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Effect of Thread Design of Orthodontics Mini Implants on Their Stability - A Pilot Study

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Abstract- Objectives- This FEM study was conducted in order to investigate the effect of thread design of an orthodontic mini-implant on primary stability and strain pattern and magnitude in the surrounding bone structure during orthodontic loading.

Materials and Methods- The mini-implants by six different manufacturers such as Aarhus Mini-Implant (American Orthodontics), AbsoAnchor (Dentos), Dual-Top (Jeil Medical), LOMAS (Mondeal), IMTEC Mini Ortho Implant (IMTEC), tomas (Dentaurum) were placed in porcine jaw bone segments and they were subjected to micro CT scan. FE model was constructed using program system MSC. Marc/Mentat. The load of 400 grams was gradually applied. In each case we determined the deflection of the implant head as well as the distribution of strain in the cortical and cancellous bone. To investigate the effect on stability, the resulting force/deflection ratios were calculated. One way ANOVA test was used to analyze the correlation between resulting bone strain and thread depth and thread edge.

The resulting strain was ranging from 324 for to 2000 (Aarhus 9.6X2 and Abs anchor 10.5x1.4, respectively). No statistically difference was found for all the mini implants in relation to thread edge ($P>0.05$). However statistically difference was found between the thread depth ($p<0.05$) where the mini implants with deeper thread showed more strain than that with less depth. Even the strain for all the implants was within the physiological limits, mini implants with deeper thread showed more bone strain than the with less depth. No statistic difference was found between the mini implant with sharp and blunt edges.

Keywords- *Orthodontic anchorage, Mini-implants, Biomechanics, Finite element method, Thread design*

I. INTRODUCTION

Finite element analysis (FEA) is one of the very useful mathematical tools for predicting the effects of stress on the tissues in orthodontics as well as in other medical and dental fields, where the complex geometric objects and their physical properties are computer constructed by using a mathematical method. The biomechanical behavior of various components of the models are then calculated in terms of stress and strain [1]. The first use of finite element method in dentistry was to perform a two-dimensional model to investigate the stress distribution of human teeth [2]. It is a common way to find stress, displacement, and strain in dental implants [3-5]. This method has proven its efficiency in different applications in orthodontics [6,7].

The mini-implants are a temporary anchorage devices used as anchorage reinforcement or as the only source of anchorage, appear to be useful supplements to fixed appliances in contemporary clinical orthodontics. They can be stable enough to withstand orthodontic forces. Although they are becoming popular in orthodontics, but there is little information about their biomechanical performance.

In this study, three-dimensional (3D) models of the implants and bone adjacent to the implant were generated and the maximum principal strain and strain energy density distributions of the implants and bone were evaluated by FE analyses. This study was aimed at investigating the effect of thread design of an orthodontic mini-implant on primary stability and strain pattern and magnitude in the surrounding bone structure during orthodontic loading.

II. MATERIAL AND METHOD

Various mini-implants systems studied are Åarhus Mini-Implants (American Orthodontics, Sheboygan, WI, U.S.A.), AbsoAnchor® Micro Implant System (Dentos Inc., Taegu, Korea), Dual-Top™ Anchor System (Jeil Medical Corporation, Seoul, Korea), Lin / Liou Orthodontic Mini Anchorage Screw (LOMAS) (Mondeal Medical Systems, Prepare Your Paper Tuttlingen, Germany), IMTEC Mini Ortho Implant System (IMTEC Corporation, Ardmore, U.S.A.), Temporary Orthodontic Micro Anchorage System (tomas®) (Dentaurum, Ispringen, Germany). The design of the implant consists of the head, neck and body. The geometry of the mini-implant bodies especially the thread design was the main considered component of mini-implants in this study, to find out whether this variability can affect the stability of the mini-implant during loading. All the six mini-implants systems were scanned with electron microscope (Philips XL 30, Philips, Eindhoven) to study the thread design (Figure 1).

The tested mini implant thread had different thread and can be classified according to thread depth which was ranging between 100 to 275 Micrometer, thread edge which can be blunt as of IMTEC, Tomas and Dual Top or sharp Arhus, Absoanchor and LOMA and symmetrical threads (Absoanchor and Tomas) or asymmetrical (Dual Top, Ahrus, Lomas as well as IMTEC) (Figure 1)

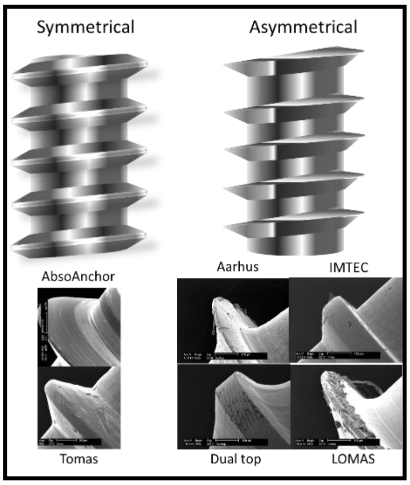

Figure 1. Electron microscopic view of all the mini implants with different thread edges

These 13 mini-implants were inserted in the porcine jaw segments and they were subjected to micro CT scan (Skyscan 1072: Sky-scan, Kontich, Belgium). The number of the µCT-sections per implant ranged from 139 to 224. Using these 2 dimensional cross sectional µCT-scan views of the specimens, the 3-dimensional model of mini-implant and the surrounding bone was generated8 with the help of the especially designed software ADOR-3D ("ADvanced Object Reconstruction in 3D") as demonstrated in figure 2.

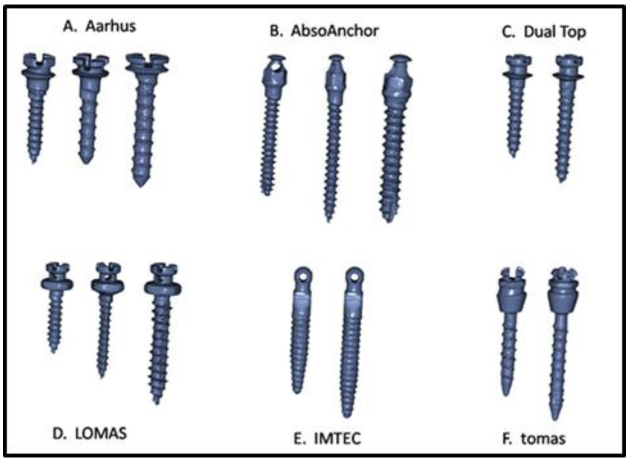

Figure 2. 3D Models of the mini implants

The number of elements used for construction of 3D model of implants ranged from 28965 to 69960 and number of nodes ranged from 6437 to 17651. Number of elements used to form the cortical bone ranged from 9755 to 41632 and nodes ranged from 1764 to 10217. Whereas number of elements in cancellous bone ranged from 15164 to 45231 and nodes ranged from 2793 to 11357. Figure 3 illustrates the 3D Models of the mini implants. All the implants studied had thread angle of 10 to 110 except IMTEC which had 50 thread angles. (Figure 3)

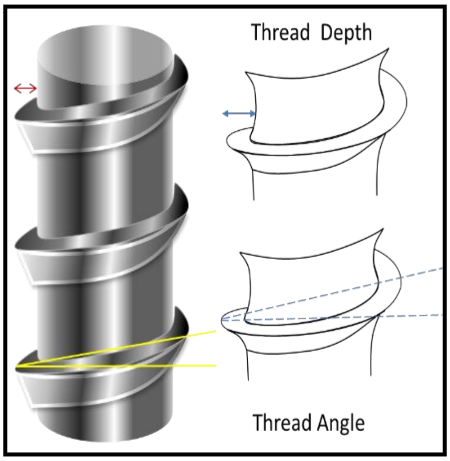

Figure 3. Schematic description of the thread Depth and Angle.

The geometric data of the mini implant and surrounding bone were separated and individually exported to the FE project. The finite element package MSC.Marc/Mentat® (MSC Software Corp., Santa Ana, CA, USA) was used for mesh generation and calculation. All the implants used in this study were made of titanium or an alloy of titanium. Therefore, system was fed with Young,s modulus (E) of 110 GPA and Poisson's ratio (v) of 0.3 for implant. The outer 2 mm thick bone substance was defined as cortical bone (E=20 GPa, v=0.3). The central bone substance possessed cancellous bone characteristics (E= 00 MPa, v = 0.3). The resulting FE models were loaded gradually with the 400 gm force. The movement of implant and the strain pattern and magnitude in the surrounding bone were calculated.

III. RESULTS

Figure 4 describe the resulting movement of all the mini implant after loading. As the thread depth increases, the implant core diameter decreases and the implant becomes fragile. SEM pictures from our study showed that the thread depth varied from 100 µm (IMTEC) to 275 µm (AbsoAnchor). All the implants studied had thread angle of 10 to 110 except IMTEC which had 50 thread angles. Therefore IMTEC implants have more threads. They should have been more stable than other implants. In our study IMTEC implants showed significantly low movement compared to AbsoAnchor and Lomas mini implants but the Aarhus and Dual top showed the least amount of movement. This finding indicates that the thread angle may not be the important factor in the stability of an implant.

The magnitude of bone strain ranged between 324 and 2000 µStrain. Implants with large number threads should cause more strain on the surrounding bone (figure 5). However, AbsoAnchor, in our study produced more strain than the IMTEC which has maximum number of threads among all the samples. This finding proves that the number of threads and the strain in the bone are not correlated. The statistical analysis was done by IBM SPSS 21. One way ANOVA test was used to analyse the correlation between resulting bone strain and thread depth and thread.edge. No statistically difference was found for all the mini implants in relation to thread edge ($P>0.05$). However statistically difference was found between the thread depth ($p<0.05$) where the mini implants with deeper thread showed more strain than that with less depth.

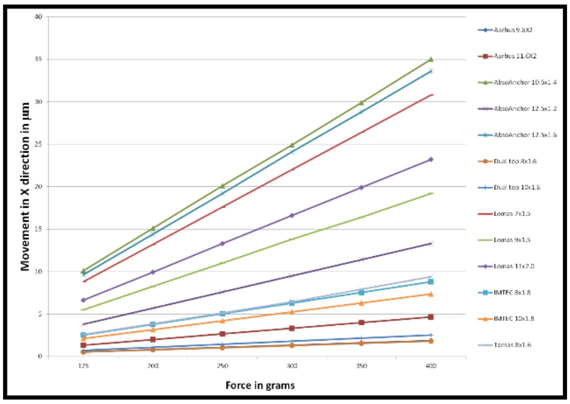

Figure 4. Movement of mini implants after loading with 400 gm.

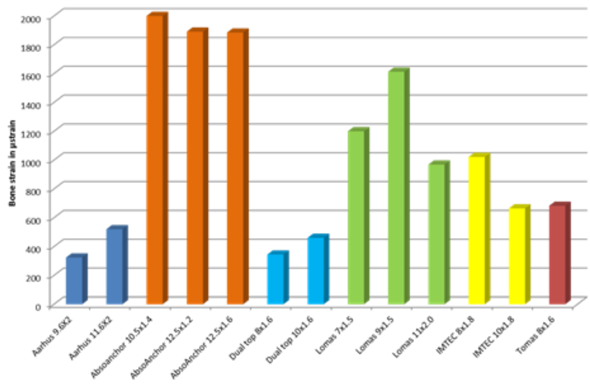

Figure 5. The resulting bone strain after loading the mini-implants.

IV. Discussion

FEM analysis has been used during the past few decades extensively in medicine and dentistry. This method of analysis has been proven to be valuable by improving the profession's understanding of various aspects of oral biomechanics [4,5].

Mechanical stress causes strain in the bone tissue which is defined as a relative change in length, whether lengthening or shortening. Unit used to measure strain is µStrain. The degree of the strain correlates with stress and the bone's mechanical characteristics [10]. According to Frost [11], the amount of strain can be divided into various ranges, permitting us to predict the effects on the bone. The limits among these various areas vary from individual to individual. According to Frost, the lower limit of the bone's equilibrium (i.e., of the load range within which, due to continuous bone remodelling processes, as much bone tissue is formed as is resorbed) is roughly 50–100 µStrain. The upper limit of this range is roughly 1,000–1,500 µStrain. If the loading is below 2000 µStrain, basic multicelluler unit of bone remodeling can easily repair the micro damage [12]. Additional strain, however, leads to microfissures and microfractures in the bone tissue, which, at roughly 3,000 µStrain surpasses ongoing repair processes leading to bone resorption. The magnitude of bone strain ranged between 324 and 2000 µStrain. This suggests that the all the mini-implants investigated in this study could be safely used without causing micro fractures.

Some of the studies suggested that cortical bone thickness play a major role on the stability of orthodontic mini-implants and on the stress distribution in surrounding bone regardless to the mini implant design. [13-17]

Thread design

The manner in which the screw penetrates into the bone depends on the cut, the depth, and the angle of the threading.

Thread Angle:

The angle of the cut in relation to the core determines how many threads there are and also the rate with which the screw is inserted into the bone at each turn. With a smaller angle, the higher the number of threads and this increases the surface area of the screw, thereby enhance stability. The number of threads are, however, also related to the impact on the bone when inserting the screw. If the threads are closer, more severe the destruction of surrounding bone. The angle chosen for Mini-implants should be optimization of the need for a larger surface and a minimum of trauma.

Fongsamootr et al, Geramy and Morgano and Chun et al [19,20] performed FEA to determine an optimal thread shape. Their results showed that the maximum effective stress de¬creased as screw pitch decreased gradually. This study, however, examined the design of the dental implant.[19,21]

In order to investigate the effects thread pitch on the initial stability of the mini-implant for orthodontic anchorage, Motoyoshi et. al., [21, 22] conducted FEM study.

They found that the maximum effective stress decreased as screw pitch decreased gradually. The maximum stress induced by the implant with thread pitch 0.5 mm was less than half of that of implant with thread pitch 1 mm and 1.5 mm. A thread pitch of 0.5 mm may be recommended to decrease the stress concentration in these experi-mental conditions. Although there is a tendency for the maximum stress to decrease as the thread pitch decreases, influences of the thread pitch variance on the stress distribution were unclear.

The initial stability is one of the important factors for success. Displacement calculated in this study can be regarded as an indicator of the initial stability.

Motoyoshi et. al., [16,17] compared the displacement implant with thread pitch of 0.5 mm, 1 mm and 1.5 mm similar patterns were observed. High-level movements were shown by the most of their implants. The displacements of the three models were 1.73, 1.82 and 1.85 mm. This result revealed that the thread pitch variance obviously not effective in raising the initial implant stability.

Lin et.al, 22 constructed eighteen CAD and finite element (FE) models to determine the relative effects of changes in mini-screw design factors on the biomechanical response. They found that the thread depth have minor contributions to cortical bone strain. Simulation results also revealed that mini-screw and bone surface contact can provide sufficient mechanical retention to perform immediately load in clinical treatment. 22

The Thread depth:

The deeper the thread, the greater the intraosseous surface area of an implant. The surfaces of most mini-implants are machine polished and the bone will adapt closely to the screw surface. As the thread depth increases, the implant core diameter decreases and the implant becomes fragile. SEM pictures from our study showed that the thread depth varied from 100 µm (IMTEC) to 275 µm (AbsoAnchor). The tomas and dual top have thread depth of 190 µm to 175 µm respectively and Aarhus and LOMAS implants have depth of 250 µm and 240 µm respectively.

Deeper the threads more stable the mini-implants as they offer more resistance to displacement. The AbsoAnchor should have shown the higher resistance to movement but in our study it showed the maximum movement among the implants studied (35 µm). The IMTEC has shallowest thread depth and should have showed maximum movement but in our study they moved minimum. These findings indicate that thread depth may not play an important role in the stability of an implant. However

The Edge:

The sharper the edges of the threads, the more precise the cut is in the bone, whereas the blunter the edges, pressure increases with crushing of the surrounding bone. Our SEM pictures showed Aarhas and AbsoAnchor mini-implants having sharp edges, they should be cutting the bone precisely with minimum trauma. Dual top and IMTEC mini-implants very blunt edges may be very traumatic. Whereas other two types of implants LOMAS and Tomas have edges which are midway. Our finite analysis findings did not support this concept. The AbsoAnchor, Lomas and Aarhus implants which have sharp edge produced the strain ranging from 324 to 2000 µstrain, whereas implants with blunt edges such as IMTEC, Dual top and Tomas produced strain ranged from 345 to 1022 µstrain. This indicates that the strain in the surrounding bone does not depend upon the edge sharpness of an implant.

Symmetry of threads:

The mini-implant threads are cut at an angle in an asymmetrical pattern with an oblique part is pointed towards the apex and the horizontal part towards the head of the screw. The threading can also be formed symmetrically. The asymmetrical design has a higher resistance to an applied extrusive force. Our SEM pictures showed Aarhus, Dual top, LOMAS, IMTEC mini-implants have this type of symmetric design. Whereas, AbsoAnchor and Tomas mini-implants have symmetrical thread which may have greater mobility for extrusive force. However, experimental investigation of these implants did not show much of a difference with other implants with regards to movement. This may be because of direction of force application in the present study was perpendicular to the long axis of implant not a vertical force.

V. CONCLUSIONS:

Further study may be conducted in order to verify the effect of thread design with all the samples having the same diameter and same length. This will facilitate the comparison between the groups.

1. Thread angle.
2. Thread edge.
3. Thread depth.
4. Thread symmetry.

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