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Research Article

Axial Push-out Resistance of Dental Implant Different Thread Designs

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Abstract

Introduction: According to some authors, there is a correlation between insertion torque of different dental implant thread designs and their axial push-out strength (PS), although other investigations have not found that to be true, accordingly this study aimed to test the effect of dental implant different thread designs on the PS of the dental implants/bone interface in a custom-made bone block using destructive mechanical testing.

Materials and Methods: Custom made dental implants were designed, manufactured, having 4 different thread designs, namely, V-shaped, buttress, reverse buttress, and trapezoid. The implants were inserted in a custom-made bone block and subjected to mechanical push-out testing and measurements were recorded and statistically analyzed.

Results: There was no statistically significant difference between the push-out force of the trapezoid and reverse buttress threads, and both had higher push-out force than those of V0shaped and buttress threads.

Conclusion: Since the insertion torque values for the T threads are generally known to be significantly higher than those of the other forms of studied threads, the trapezoid threads prove a positive relationship between insertion torque and axial push-out resistance of dental implants during destructive mechanical testing in ex-vivo natural bone samples.

Keywords: Dental Implant Thread Design, Axial Push-Out Test.

Introduction

Structurally, a good dental implant thread must bite well, have a profile that reduces shear forces, stress concentrations, and transfer compressive load to the surrounding bone [1-6]. Historically, bone screws were based around rounded "V" threads, in recent times, a variety of thread designs have appeared such as square threads, and buttress and reverse buttress threads [7-11]. An obvious advantage to choosing one thread design over another is to consider the surface area increase offered by each design; a square thread presents a larger surface to the bone, however, the other geometries, the triangular "V" thread or trapezoidal thread would also provide a decent surface area [11-14].

Thread depth affects bone/implant contact and insertion torque, as the depth pertains directly to contact area, mechanical holding power, and how much material must be displaced. A common surgical problem occurs when threading cortical bone, a good deal of torque is required, and if the threads are too deep, the combination of high torque and friction can cause bone trauma by friction generated heat and loading. This would suggest very conservative thread depths; however, threads primarily engage cancellous bone, with only a small amount of compact bone contact [8-11].

Thread pitch refers to the periodicity of the thread spacing and provides an indirect measure of both the thread count and density. In this sense, a lower pitch means more threads/length, this translates into greater bone/implant contact, so a small pitch is desirable as proved by several finite element analysis studies [5,6,14].

Having defined both pitch and depth, the only other consideration is the thread angle. If the thread were to be square, the angle would be meaningless. However, if a trapezoidal profile was selected, the angle be specified. Returning to the finite element studies, there is nothing conclusive apart from the fact that a small angle trapezoid has the best performance, where 'small' implies a thread angle of 30° However, these studies only considered angles greater than or equal to 30°, while other recent studies have suggested that a much smaller angle (6°) is effective [8,9,14,15-17].

For mechanical testing of dental implant inserted in ex-vivo bone samples, pushout and pullout tests are commonly used to test the ex vivo mechanical competence of biological fixation of orthopedic and dental implants via evaluation of the shear strength of the bone–implant interface. One of the reasons these tests are widely used is the relative simplicity of the test protocol, which usually requires a uniaxial material testing machine to be operated under displacement control using a simple support jig for the pushout test or a hookup system for the pullout test [18-21]. The most common applications for these tests include testing for the effects of implant material, surface texture, cross-sectional geometry, porosity, and surface composition. In general, the retrieved specimens are tested either in the fresh condition or after having been frozen because histological processing methods (e.g., fixation in formalin) alter the mechanical properties of bone and soft tissue [22].

Insertion torque (IT) is the result of frictional resistance between implant threads and bone; it determines primary stability, since the dental implant success rate is related to IT, among other factors. Axial push-out strength (PS) is the result of bone failure and reflects the magnitude of the PS that the screw bears before bone rupture. Studies have examined the correlation between IT and axial PS to determine whether IT can predict screw retention in bone tissue. According to some authors, there is a correlation between IT and axial PS, although other investigations have not found that to be true [23-27]. Accordingly this study aimed to test the effect of dental implant different thread designs on the PS of the dental implants/bone interface in a custom-made bone block using destructive mechanical testing.

Materials and Methods

Custom made dental implants were designed, manufactured, having 4 different thread designs, namely, V0shaped, buttress, reverse buttress, and trapezoid. The implants fixture length was 15 mm and diameter was 3.5 mm. (Figure 1) The implants were inserted in a custom-made bone block and subjected to mechanical push-out testing,

The materials and methods used for the development of a composite bone model were as follows: Cancellous bone sample dimensions were: 20x20x10 mm, while cortical bone sample dimensions were: 20x20x1.5 mm. Clear epoxy resin was used assemble the 2 bone layers in the study bone block. Then, an osteotomy was drilled in the composite bone model using sequentially larger drills used (Figure 2).

Mechanical push-out testing of the proposed thread designs

- A custom-made holder was designed to support the sample during the insertion and mechanical push-out of the screws. (Figure 3a)
- The holder was made of an upper part (the indenter) used to push out the screw and a lower part (the base) used to support the screw. (Figure 3b, and c)
- A torque driver with a dial gauge was used to drive the screw into the bone sample and provide a reading of the insertion torque. The torque driver had a square foot, on the other hand, the screw had a top external hex, accordingly, a custom-made adapter was designed, manufactured and used to facilitate engagement of the screw by its driver.
- An instron machine was used to push-out the screw and provide measurement of the push-out strength. (Figure 4a-c)

- A total push-out force of 2000 N in the rate of 100 N/min was used.
- Measurements were recorded and statistically analyzed.

Figure 1: Proposed designs and actually manufactured dental implant models.

a) The standard V-shaped thread design
b) The buttress thread design.
c) The reverse-buttress thread design.
d) The trapezoid thread design.
e) The manufactured standard V-shaped thread implant.
f) The manufactured buttress thread implant.
g) The manufactured reverse-buttress thread implant.
h) The manufactured trapezoid thread implant.

Figure 2: The composite bone model dimensions, and prepared osteotomy: (a) The compact and cancellous bone samples width and length were equally set to 20 mm. The cancellous bone sample thickness was 20mm. (b) The compact bone samples thickness was 1.5mm. (c) Assembly of the composite bone model parts. (d) Drilled osteotomy.

Figure 3: Designing and manufacturing a holder to support the samples during testing.

a) Diagrammatic illustration of the implant holder.
b) The holder base.
c) The indenter.

Figure 4: The Instron machine push-out testing of the proposed dental implant design.

a) General view of the Instron machine.

b) General view of the push out attachment.

c) Close up on the push-out rod and the implant bone complex.

Results

Mechanical push-out testing of the proposed dental implants with different thread designs.

Figure 5 presents the paired T test statistical analysis of the axial push-out test results for the four different thread designs tested, V-shaped (V), buttress (B), reverse buttress (RB) and trapezoid (T)

- $^{a}p<0.01$: The push-out force of type T threads was significantly higher than that of type B threads.
- $^{b}p<0.025$: The push-out force of type RB threads was significantly higher than that of type B threads.
- $^{c}p<0.025$: The push-out force of type T threads was significantly higher than that of type V threads.
- $^{d}p<0.05$: The push-out force of type RB threads was significantly higher than that of type V threads.
- $^{e}p>0.05$**:** there was no statistically significant difference between the push-out force of the T and RB threads.

Figure 5: The axial push-out test results for the four thread designs tested. V-shaped (V), buttress (B), reverse buttress (RB) and trapezoid (T).

Discussion

Pulling or pushing the titanium dental implants entirely out of the bone was not necessarily the ideal test condition as this type of test, it is possible that 'end effects' could affect the results. If one end of the implants are wider or rougher than the rest they can resist total pull or push-out more than if they were uniform. Shirazi-Adl., *et al*, [26] found that material arrangements and boundary conditions can substantially alter the pullout force. Thus, comparisons of results of pushout tests with different design arrangements should be approached with caution. On the other hand, Berzins., *et al*, [27] found that the interface shear modulus was significantly affectedly the length of the implants, but the ultimate fixation strength was unaffected by implant diameter and length in the range studied.

The dental implant design utilized in this study had a 15 mm length which was chosen as it was reported that implants shorter than 10mm had a higher probability of failure than those longer than 10mm [1,2] However, there was a limitation on the maximum allowable implant diameter to avoid dehiscence in a clinical situation of narrow edentulous ridges, [3] this kept the diameter of the implants used in this study to 3.5 mm. A controversy existed regarding the shaft shape, an axial load is translated to the bone purely as a shear force with cylindrical shafts, whereas as a tapered type screw transmits a smaller shear force while adding a compressive force, [4-6] this can be a logic conclusion; however, it does not take into consideration the presence of the threads which disrupts the shear at the interface to varying degrees depending on its geometry. Accordingly, choosing the prober shape of threads together with a cylindrical shaft can yield a better stress distribution. Moreover, using a parallel sided shaft shape facilitated the manufacturing process for the implants used in this study, and eliminated the need for specific requirements of the drills used.

Thread Pitch used in this study was 0.75 mm. some studies claimed that increasing the thread density and count both improve the bone/implant contact within cancellous bone [5,6,14] however, further studies should be conducted to determine the minimal critical level the thread can reach before turning into the micron scale.

The main function of the foot of the screw is both to guide the rest of the screw into the hole and to ensure that the screw can make progress. Accordingly, a round apex with 3 cutting flutes were used for the foot design. As the thread cutting system removes material, the debris gets carried along in the cutting flute cavities. The bone debris is rich in BMPS and other naturally located growth factors that can help in bone formation and remodeling [10-13].

Finally, though the reverse buttress threads had a similar axial push-out resistance to the trapezoid threads, this study concluded that a trapezoid thread will always present a larger surface to contact the bone and a statistically significant higher axial push-out resistance than the triangular "V" or buttress threads.

Conclusion

Since the insertion torque values for the T threads are generally known to be significantly higher than those of the other forms of studied threads, the trapezoid threads prove a positive relationship between insertion torque and axial push-out resistance of dental implants during destructive mechanical testing in ex-vivo natural bone samples.

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Declarations of Interest

None.

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