

## Thread Pitch Variant in Orthodontic Mini-screws: A 3-D Finite Element Analysis

Fatemeh Motaghi Dastenaei<sup>1</sup>, Mahdi Moghimi Zand<sup>2\*</sup>, Saeed Noorollahian<sup>3</sup>

1. Graduate MS Student, School of Mechanical Engineering, Isfahan University of Technology, Isfahan, Iran

2. Assistant Professor, School of Mechanical Engineering, College of Engineering, University of Tehran, Tehran, Iran

3. Assistant Professor, Dental Implants Research Center, Department of Orthodontics, School of Dentistry, Isfahan University of Medical Science, Isfahan, Iran

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### Abstract

Orthodontic miniscrews are widely used as temporary anchorage devices to facilitate orthodontic movements. Miniscrew loosening is a common problem, which usually occurs during the first two weeks of treatment. Macrodesign can affect the stability of a miniscrew by changing its diameter, length, thread pitch, thread shape, tapering angle and so on. In this study, a 3-D finite element analysis was done to show the effect of thread pitch variant on the stress distribution pattern of the screw-cortical bone interface. While orthodontic forces were applied, stresses were usually concentrated at the first thread of the screw in contact with the cortical bone. The cortical bone provided a significant percentage of stability compared to the trabecular bone against orthodontic forces. Therefore, spongy bone was removed from the finite element analysis. The changes of maximum von Mises stresses were shown on the charts. The results showed that stresses decreased with decrease in thread pitch, but they increase when thread pitch becomes less than a certain value. The pattern of stress distribution differed when the stresses were increased. The results are beneficial for the design of an ergonomic dual miniscrew, with better properties than the commercially available miniscrews and based on the results, a new dual miniscrew is recommended.

**Keywords:** *dual design, FEA, miniscrew, orthodontics forces, thread pitch.*

### 1. Introduction

Orthodontic miniscrews are temporary anchorage devices (TADs) which are used for a wide range of applications. They are commonly used because of their advantages: convenience in insertion and removal, minimal surgical invasiveness, being ready for immediate loading

after surgery and low cost advantage [1-5]. Therefore, they have gained much popularity over the past few years [4].

Miniscrews are used as anchorage for teeth and to cause orthodontic movements including space closure, space open, open bite treatment and uprighting of posterior teeth [2, 3]. According to Figure 1, the implantation site is in the jawbone, between two roots of the teeth.

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\* Corresponding Author Email: mahdimoghimi@ut.ac.ir, Tel.: +98 21 61114807



**Fig. 1.** The site of the implantation is in the jawbone, between two roots of the teeth

The major disadvantage of miniscrew is that their primary stability can be lost, which usually occurs within the first two weeks of treatment [4, 6]. Primary stability refers to the main factors affecting the patient such as host bone properties (quantity and quality of the jawbone at the placement site), surgery procedure (mandibular plane angle, torque and force levels) and design properties of the miniscrew (such as diameter, length, thread shape, thread pitch and screw material) [1, 4, 5]. When the screw loses its primary stability, failure is normally due to loosening [4, 6].

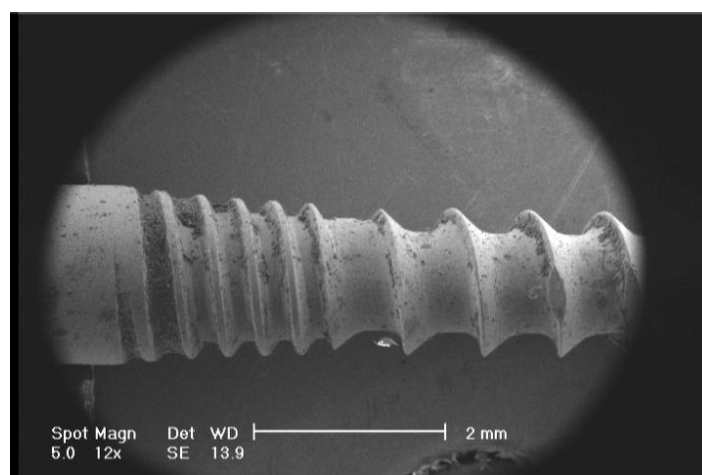
Among the various design parameters of a miniscrew, thread pitch plays an important role because of the influence on anchorage surfaces [7]. Jones (1964) defined thread pitch as: "The distance from the center of the thread to the center of the next thread, measured parallel to the axis of a screw" [7].

In 1976, Weinstein et al. became the first to use *finite element analysis* (FEA) in dental implants [5]. In 1991, Clelland et al. found a stress distribution pattern in the screw and related tissues around the implant by means of 3-D FEA [4].

Motoyoshi et al. (2005) in their 3-D FEA compared screw pitches of 0.5, 1 and 1.5 mm. They mentioned more favorable stress distribution of shorter screw pitch compared with longer ones [7]. In another FEA, Kong et al. (2006) noticed that stress decreased when thread pitch decreased from 1.6 to 0.8 mm, then it increased when thread pitch became smaller than 0.8 mm [7]. Another study (2011) claimed that there was no significant difference between thread pitch distance and the pattern of stress distribution [8].

As already mentioned, thread pitch performs the function of providing stability for the miniscrew, but it seems that the changes in the stresses from pitch variants are not yet clearly recognized because much investigation has not been conducted due to data variation in published studies. Thread pitch is one of the most important parameters that provide initial stability for the miniscrew. Therefore, this study was conducted to investigate the effects of pitch variations on stress distribution by FEA methods comparing the differences from other studies and by reducing the distances of the thread pitch (Thread pitches were 1, 0.9, 0.8, 0.7 and 0.6 mm).

A dual-thread miniscrew is a screw with two different pitches and cortical or spongy bone interfaces. The micro-threads face of the cortical bone has a thickness of 2 mm. A micro-thread pitch is equal to half of the spongy thread pitch. Figure 2 shows a dual-thread miniscrew of Yesanchor Company, captured by a scanning electron microscope (SEM).



**Fig. 2.** A dual miniscrew of Yesanchor (Korea), SEM laboratory of Isfahan University of Technology

To design a new dual-thread screw, we added the thread pitches and half values of the mentioned thread pitches to the results (Pitches: 0.5, 0.45, 0.4 and 0.35 mm). A thread pitch of 0.3 mm could not be modeled because the selected height of the threads in this study is 0.331.

*Finite element method (FEM)* is a non-invasive, alternative and easy procedure to predict stress and strain distribution, which can be used before clinical tests [8, 9].

The von Mises yield criterion applies best to ductile materials such as metals [10]. Equivalent von Mises stress depends on the entire stress field or the combination of tensile, compressive and shear stresses [11]. The von Mises stress is defined by the formula:

$$s_0 = \sqrt{1/2 \left[ (s_1^2 - s_2^2)^2 + (s_2^2 - s_3^2)^2 + (s_3^2 - s_1^2)^2 \right]} \quad (1)$$

where  $s_1$ ,  $s_2$ , and  $s_3$  are the principal stresses [12].

## 2. Methods

A popular miniscrew was bought from Jeil Company (Jeil Medical Corporation, Seoul, Korea; Diameter 1.6 mm, Length 8 mm). Selected dimensions enable miniscrews to be

used in a wide region of oral cavities, especially in the thick cortical bone area of the mandible [8]. The diameter of the bought miniscrew was narrow enough to be placed between the adjacent roots of the teeth and wide enough to avoid fracture.

A Jeil miniscrew with a pitch of 0.75 mm was modeled in the CAD software Dessault Systems Catia V5R21. A cortical bone block of 4×4×2 mm (thickness) was also modeled around the mini-implant while all threads were embedded in the bone, except for the 0.1 mm top threads of the screw. The cortical bone absorbs most of the stresses and therefore may be the determining factor of the miniscrew's stability. As a result, we ignored the trabecular bone (4×4×8 mm thickness) when modeling the present study [10]. Figure 3 shows the stress contours on the screw and cortical bone when a 2 N orthodontic force is applied. The materials were considered to be linear elastic, homogenous and isotropic. The Young modulus for titanium screw, cortical and spongy bone was assumed to be 113800, 13700 and 1370 MPa, respectively [13,15] and poisson's ratio was considered 0.342, 0.3 and 0.3, respectively [13,15].

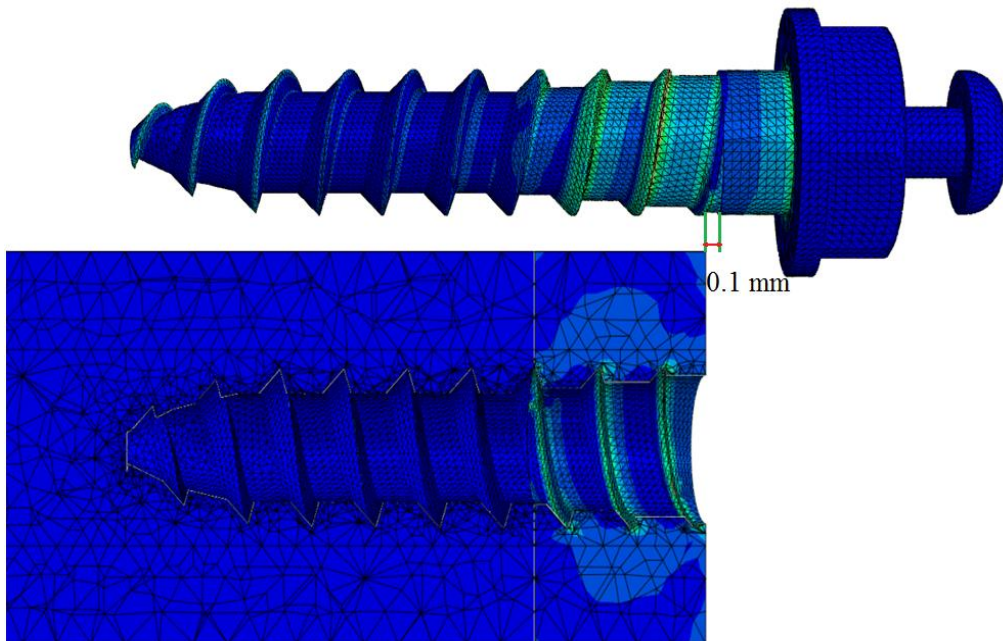


Fig. 3. Miniscrew in the bone layers with a distance of 0.1 mm. A section view of cortical and spongy bones. Majority of the stress is transferred to the cortical layer

The spongy bone is free of stress which verifies the previous findings [3]. A distance of 0.1 mm was considered to avoid wrong stress concentration at the top of the screw. Figure 4 shows the importance of the cortical bone in providing stability for the miniscrew. The peak Von Mises stresses usually occurs at the first anchorage thread.

The picture of stress distribution verifies the result of the study and states that the stress concentration of the implant usually occurs on the first thread and is higher than in other threads [11].

The other screws whose pitches are mentioned were also modeled. The thread pitch was varied from 1 to 0.6 mm by steps of 0.1 mm.

Based on the Jeil dimensions as shown in Figure 5, each screw was 1.6 mm in the outer diameter and 8 mm in length. The thread shape was reversed to fit in the cutting view of a triangle with the thread ridge thickness fixed at 0.25 mm, and a height of 0.331 fixed at an apex angle of 63 degrees, to fix the factors, except the thread pitch. The screws were imported to the Abaqus/CAE version 6.13-1, 2013.

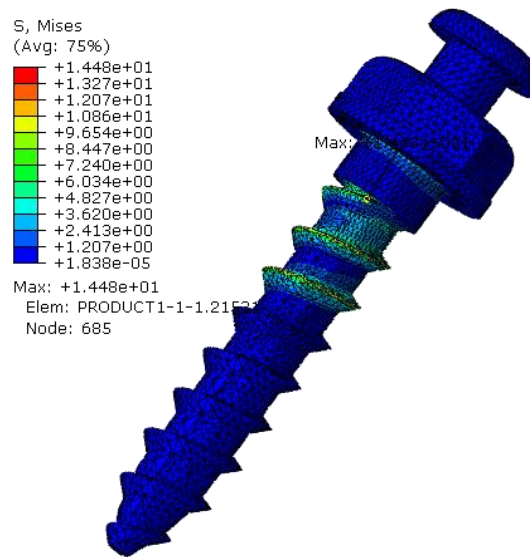


Fig. 4. Stability provided by cortical bone. Stress usually concentrates on the first thread of interface with cortical bone

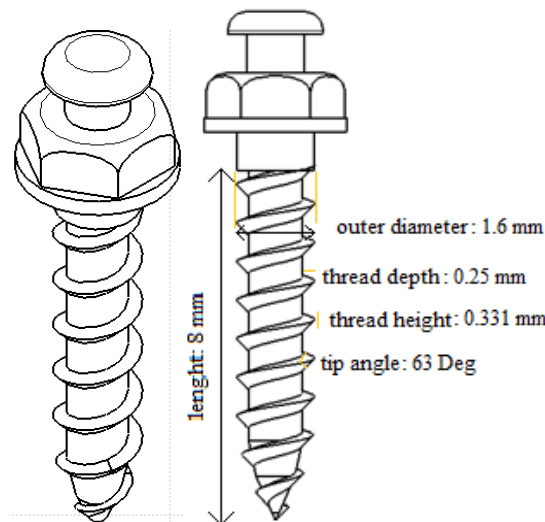


Fig. 5. Implant Macro-design, used dimensions based on Jeil parameters

Both the bone and implant (made of titanium alloy Ti6Al4V) were considered to be isotropic, homogenous and linear elastic, based on the volume of definition in the literatures [1, 6, 8, 10, 11]. Table 1 shows the values.

Also a frictional co-efficient of 0.5 was assumed and used to simulate the miniscrew/bone interface [6]. Based on fig. 6, boundary conditions (BCs) were applied to all 4 side surfaces of the cortical bone to immobilize the bone block. Therefore, three displacements and rotations of three degrees of freedom (DoF) of the bone block were restrained. An experimental orthodontics traction force of 2 N (200 cN or ~200 gram-force in orthodontics terms) was applied to the head of each mini-screw in the direction of the screw axis to show the influences of the different thread pitches on the stress

distribution pattern [8]. Each mini-screw was forced to have the displacement only in the vertical direction. In other words, additional BC was applied to the screw to restrain the movement in all directions except the direction of the applied force.

A mesh of quadratic 10-node tetrahedral structural solid element (C3D10)– that is optimized for use in contact analyses– was considered before applying each mini screw implant and bone blocks models [10].

At first, a validation should be done to show the correction of the results; which is obtained by the refining mesh and convergence tests. Figure 7 shows that the peak von Mises stresses for 0.1 and 0.05 mm meshes are very close to each other (12.97 and 12.83 MPa, respectively).

Table 1. Mechanical properties of materials used in the present study

Material	Young's modulus (MPa)	Poisson's ratio	Density (gr/cm <sup>3</sup> )
Ti6Al4V	113800 [13]	0.342 [13]	4.43 [14]
Cortical bone	13700 [15]	0.3 [15]	1.7 [5]

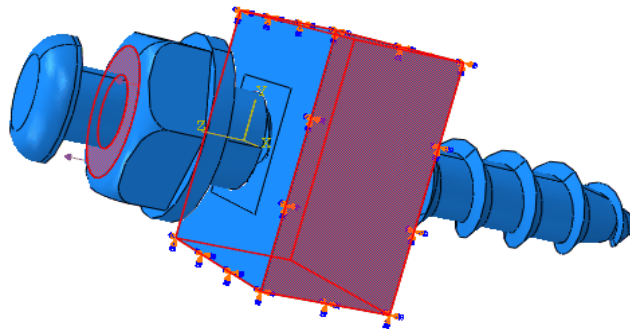


Fig. 6. BCs and Force; 6 DoF of side surfaces of cortical block was restrained

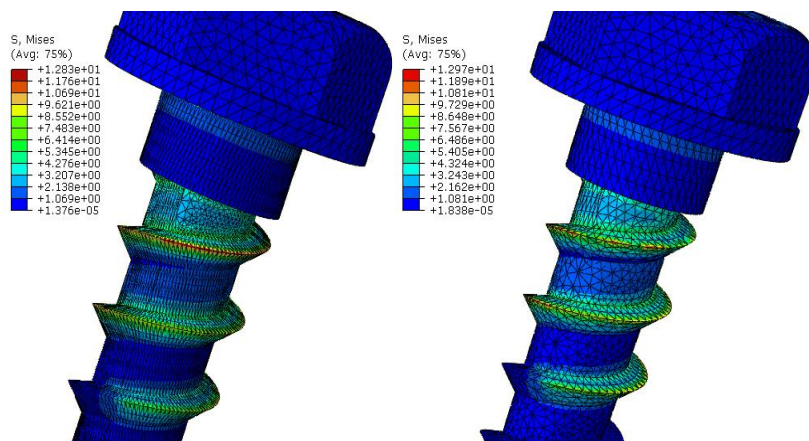


Fig. 7. Mesh refining and validate the results

By choosing a mesh of 0.1 mm, each product consisted of approximately 300,000 nodes and 200,000 solid elements.

### 3. Results

Each analysis was run and the peak von Mises (equivalent) stresses was extracted. Figure 8 shows the stress distribution pattern for the thread pitch, equal and more than 0.6 mm. Stress is significantly concentrated at the apex of the threads, which are in contact with cortical bone.

Figure 9 shows that the maximum equivalent stress is reduced as the screw pitch is decreased gradually from 1 to 0.6 mm by steps of 0.1 mm [3].

Deciding to design a dual-thread mini-screw to gain more stability encouraged us to do another FEA for the screws by the pitches equivalent half of the previous state.

Figure 10 shows the stress distribution pattern of the screw when the thread pitch became equal and less than 0.45 mm. It shows that the stress distribution pattern differed from the previous state, while in this state an indirect relation between the thread pitches and maximum von Mises stresses was seen.

Figure 11 Summarizes the results of the present study.

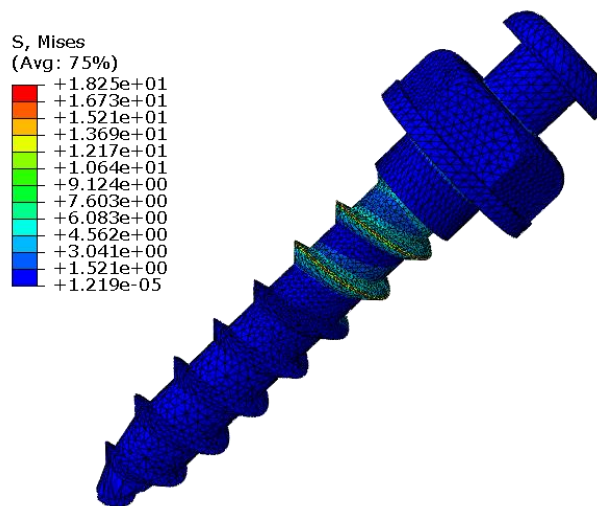


Fig. 8. Stress distribution pattern when the pitch is equal and more than 0.6 mm

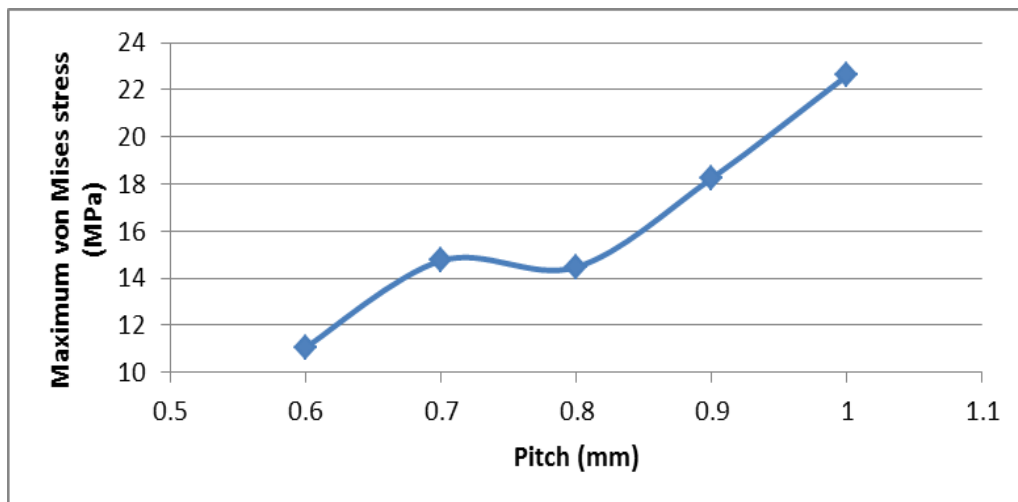


Fig. 9. Peak von Mises stresses of the screw- Pitch variant from 0.6 to 1 mm

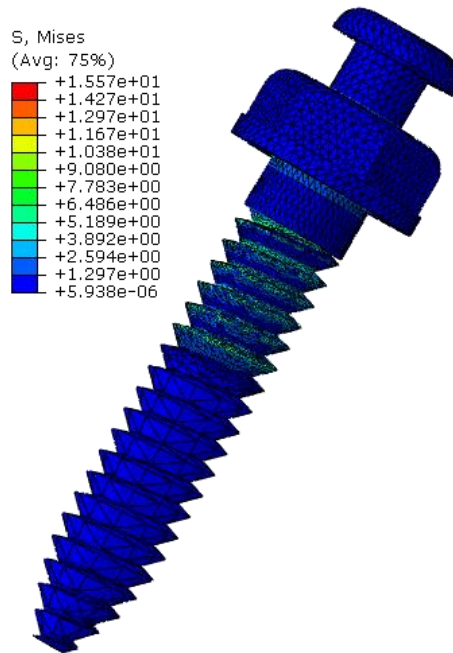


Fig. 10. Stress distribution pattern when the pitch is equal and less than 0.45 mm

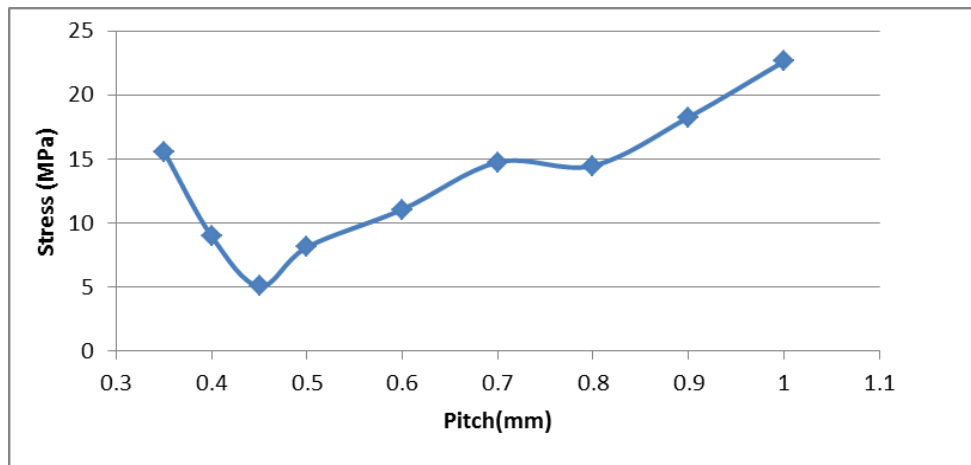


Fig. 11. Peak von Mises stresses of the screw- pitch variant

We can appreciate from the figures presented above that we can choose 0.9 and 0.45 mm thread pitches to design a dual-thread miniscrew. Also, 0.8 and 0.4 mm is another choice to do this. The decisions are because of the fact that majority of the stresses are absorbed by cortical threads and they do not allow spongy threads to bear excessive stresses [16]. Choosing thread pitches of 0.8 or 0.9 mm results in a more rapid and easy (lower torque and stress) entrance into the bone than the Jeil (pitch of 0.75 mm) [17]. Also, the dual-thread screw shows a significantly lower maximum insertion torque (MIT) than the typical screws

when the bone meets micro-threads, which helps to reduce the risk of the fracture significantly [17]. It should also be noted that excess helix angles for a faster insertion, may jeopardize the ability of implants to transfer axial load [7]. Hence, we can design micro-threads with trapezoid shape to protect the triangular shape of spongy threads against vertical loads. These reasons show that the new model is more ergonomic than the Jeil model.

#### 4. Conclusion

The main results of the current study are as follows:

- Stress concentration usually occurs at the first thread of the implant.
- Maximum stability of the miniscrew is provided by cortical bone.
- The stress values associated with spongiform bone were much less than those of the cortical bone.
- Stress decreased when screw pitch decreased from 1 to 0.5 mm; it was concentrated at the apex of the threads. The stress increases when the screw pitch became less than 0.45 mm and the stress distribution pattern was different from the previous state.
- Choosing thread pitches of 0.9 mm and 0.45 mm or 0.8 mm and 0.4 mm (for a miniscrew with dimensions of 1.6 mm×8 mm for outer diameter and length respectively) seems appropriate to create a new dual miniscrew design that can provide ergonomic aims, because of less insertion time, torque and stress; for larger thread pitches and lower MIT than the Jeil miniscrew.

The purpose of the present study was to create a new and improved design of the screw with better ergonomic properties than the Jeil, by considering pitch variety. The other dimensions were fixed on Jeil dimensions.

This study is the first to compare various pitches by small difference to reach a chart base. As a result, we could decide on certain pitches to make new designs (dual designs). We should notice that the values were only extracted from the reactions between cortical bone and miniscrews. The values are certainly more than real values when the spongy bone is not removed.

In future studies, a dual miniscrew with thread pitches of 0.8 and 0.4 mm or thread pitches of 0.9 and 0.45 mm can be created and the stresses should be compared, so as to decide on a better and more ergonomic dual miniscrew.

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