimensions and shape of the implant thread. Axial tractive forces and at 45° were applied on every orthodontic implant. After measuring the tractive force when removing the mini-implant, the values were registered in charts and the correlations for each bone sample were represented graphically.

RESULTS

In figure no. 4 one can see the measurements for sample no. 1 with respect to the characteristics of the bone support: cortical thickness and density and medullary thickness and density. For each of the evaluated samples with inserted implants, the values were charted.

Figure no. 4. Analysis of bone characteristics for sample no. 1. a. Variation of cortical bone density-on a measured distance of 0.76 mm, the cortical density was 2731 HU

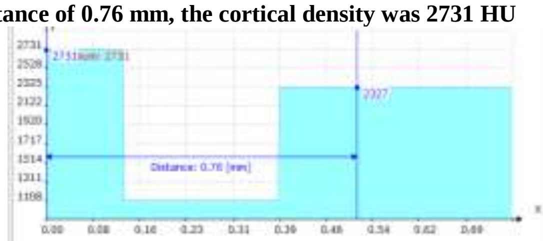


Figure no. 4. b. CT scan of the bone sample. The medullary thickness and density for the internal and external cortex were measured.

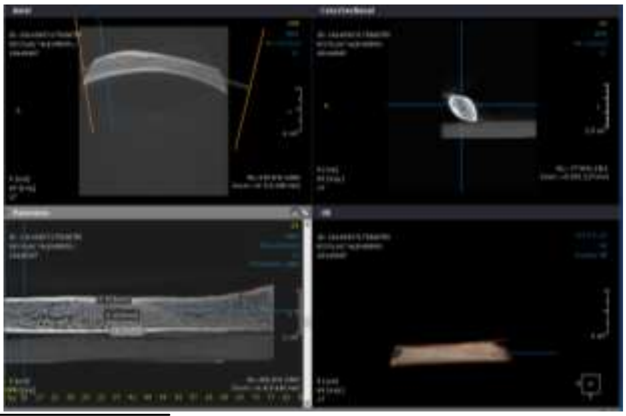
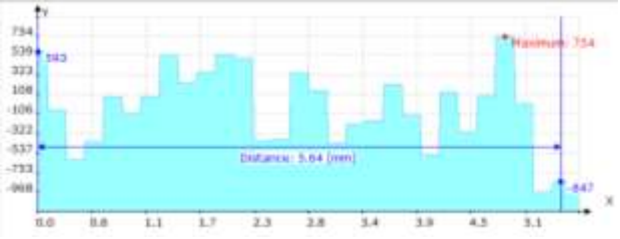


Figure no. 4. c. Variation of medullary bone density-on a measured distance of 5.64 mm, the medullary density was 754 HU



In table no. 2 one can observe the variations of the tractive force dependent on cortical thickness

Table no. 2. Variations of the tractive force in connection with cortical thickness

Sample	Cortical thickness (mm)	A1.1 (radius) Tractive force	A1.2 (angle) Tractive force	A2.1 (radius) Tractive force	A2.2 (angle) Tractive force
1	0.70	5,5	6	6,5	7
2	0.94	9	8	7	8
3	2.08	36,5	38	25	9,5
4	0.91	8,5	8	9	20
5	1.16	22	25	30	30
6	1.21	25	27	25	29
7	1.35	30	35	33	30
8	1.44	30	35	33	30

One can notice that dependent on the cortical bone thickness, the results of the tractive forces differ a great deal. Thus, in case of cortical thickness less than 1 mm, the tractive forces do not exceed 10N. Instead, in case of cortical thickness of over 1 mm, the tractive forces reach up to 35N. Cortical thickness is a parameter that influences directly the stability of the mini-implant.

The thicker the cortical bone, the higher the forces that tend to detach the implant.

Table no. 3. Variation of the tractive force in connection with the cortical bone density

Sample	Cortical density (HU)	A1.1 (radius) Tractive force	A1.2 (angle) Tractive force	A2.1 (radius) Tractive force	A2.2 (angle) Tractive force
9	703	22	25	30	30
10	3158	30	40	35	45
11	1432	30	35	33	30
12	1320	25	25	28	33
13	1777	30	30	33	33
14	991	22.5	22.0	20	20
15	1234	40	40	29	28
16	1241	29	28	29	29

Cortical bone density has major importance on the primary stability of orthodontic implants. Thus, in case of densities lower than 1000HU, the tractive forces have values below 30N, regardless of the type of implant used.

Table no. 4 presents the values of medullary thickness on bone samples and the variation of the tractive force on each type of implant.

Table no. 4. Variation of the tractive force in connection with the medullary bone thickness

Sample	Medullary thickness (mm) Tractive force	A1.1 (radius) Tractive force	A1.2 (angle) Tractive force	A2.1 (radius) Tractive force	A2.2 (angle) Tractive force
17	12.89	10	10	7.5	7.5
18	15.71	12	8	20	5.5
19	7.46	20	7.5	30	7.5
20	21.22	6	6	15	20
21	16.50	12	8	5	5
22	13.65	10	10	15	7.5
23	14.30	11	12	18	8.5
24	14.35	11	13	18	8.6

In case of medullary bone thickness variations, the values registered did not have any major influence on the stability of the orthodontic implant. Thus, one can see that higher medullary thickness is not proportional to the increase of the tractive force value.

Table no. 5. Variation of the tractive force in connection with the medullary bone density

Sample	Maximum medullary density (HU)	A1.1 (radius) Tractive force	A1.2 (angle) Tractive force	A2.1 (radius) Tractive force	A2.2 (angle) Tractive force
25	1034	5	5	6	6
26	754	5.5	5	6.5	7
27	815	22.0	23.0	18	19
28	829	5	5	7.5	7.5
29	962	30	35	33	30
30	983	35	30	32	31
31	997	30	30	33	33
32	1021	28	29	31	32

Similar to the tractive force values on medullary bone thickness, with regard to the medullary density variations, the tractive force values were not considerably increased once the density increased.

The growth trend of the tractive force on the orthodontic implant along with cortical thickness growth is maintained, regardless of the medullary bone density. One can notice increased values of the tractive force where cortical thickness is increased, but the same value of the tractive force may be found in case of a low medullary density.

Also, in case of a bone with high medullary density and thickness, we can see that the values of the tractive force grow significantly.

The researches have demonstrated also that high tractive forces may be determined only in case of the bone with thick and dense cortical, even if the medullary thickness and density are relatively low.

A. The influence of cortical bone thickness on the magnitude of the tractive force [N] determined in axial plane and at 45° demonstrates that:

a) regardless of the thread shape (radius or angle) for the type of mini-implant with the **thread pitch p = 0.5**, the relation established between the cortical thickness and the value of the tractive force of the mini-implant is the following:

- for the cortical thickness with values between: 0.68 – 0.97mm, the tractive force has values in the range of: 5.0 – 22.5N
- for the cortical thickness with values between: 1.22 – 2.00mm, the tractive force has values in the range of: 22 – 35N
- for the cortical thickness with values between: 2.08 – 2.30mm, the tractive force has values in the range of: 38 – 42N

b) regardless of the thread shape (radius or angle) for the type of mini-implant with the **thread pitch p = 0,8**, the relation established between the cortical thickness and the value of the tractive force of the mini-implant is the following

- for the cortical thickness with values between: 0.68 – 0.97 mm, the tractive force has values in the range of: 6 – 20.0N

- for the cortical thickness with values between: 1.22 – 2.30mm, the tractive force has values in the range of: 30 – 35N

One can notice that the values of the tractive force are directly proportional to the growth of the cortical bone thickness, no matter the thread shape or the thread pitch of the orthodontic mini-implants.

B. The influence of cortical bone density on the magnitude of the tractive force in axial plane and at 45°:

a) regardless of the thread shape (radius or angle) for the type of mini-implant with the **thread pitch p = 0.5**, the relation established between the cortical density and the value of the tractive force of the mini-implant is the following:

- for the cortical density with values between: 900 – 1100 HU, the tractive force has values in the range of: 15.5 – 17.5N
- for the cortical density with values between: 1200 – 1500HU, the tractive force has values in the range of: 17.5 – 20N
- for the cortical density with values between: 2000 – 3200HU, the tractive force has values in the range of: 25 – 27.5N

b) regardless of the thread shape (radius or angle) for the type of mini-implant with the **thread pitch p = 0.8**, the relation established between the cortical density and the value of the tractive force of the mini-implant is the following:

- for the cortical density with values between: 900 – 1100 HU, the tractive force has values in the range of: 5.5 – 17.5N
- for the cortical density with values between: 1200 – 1500HU, the tractive force has values in the range of: 18 – 20N
- for the cortical density with values between: 2000 – 3200 mm, the tractive force has values in the range of: 24.5 – 27.5N

We can see that the values of the tractive force are in line with the growth the cortical bone density, no matter the thread shape or thread pitch of the orthodontic mini-implants. Nevertheless, for mini-implants with the thread pitch of 0.5, a higher tractive force was registered than in case of the ones with the thread pitch of 0.8, at the same values of the cortical density.

C. The influence of medullary bone thickness on the magnitude of the tractive force in axial plane and at 45° leads to the following observations:

- for medullary bone thickness of up to 7.45 mm, the tractive force has the highest value of 35N
- for medullary thickness between 12.0 – 14.0 mm, the tractive force has values in the range of: 7.5 – 10N
- for medullary thickness between 15.5 – 21.0 mm, the tractive force has values in the range of: 5 – 10N

In what concerns a low medullary bone thickness, the value of the tractive force may increase 3-4 times, compared to the value of the force registered in case of mini-implants inserted into a bone with high medullary thickness.

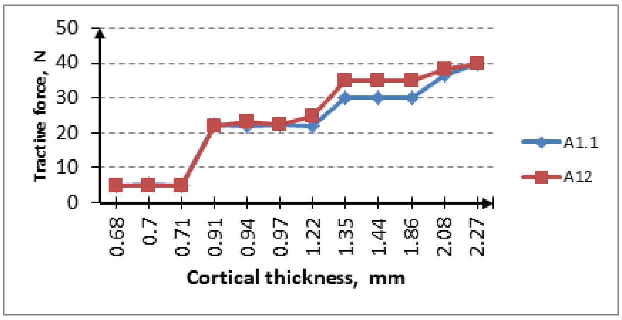
D. The correlation of cortical bone thickness with the medullary bone density on the magnitude of the tractive force in axial plane and at 45° illustrates the following aspects:

- for cortical thickness values between 0.5 – 0.75mm and medullary bone density values between 750 – 1035HU, the tractive forces have values in the range of 5.0 – 7.5N
- for cortical thickness values between 1.30 – 1.90 mm and medullary bone density values between 400 – 815 HU, the tractive forces have values in the range of 18.0 – 35N
- for cortical thickness values between 2.08 – 2.27mm and medullary bone density values between 300 – 323HU the tractive forces have values in the range of 25 – 40N (high cortical bone thickness and low medullary bone density determined high values for the tractive force)

The influence of cortical bone thickness is more important than the one of medullary bone density on the magnitude of tractive force and implicitly on the primary stability of mini-implants for orthodontic anchorage.

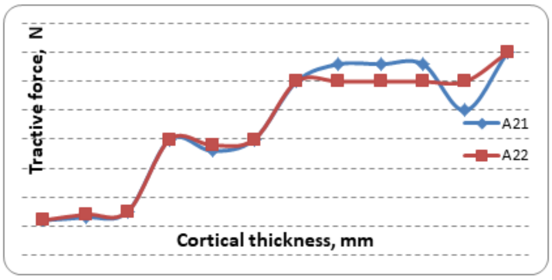
Figure no. 5 presents graphically the correlations of the factors that influence the maximum value of tractive force (value of the force at mini-implant removal).

Figure no. 5. The variation of tractive force dependent on cortical thickness



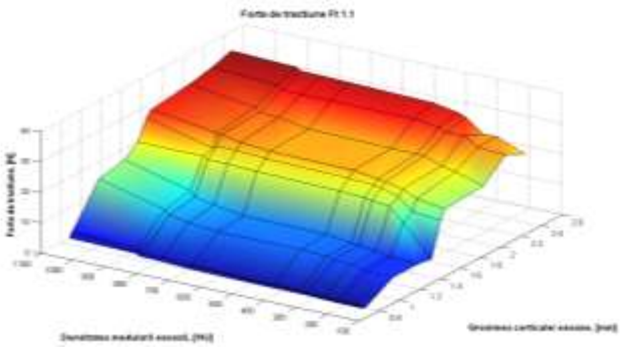
With regard to mini-implants with the thread pitch of 0.5 mm, the tractive force remains equal for the two types of implants up to a value of cortical thickness of 0.97 mm, after which, the value of the tractive force on the mini-implant with angle-shaped thread pitch increases more than the one registered for the round-shaped thread pitch, values which equalize at a cortical thickness of approximately 2.27 mm (figure no. 5).

Figure no. 6. The variation of tractive force dependent on cortical thickness



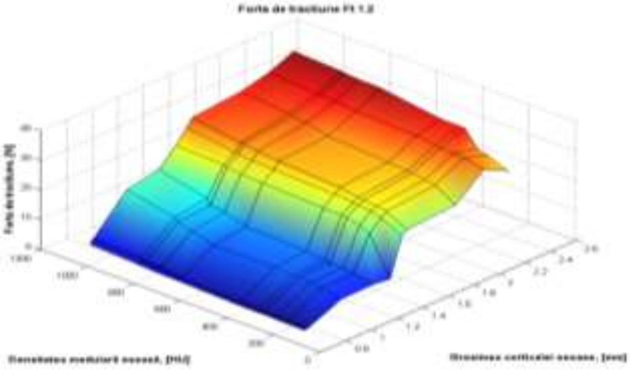
As opposed to mini-implants with the thread pitch of 0.5 mm where from a certain value of the cortical bone thickness of about 1 mm, up until the values of the tractive force were equal regardless of the shape of the thread, there was an increase of the value of the tractive force for the mini-implants of angle-shaped thread, in what concerns the implants with the thread pitch of 0.8 mm and following the same growth pattern of the tractive force values which remain relatively equal up to a certain cortical thickness, the force rate gets reversed and the tractive force of the angle-shaped implant becomes lower than the radius-type one (figure no. 6).

Figure no. 7. The relation of the tractive force with the characteristics of the bone structure for the A1.1 type mini-implant



One can notice in figure no. 7 that the tractive force applied on a mini-implant with the thread pitch of 0.5 mm and round shape of the thread increases proportionally with the growth of the medullary bone density, but mostly with the growth of the cortical bone thickness, maximum values expressed in the chart with an intense red colour.

Figure no. 8. The relation of the tractive force with the characteristics of the bone structure for the A1.2 type mini-implant



In figure no. 8, one can see that for orthodontic implants with the thread pitch of 0.5 mm and an angle-shaped thread, the same tendency of growth of the value of tractive force in connection with both the growth of medullary bone density and also with the growth of cortical thickness is kept.

Figure no. 9. The relation of the tractive force with the characteristics of the bone structure for the A2.1 type of mini-implant

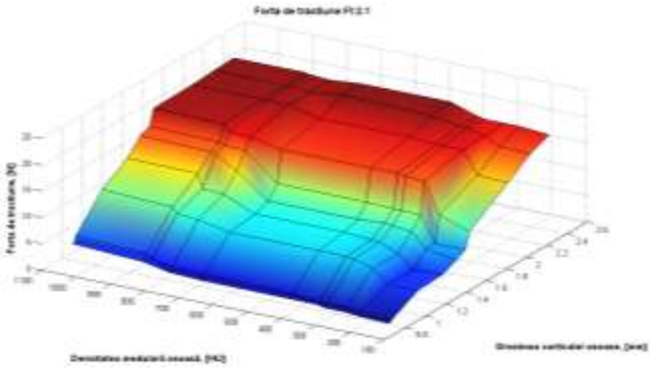
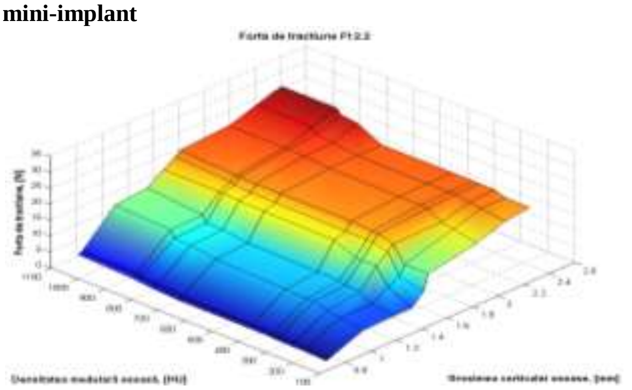


Figure no. 10. The relation of the tractive force with the characteristics of the bone structure for the A2.2 type of mini-implant



For the implants with the thread pitch of 0.8 mm and a round-shaped thread, the tendency of growth of the value of tractive force in connection with the growth of medullary density and growth of cortical thickness of the bone in which the implants were inserted is kept; the significant aspect is that, in this case, the values of the tractive force are increased for the majority of the bone samples. This observation comes in comparison with the situation presented in figure no. 9 where we show the range of values of the tractive force applied upon the implants with the thread pitch of 0.8 mm and an angle-shaped thread, where, although the growth tendency of the force value is kept, the ratio of the force and the number of cases where these high values are met are a lot diminished.

DISCUSSIONS

The studies of Zhao and collaborators (7) performed on animals (dogs) tested the primary stability of several orthodontic mini-screws placed on the anterior area of the mandible stating the following assertions: (8) the values of bone density and cortical thickness of the mandible are higher at grown dogs than at young ones, even at uniform cortical bone thickness; (9) the forces applied on the mini-implants inserted in the bones of grown dogs were a great deal higher than the ones applied on the bones of young dogs; (10) there are strong correlations between the forces applied and the mandibular cortical thickness; (11,12) bone density has great importance on stability as opposed to the cortical bone thickness.

As Cheng (13) states, the possible accidents and complications associated with the use of mini-implants include: damaging tooth roots, damaging vessels, nerves and the maxillary sinus, the fissure or fracture of the mini-implant.

Recently, Watanabe and collaborators (14) have used CBCT to assess the relation between the root and the screw and found that CBCT is much more indicated than the periapical X-rays for assessing the mini-implant proximity to the root. To evaluate the stability of the screws, Uemura and collaborators (15,16) have used a Periotest device to measure the mobility of the implant based on the insertion area. Periotest was developed in order to measure periodontal integration and the rigidity of the bone-implant interface in dental implant surgery.

Freudenthaler and collaborators (17) have reported the use of biocortical titanium screws for orthodontic anchorage into the mandible. The screws were used for the molar protraction by means of the extraction sites. To obtain a translation movement of the tooth, the orthodontic force was applied only on the vestibular head of the screw.

According to statements made by Sung and collaborators (18), the fissure or fracture of the implant during insertion or removal has the most incidence when the insertion place is located in the mandibular lingual area or in the retromolar space.

Implant loss was not categorically associated with the patients' general pathology. Moy (19,20) considers that implant loss is more likely correlated with bone quality, bone mass and surgical technique used. Still, due to minimum complications, advantages and multiple clinical applications, the use of mini-implants for orthodontic anchorage may be an advantageous clinical solution. More than that, orthodontic screws are considered temporary devices easy to remove which do not require osseointegration and post-removal healing is total.

Miles and Rinchuse (21,22,23) specify as accidents of orthodontic mini-implant insertion the following: damaging the root; damaging the inferior alveolar nerve, the mental, greater palatine, buccal and lingual nerves; implant sliding under the periosteum; fissure or fracture of the implant; mucosa emphysema caused by the air flow eliminated by the turbine in case of a failed surgical technique; bone necrosis caused by overheating, sinus perforation; and gingival inflammation post-surgery.(24,25)

In case of frequent loss of implant stability, one should take into consideration the use of the median palatine suture area because this offers quality bone and superior quantity as opposed to other areas.

CONCLUSIONS

- Tractive force and primary stability of the mini-implant grow along with the growth of cortical thickness.
- The tractive force on the mini-implant up until we noticed the removal of the implant into the traction device increases along with the growth of cortical bone thickness.
- The values of tractive force are influenced more by the cortical bone thickness than by the values of cortical density, observation confirmed also by previous research.
- Bone thickness and density do not influence significantly the primary retention of mini-implants.
- Once the medullary thickness grows, the value of the tractive force decreases on radius-shaped thread mini-implants.
- There are no significant differences between the two types of materials used for mini-implants: titanium and Ni-Cr-Mo alloy in what concerns the tractive force used on different thicknesses and densities of the cortical and medullary bone.

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