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Role of Thread Geometry in the Compressive Strength of Dental Implants

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Abstract:

The objective of this study was to evaluate the effect of different dental implant thread geometries on the compressive strength of dental implants. Based on thread form, sixty custom-made grade 4 titanium dental implant screws were prepared and grouped into; V-Shape (Group 1), Square Shape (Group 2), Buttress Shape (Group 3), and Reverse Buttress Form (Group 4); Standard lab analysis set up as recommended in ISO14801. The implants were embedded in an acrylic block and tested under a 30 °off-axis compression load. The compressive strength test was carried out using a Universal Testing Machine (UTM). The resulting data were analyzed by one-way ANOVA followed by Tukey's test. The results showed that Group 1 (V-Shape) was found to be statistically significantly higher than Group 2 (Square Shape Threads) and Group 3 (Buttress Thread Shapes). Group 4 (Reverse Buttress Shapes) was found to be statistically significantly higher than Group 2 and Group 3. There is no statistically significant difference between Group 2 and Group 3 ($p>0.05$). There is no statistically significant difference between Group 1 and Group 4 ($p>0.05$). The results of this study suggest that various thread designs may play a critical role in the fracture load of implants under static load, where the reverse buttress and V-shape thread designs show better resistance than the other shapes.

Keywords: *Dental Implants; Thread Shapes; Compressive strength.*

1. Introduction

Long-term clinical success of dental implants depends mainly on osseointegration and the effective transmission of occlusal forces to host alveolar bone. The thread design is aimed to provide not only better initial fixation but also improved load transfer, where axial forces are transformed into compressive stresses at the bone–implant junction. Because bone is more tolerant to compressive stress than to tensile or shear and its complexity increases dramatically the stresses under compressive load, the design of implant threads may influence considerably their strength in compression and overall mechanical behavior when subjected to function loads [1]. How and where those forces are transferred is determined by the particular profile of the thread, be that V-shape, Square, Buttress or Reverse Buttress. V-shape threads are often used for their self-tapping properties, but square or buttress designs are usually also proposed in theory to transfer more of the occlusal load into advantageous compressive rather than disadvantageous shearing stress [2].

Although numerous forms of designs afford available on the commercial market, there is still a crucial clinical issue that has not been elucidated yet: what impact do these particular changes on geometry generate from an intrinsic compressive strength perspective for implant body. The majority of literature depicts the stress distribution in peri-implant bone, although the structural response of the titanium body to axial deformation or fracture is equally important, especially in posterior areas where chewing forces are a maximum [3]. A cutting thread profile that enhances bone-implant interface but excessively reduces the core diameter or generate a stress concentration points into the metal could cause early failure. It follows that the mechanical limits of such geometries need to be studied under standardized loading conditions, so as to prevent that aesthetic and biological improvements are being achieved at the expense of structural integrity [4].

Hence, there is a demand to understand carefully how geometry of the implant thread affects its compressive strength, an important mechanical property in relation with implant durability since it does not deform or fracture under occlusal forces. Although many studies have been done considering stress distribution through finite element analysis or primary stability in various bone qualities, relatively few looking directly at the axial load capacity of implants with different thread geometries under controlled mechanical test conditions. This knowledge gap restricts the ability of clinicians and industrial developers to make informed decisions on optimal implant design for improved mechanical behaviors and long-term clinical efficiency. Therefore, the research question that was evaluated in this study was whether several dental implant thread designs (V-shape, square shape, buttress shape and reverse buttress form) significantly influence the compressive strength of dental implants. As the null hypothesis, there is no significant difference between two groups in the compressive strength of implant body that has different thread design.

2. Material and method:

Sixty (N= 60) custom made bone level dental implants Ti-GR4 (ASTM F67) [5] ranging in diameter, length (4.1x10 mm), surface roughness, material and body design were tested with four different thread shapes namely V-shape, Square shape, Buttress and Reverse buttress threads under laboratory conditions using test setup equivalent to that recommended by ISO 14801 protocols [6].

The materials utilized in this study, along with their specifications, and manufacture recommendations are listed in Table 3.

Table 1. Implant and Abutment Specifications.

Implant Specification				
Implant thread shape	V-shape	Square shape	Buttress shape	Reverse buttress shape
Diameter	4.1 mm	4.1 mm	4.1 mm	4.1 mm
Length	10 mm	10 mm	10 mm	10 mm
Implant Type	Bone Level	Bone Level	Bone Level	Bone Level
material	Ti-GR4(ASTM F67)	Ti-GR4(ASTM F67)	Ti-GR4(ASTM F67)	Ti-GR4(ASTM F67
Fixture design	Self-taping	Self-taping	Self-taping	Self-taping
Surface treatment	SLA	SLA	SLA	SLA
Surface roughness	1.8µm	1.8µm	1.8µm	1.8µm
Thread depth	0.44 mm	0.44 mm	0.44 mm	0.44 mm
Connection type	Conical	Conical	Conical	Conical
Abutment Specifications				
Material	Ti-GR5 (Ti–6Al–4V alloy)			
Gingival hight	4 mm			
Diameter	5 mm			
Torque	30 Ncm			
Lot no	PAD50GH4M18191004			

The 60 implant specimens were divided according to shapes of implant threads into four different groups as follow; Group #1: V- Shape Thread Implant Design (n=15). Group #2: Square Shape Thread Implant Designs (n=15). Group #3: Buttress Shape Thread Implant Designs (n=15). Group #4: Reverse Buttress Shape Thread Implant Designs (n=15).

The specimens were oriented vertically along the center of an acrylic resin block (Orthodentic Base Polymer Self-Cure Acrylic Resin) (Ref No: 0254), with a modulus of elasticity greater than 3 GPa According to the standard methods described in ISO 14801 and in order to keep the gap between the resin platform and top of implant fixture (apical from nominal bone level) at 3 ± 0.1 mm in order to simulate clinical bone loss.

A common titanium straight abutment by gingival height of 4mm and diameter of 5mm was connected to each implant specimen with a screw torque being at about 30 Ncm, according to the manufacture instructions, by means of using torque ratchet. In the surface of each specimen. A 5mm diameter hemispherical Cobalt-Chromium Alloy Crown was cast and seated onto an abutment of each specimen by using Zinc Phosphate Cement (Roorkee LOT#. ZP0802) and cap, this structure referred to as the "cap", Compliance with the specifications: The cap was suitably made up in accordance with prescribed requirements. An 11 mm separation between the simulated bone level and center of sphere of crown (The moment arm that is needed according to ISO 14801 that avoided lateral constraint.

Implant samples all were placed in the center of the resin; they were brought until static (compressing) load. In this study's experiment, a custom-made implant holder was made of stainless steel (Ufuk Kontrol Araçları, Gebze_istanbul) and 30 ± 2° away from the vertical load application according to ISO 14801 requirement regarding specimen holder. Afterwards the acrylic blocks with implant/abutment/crown assemblies were inserted in a testing device. The test fixture together with specimens was mounted 30° angle with the respect to the applied load according to ISO 14801 guidelines.

Compressive test was conducted in an INSTRON Universal Testing Machine (3345, 3345J7324; INSTRON, USA) maintained at the Hard Tissue Laboratory of Yeditepe University Maximum load of 5kN was evaluated using a small Instron tabletop tensile tester. It is suitable for tension and/or compression applications and able to be mainly operated by Bluehill Lite software equipped with this machine. Each test specimens were pre-loaded slightly (0.5N) to ensure that all parts and the acrylic blocks were fully seated prior to each testing session.

Off-axis loading was applied to every implant arrangement with the tensiometer's vertical piston that moved downward at a constant speed of 0.5 mm/min and 30° oblique force as prescribed by ISO 14801 standard, on the hemispherical cap of each implant, using flat indenter until either specimen breakage or indicating decrease in force (deformation) by the testing machine. The test didn't stop until the implants broke (some tests stopped with a bent implant), testing machine automatically stopped working when there was a sudden drop in specimen force.

Statistical analysis

Statistical analysis Data were analyzed with IBM SPSS 22.0 statistical package program and presented as the mean and standard deviation. Normality of quantitative data distributions were examined using the Shapiro-Wilk test. The parameters are compared between groups according to their normal distribution by the one-way ANOVA test, and difference is determined with Tukey HDS test. A p-value less than 0.05 was considered statistically significant.

3. Results:

The data were displayed as Minimum-Maximum loads (max) and as mean standard deviations (SD). One-way ANOVA test was utilized for the intergroup comparisons of parameters with normal distribution and Tukey HDS test was utilized for the determination of the group causing the difference. Statistical significance was accepted as $p<0.05$. In this study, V-Shape Threads applied samples are named as "Group 1", Square Shape Threads applied samples "Group 2", Buttress Thread Shapes applied samples "Group 3", Reverse Buttress Shapes applied samples are named as "Group 4". The mean and SD of Maximum Loads (N) was 482,38±45 in V-Shape Threads (Group 1), 422,08±41 in Square Shape Threads (Group 2), 407,95±46 in Buttress Thread Shapes (Group 3), and 484,53±57 in Reverse Buttress Shapes (Group 4). (Table 2). According to the results of the one-way ANOVA test, there are a statistically significant difference between the groups in terms of Maximum Loads (N) levels (p:0.000; $p<0.05$).

Table 2. Evaluation of the compressive strength of the groups in terms of maximum Load (N)

	Mean±SD
Group 1	482,38±45
Group 2	422,08±41
Group 3	407,95±46
Group 4	484,53±57

*p<0.05.

As a result of post hoc analysis, the fracture resistance of Group 1 was found to be statistically significantly higher than Group 2 and Group 3 (p_1:0.007; p_2:0.001; $p<0.05$). Group 4 was found to be statistically significantly higher than Group 2 and Group 3 (p_1:0.005; p_2:0.001; $p<0.05$). There is no statistically significant difference between Group 2 and Group 3 ($p>0.05$). There is no statistically significant difference between Group 1 and Group 4 ($p>0.05$). (Figure 1)

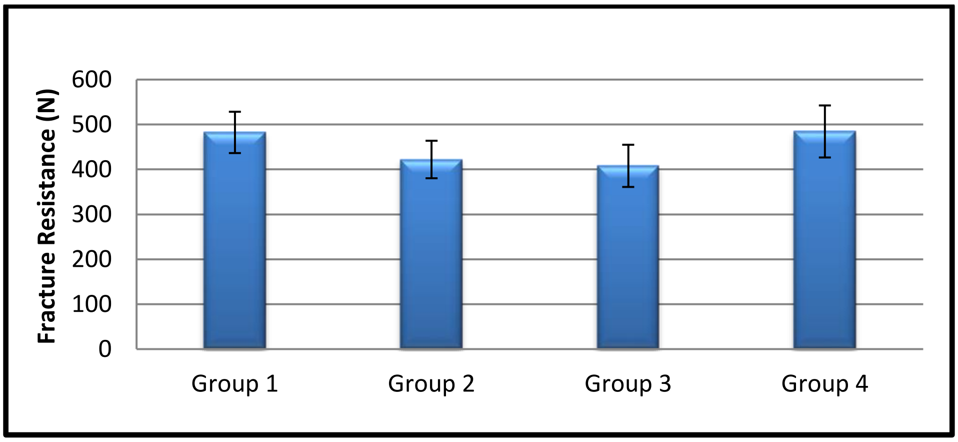

Figure 1. Bar Chart Illustrates the Mean of Maximum load (N).

4. Discussion:

The utilization of dental implants in the treatment of partial and full edentulous patients has made it feasible to restore function into the stomatognathic system. while preserving dental tissues and the longevity of the treatment. Because of the high efficacy, dental implant has frequently been used as a treatment modality in many patients [7].

Global implant survival rates in implants placed in partially edentulous portion after 3-7 years of loading are presented at 95.3% [8]. Nevertheless, and perhaps not surprisingly many problems exist with dental implants which appear to be encountered and dental surgeons need to be aware of in order to prevent additional biomechanical complications and implant failure [9]. These issues may be disengagement or fractures of the prosthesis and abutment screws and implant fractures [7]. Of all mechanical failures, implant fractures are considered the most annoying as they may occur after functioning over time. Implant Fracture The incidence of implant fracture varied significantly (0.0% to 3.45%) in the available literature [9].

Four front thread forms of screw-retained implants were used in this study: V-shape thread, square shape thread, buttress thread form, and reverse buttress thread form (defined according to the thickness of the threads and face angle) [10]. Misch *et al.* has described certain functions of threads; to enhance the resistance to initial contact, increase the surface area for functional use, add stability, and allow for dispersions and there have been other types distribution of stress in the zones of interfacial alongside suitably modified pitched-threads [11]. Steigenga *et al.* observed that both V-shape and reverse buttress threads exhibited similar stress figures, while square threads endured much lower stress in compression and, more importantly, shear forces [12]

By the other hand, posterior to initial healing the square thread has higher values of reverse torque when compared with V-shaped and reverse buttress screws [13]. The high level of stress is mainly transmitted through the implant surface of the thread valley, which decrease/stresses bone at this interface, that could favorably contribute to osseointegration and be advantage for threaded implants with improved bone-implant contact. By the way, there was more areas of low interfacial stress at the implant location in trabecular bone for the square thread compared to a triangular thread [13].

Triangle thread forms and straight–body forms, compared to non-threaded implants, square thread forms and tapered body form all showed higher maximum tensile and compressive stress by Rismanchian *et al.* [14]

A similar study was performed by Eraslan et al. [15], but with 4 different thread forms and a 100 N static axial load. The study found that the highest average stress was contained in cortical bone of cervix region around proximal thread Take square type Th least induced stress. At the same time, earlier FEA and animal experiments demonstrated that square thread shape results in effectively stress distribution and bone–to–implant contact area (BIC) [15–17].

At present, very little work has been done regarding the influence of implant thread design upon the overall strength of an implant and no direct comparisons between different available designs exist in literature. The purpose of this study was to compare and assess the impact of various dental implant thread shapes on fracture resistance.

The null hypothesis was rejected when we found significant differences in the compressive strength among various dental implant thread forms. Groups 4 (reverse buttress) and Group 1(V- shape threads) has statistically significant higher strength in the static load test than both square thread & buttress threads designs. V-shaped and reverse buttress normally have a face angle of 30 and 15 degree which has been shown to create more shear force at the interface than square threads that present no real face angles and thereby lowest shearing power from among the group. The axial loads transmitted by the v-threaded and reverse buttress threads are primarily a combination of compression, tension and shear [11]. This finding was consistent with Bumgardner *et al*. [13] that demonstrate altering the face angles may affect forces at the implant to bone interface. Small face angles type of facesolve.com tend to raise the tensile and compressive kind forces while an increase in the face angles has been shown to increase the shearing kind forces at implant to bone interface. This concept is observed to take place any of the thread shapes of their group. These shearing stresses have been observed to ultimately produce even more defects [18].

Additionally the results of this study show that thread macro-geometry has a clear impact on the maximum compressive load to failure of dental implants, with V-Shape (Group 1) and Reverse Buttress (Group 4) designs providing better mechanical resistance than Square (Group 2) and Buttress (group 3). There was no statistically significant difference between Group 1 and Group 4 indicating that elements of these two configurations retain specific structural features which except with less damage to the core during axial load application. On the other hand, as much lower compressive strengths were measured in G2 and G3; these also appear having a higher stress concentration factor or decrease effective area of implant core [18].

The improved behavior of V-shape thread could be due to its geometric advantage in load spread over the flank of screw threads. Wide under the head and to a point, in V-profile forming base of thread that continuously increases in size until thread merges with implant body eliminating trenches that often lead to cut outs or mechanical failure. The observation is consistent with biomechanical theory that shows that L or rounded interfaces create a lower level of stress intensity factor than sharp, perpendicular interfaces. In the same manner, the structure of Reverse Buttress with subtle angled load-bearing face is apparently able to offer a sturdier structural configuration that withstands deformation from high-magnitude compressive forces and hence reminiscent the strength characterizes V-shape and traditional designs [11].

In comparison, the Square and Buttress thread types had decreased compressive strength values. In Square, the 90-degree angles of the thread-to-core junction result in high stress-concentration areas. When the corners are compressed, they serve as crack initiation regions. Also, to accommodate the broad flat abutment geometry of a Square, or rectangular Buttress thread and have some similarity of outside diameter the inner core on many implant designs has been reduced. Compressive strength is directly proportional to the cross-sectional area of the core, and this decrease in value clarifies the decreased load-bearing capacities by groups 2-3. The statistical equivalence of these two groups indicates that both geometries exerted equivalent mechanical sacrifices on the titanium base [13].

These findings draw attention to a fundamental compromise in implant design, although Square and Buttress threads are frequently promoted in clinical studies as facilitators for increasing the bone-to-implant interface and minimizing stress in the surrounding bone, they may also inherently compromise the integrity of the implant's central section. In these cases, a thread design such as V-shape and Reverse Buttress may be more appropriate to avoid fatigue-related fractures, particularly in patients presenting higher occlusal loads (e.g., bruxism patient or posterior mandible rehabilitation). Further investigation of internal stress vectors that form and results in the failure patterns we identified will also require FEA (Finite Element Analysis) for future studies.

In conclusion, the present study shows that dental implant thread macro-geometry has a significant effect on structural load-bearing capacity rejecting the null hypothesis. Statistically higher compressive resistance of the V-Shape (Group 1) and Reverse Buttress (Group 4) designs compared to the Square and Buttress type might be attributed to a more robust core diameter, leading to lower stress at thread-core junction. Although Square and Buttress designs are commonly employed to maximize load transfer between the surrounding bone, considering this evidence they may contribute as a limiting factor this effect in the implant body. Thus, in the presence of high masticatory loads, V-shape or Reverse Buttress profiles could be preferred in clinic to increase the implant mechanical resistance and prevent fatigue.

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