Implant-Abutment Interface: A Comparison of the Ultimate Force to
Cause Failure between Small Diameter Implant Systems.

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Abstract

Limited available alveolar ridge bone or space deficiencies are some of the challenging scenarios, which led to the development of the narrow diameter implants. Several dental implant companies have developed narrow diameter implants with different designs. Clinicians often have concerns about the durability and function of the narrow diameter implants. The purpose of this study was to explore and compare the ultimate failure resistance of the smallest diameter of the two-stage type implant provided by five commonly used dental implant systems. Thirty implants (Astra OsseoSpeed 3.0mm and 3.5mm (Astra Tech AB, Mölndal, Sweden), Straumann Bone Level 3.3mm (Straumann AG, Basel, Switzerland), Zimmer Tapered Screw-Vent 3.7mm (Zimmer Dental Inc., Carlsbad, CA, USA), Biomet 3i Full OSSEOTITE Certain 3.25mm (Palm Beach Gardens, FL, USA) and Noble Biocare Speedy Replace 3.5mm (Gothenburg, Nobel Biocare, Sweden)), five from each type, were tested in this study. A rigid clamp was used to hold the implants in a 30-degree angle to the static load vector. Load continued until the sample broke or obviously deformed. Peak loads were recorded at that point for all the studied implant systems. The mean fracture/deformation peak load values were 367.2 N, 568.8 N, 576.2 N, 802.8 N, 679.0 N and 553.4 N respectively. Generally, implants with larger diameters showed higher amount of load to failure, in comparison to narrower diameter implants. Ti-Al-V alloy implants generally took more force to cause failure than CP Ti implants. As always, laboratory results should be verified by clinical trials.
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Chapter 1

Introduction

Most implant systems are composed of an endosteal part which is in bone and an abutment which attached to retain or support the dental prosthesis. (1) Dental implant research has been mostly focused on improving the rate and quality of osseointegration. However, implant failures also happen, even after successful osseointegration. Fractures occurring at the implant or the implant-abutment interface are often reported. (2, 3) These failures could be simple as abutment screw loosening and breakage or abutment stripping and breakage. On the other hand, it could be an even more catastrophic failure if the implant body broke or stripped. Implant breakage or stripping is very difficult to correct clinically. (3-5) The implant must be completely removed; creating an often-large bony defect that might affect the adjacent vital structures.

Placement of successful dental implants is influenced by the quality and quantity of the supporting bone. The dentist also has to keep in consideration the dimensions of the edentulous span and the proximity of vital structures during the prosthetic and surgical treatment planning. Frequently, the implant site requires preparation, such as ridge augmentation and/or sinus membrane elevation, prior to implant placement. (6, 7) Cases with inadequate edentulous space require adjunctive orthodontic teeth movement to provide the space for dental implant (6). These clinical necessities can increase morbidity, duration, and cost of dental implant as a treatment option.
Dental implant companies have developed narrow diameter implants to bypass some of these obstacles. (7) Small diameter implants have been advocated for cases with limited inter-radicular space, thin ridges and narrow teeth replacement, such as mandibular incisors and maxillary lateral incisors. However, clinicians have bypassed these recommendations and have started placing the small diameter implant whenever there are space limitations or horizontal ridge deficiency. Clinically, mechanical complications may increase with single small diameter implants placed to restore teeth under increased occlusal forces. The durability and success rate of small diameter implants are supported by limited number of case reports. (8-11) However, incidences of implant fracture are also reported in these reports. Berglundh et al. reported that implant fractures represent 5% to 20% of the lost implants during function. (12) Other studies claimed that narrow diameter implant are more prone to crestal bone loss due to stress concentration as demonstrated by finite element analysis. (13) This bone resorption may compromise the crown height space and place the implant at higher risk of fracture.

Earlier studies have compared the fracture strength and failure modes of the regular diameter implants. These studies were performed on different implant systems under variety of load application modes. (5, 14) One study found a significant decrease in the implant strength, as the implant diameter was reduced. It was reported that a 3.75mm implant was three times weaker than 5mm implant and six times weaker than 6mm implant. (15)

The diameter of narrow implants range from 3.0mm to 3.5mm. They are also available as a one piece, combination of the implant and abutment. Two-piece implants have a
separate implant to which the abutment is connected via a small screw. The one piece implants are may be stronger than the two pieces systems, because they have a integral one piece without any connection, but little data is available to support this claim.(16) Likewise, there are several situations that indicate the use of the two-piece systems in order to correct the emergence profile and the crown angulations. In such cases, the strength of the narrow implant-abutment interface is very critical and should be investigated. Also, the effect of bone loss around the implant on the overall strength of the system has not been evaluated.

Fatigue testing is considered to be the most accurate test to produce data of clinical relevance. (17) However, according to general engineering principals and laws of mechanics, using static loading tests can also generate clinical relevant data(18). The fatigue limit and the ultimate tensile strength of both titanium and titanium alloy are related.(19) Previous studies have estimated that an average individual makes about $10^6$ chewing cycle per year.(20) Under fatigue testing, titanium and titanium alloy spacemen fracture approximately after $10^6$ load cycles at 50% of the ultimate force required to break the same specimen under static loading. Previous studies and laboratory investigation have demonstrated this relationship between titanium ultimate fracture/fatigue strength.(18)
Chapter 2

Materials and Methods

Six commercially available implant designs from 5 companies were subjected to laboratory analysis. Five Astra OsseoSpeed 3.0X13mm implants (“Astra 3.0”) with 4.0X2mm TiDesign abutments (Astra Tech AB, Mölndal, Sweden) five Astra OsseoSpeed 3.5X13mm implants (“Astra 3.5”) with 4.5X2mm TiDesign abutments (Astra Tech AB, Mölndal, Sweden), five Biomet 3i Full OSSEOTITE Certain 3.25X13mm implants (“3i”) with straight 2.0mm Certain internal connection abutments (Biomet 3i, Palm Beach Gardens, FL, USA), five Noble Biocare Speedy Replace 3.5X13mm implants (“Noble”) with NP esthetic abutment (Gothenburg, Nobel Biocare, Sweden), five Zimmer Tapered Screw-Vent 3.7X13mm implants (“Zimmer”) with 1mm cuff height straight Hex-Lock Contour abutments(Zimmer Dental, Carlsbad, CA), and five Straumann Bone Level 3.3X14mm implants (“Straumann”) with NC 2mm Abutment (Straumann AG, Basel, Switzerland) were compared (Figure 1). The testing protocol was based on the ISO recommendations, ISO 14801 (Figure 2). Each sample was secured in a rigid clamping device 3.0 mm apically from the normal bone level. The abutments were torqued according to manufacturer’s recommendations.
Figure 1. Experimented implant systems: a) 3i, b) Nobel, c) Zimmer, d) Astra 3.0, e) Astra 3.5 and f) Straumann.

Figure 2. ISO 14801 graphic representation. Figure keys: 1) loading device, 2) nominal bone level (clamp the specimen at a distance 3.0 mm ± 0.5 mm apically from the nominal bone level), 3) connecting part, 4) hemispherical loading member (distance \( l = 11.0 \text{ mm} \pm 0.5 \text{ mm} \) from the center \( C \) of the hemisphere to the clamping plane), 5) dental implant body and 6) specimen holder.
Custom implant holders were fabricated for this research project, (Figure 3). The holder was designed in compliance with the ISO recommendation for specimen holder and was a vice-type holder fabricated from stainless steel. Two aluminum sleeves are placed around the implant and then secured in the vice, (Figure 4). The clamp secured the implants at 30° compared to the vertical axis.

Figure 3. Implant holder

Figure 4. a) Aluminum insert, b) Insert and specimen in the holder.

Figure 5: Chromium cobalt coping
Figure 6: different crown/implant assemblies
Chromium cobalt copings were fabricated to provide a loading surface with equal heights from the level of the rigid clamp; 11 +/- 0.5 mm, to the center of the hemisphere to the clamping plane (Figures 2 and 5). The crown/implant assembly was angled 30° to the vertical axis as seen in Figure 3.

The implants were loaded using an universal testing machine (Model 4204 Instron, Canton, MA). The implant designs were selected and loaded in random order. A small torque of 20 N-cm was applied to the abutment screw prior to commencement of loading to ensure complete seating. Off-axis loading was performed with the vertical piston at a rate of 0.5mm/min. This test was carried out until the implant fractured or underwent obvious deformation after obtaining the peak load value.

Load and displacement values were recorded throughout the loading with Testworks (Software Research Inc., San Francisco, CA) computer software. The data were then analyzed using Microsoft Excel (Microsoft, Redmond, WA). The data were used to create load displacement curves and analyze maximum load levels. Statistical analysis of the mean peak load values was performed using t-test and one-way ANOVA.
Chapter 3

Results

The peak load values of the studied sample are presented in Table 1. The mean peak load and standard deviation values for the studied samples for Astra OsseoSpeed 3.0mm, Astra OsseoSpeed 3.5mm, Biomet 3i Full OSSEOTITE Certain 3.25mm, Noble Biocare Speedy Replace 3.5mm, Zimmer Tapered Screw-Vent 3.7mm and Straumann Bone Level 3.3mm were 367.20N (SD 98.05N), 568.80N (SD 85.24), 679.00N (SD 81.09N), 553.40N (SD 56.96N), 802.80N (SD 134.50N) and 576.20 N (SD 71.45N), respectively (Figure 7).

Zimmer Tapered Screw-Vent 3.7mm provided the most resistance to failure loads followed by Biomet 3i Full OSSEOTITE Certain 3.25mm, with no statistically significant difference between them (p=0.05). Significantly, Astra OsseoSpeed 3.0mm was provided the least resistance to failure loads among the studied groups. The mean peak load values of Straumann Bone Level 3.3mm, Astra OsseoSpeed 3.5mm and Noble Biocare Speedy Replace 3.5mm implants were statistically below Biomet 3i Full OSSEOTITE Certain 3.25mm, but with no significant difference among those groups (P=0.05 one-way ANOVA).
Table 1: peak load values

B= Broken Implant  D= Deformed Implant

<table>
<thead>
<tr>
<th>Implant System</th>
<th>Peak load for the 1st Specimen (N)</th>
<th>Peak load for the 2nd Specimen (N)</th>
<th>Peak load for the 3rd Specimen (N)</th>
<th>Peak load for the 4th Specimen (N)</th>
<th>Peak load for the 5th Specimen (N)</th>
<th>Average Peak Load (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astra Ø3.0</td>
<td>429\textsuperscript{D}</td>
<td>332\textsuperscript{D}</td>
<td>282\textsuperscript{D}</td>
<td>507\textsuperscript{D}</td>
<td>286\textsuperscript{D}</td>
<td>367.2\textsuperscript{c} (98.05)</td>
</tr>
<tr>
<td>Astra Ø3.5</td>
<td>538\textsuperscript{D}</td>
<td>658\textsuperscript{D}</td>
<td>461\textsuperscript{D}</td>
<td>654\textsuperscript{D}</td>
<td>533\textsuperscript{D}</td>
<td>568.8\textsuperscript{b} (85.24)</td>
</tr>
<tr>
<td>3i Ø3.25</td>
<td>677\textsuperscript{D}</td>
<td>557\textsuperscript{D}</td>
<td>685\textsuperscript{D}</td>
<td>691\textsuperscript{B}</td>
<td>785\textsuperscript{B}</td>
<td>679\textsuperscript{a,b} (81.09)</td>
</tr>
<tr>
<td>Noble Ø3.5</td>
<td>577\textsuperscript{H}</td>
<td>481\textsuperscript{H}</td>
<td>518\textsuperscript{H}</td>
<td>561\textsuperscript{B}</td>
<td>630\textsuperscript{B}</td>
<td>553.4\textsuperscript{b} (56.96)</td>
</tr>
<tr>
<td>Zimmer Ø3.7</td>
<td>657\textsuperscript{D}</td>
<td>979\textsuperscript{B}</td>
<td>679\textsuperscript{B}</td>
<td>836\textsuperscript{B}</td>
<td>863\textsuperscript{D}</td>
<td>802.8\textsuperscript{a} (134.50)</td>
</tr>
<tr>
<td>Straumann Ø3.3</td>
<td>527\textsuperscript{D}</td>
<td>585\textsuperscript{D}</td>
<td>543\textsuperscript{D}</td>
<td>697\textsuperscript{D}</td>
<td>529\textsuperscript{D}</td>
<td>576.2\textsuperscript{b} (71.45)</td>
</tr>
</tbody>
</table>

SD is mentioned in the parenthesis. All same small letters indicate no statistical significant difference.
Figure 7: The peak load values (N): a) Astra OsseoSpeed 3.0mm, b) Noble Biocare Speedy Replace 3.5mm, c) Astra OsseoSpeed 3.5mm, d) Straumann Bone Level 3.3mm, e) Biomet 3i Full OSSEOTITE Certain 3.25mm and f) Zimmer Tapered Screw-Vent 3.7mm.

Implant samples were also evaluated for their mode of failure. Studied implants displayed failures with significant variation. All Noble Biocare Speedy Replace 3.5mm implants were cracked through the collar to the first thread (Figure 8). One of the Biomet 3i Full OSSEOTITE Certain 3.25mm implant was cracked through the collar to the first thread at peak load value of 691N, one had crack between the 2nd and 3rd threads at peak load value of 785N (Figure 9). Three of the Zimmer Tapered Screw-Vent 3.7mm were cracked half away through the collar at peak load values of 979N, 679N and 836N (Figure 10). None of the other implants systems, Astra OsseoSpeed 3.0mm, Astra OsseoSpeed 3.5mm and Straumann Bone Level 3.3mm had any obvious crack after testing. While majority of the deformation occurred in both abutments and implants'
collars, most of the Biomet 3i Full OSSEOTITE Certain 3.25mm had bent between the level of 2nd and 4th threads.

Figure 8. Fractured Nobel Biocare Speedy Replace NP 3.5 implants.

Figure 9. Fractured Biomet 3i Full OSSEOTITE Certain 3.25mm implants.

Figure 10. Fractured Zimmer Tapered Screw-Vent 3.7mm implants.
Figure 11: Deformed implants

Figure 12: Astra OsseoSpeed 3.0mm Load Displacement Graph
Figure 13: Astra OsseoSpeed 3.5mm Load Displacement Graph

Figure 14: Biomet 3i Full OSSEOTITE Certain 3.25mm Load Displacement Graph
Figure 15: Noble Biocare Speedy Replace 3.5mm Load Displacement Graph

Figure 16: Straumann Bone Level 3.3mm Load Displacement Graph
Figure 17: Zimmer Tapered Screw-Vent 3.7mm Load Displacement Graph
Chapter 4
Discussion

Clinicians should always consider the long-term success of treatment. The potential mode of implant failure is important to consider, even at the treatment planning stage. Patients seeking dental implants often ask about the longevity of dental implant supported prosthesis. Dental implant fracture is one of the most common catastrophic long-term failures. Studies show that implant body fracture can be a significant percentage of the long-term failures. Even so, these studies considered mostly the regular diameter implants.(21) The fracture risk may be even higher with a narrow diameter dental implant. There are several factors that influence the resistance of the implant body to fracture. These factors may include the biological loading environment, biomaterial, design and size of the implant. It is generally known that multiple implant supported prostheses have better load distribution and, hence, lower stress concentration at the abutment-implant interface compared to single implant supported crown.(22) This project focused on the ultimate failure strength of narrow diameter implants and crowns combinations.

According to Misch et al, the size of dental implant is considered to be the most important determining factor for the implant resistance to fracture or deformation. Two-piece implants or hollow structures, and fracture resistance are inversely proportional to the radius of the test sample according to the equation:

\[
I (\text{moment of inertia})_{\text{hollow cylinder}} = \frac{1}{4} \pi (\text{radius outer diameter})^4 - (\text{radius inner diameter})^4
\]
Minor changes in the implant diameter could result in significant change in fracture resistance. This fact is very obvious in our study by comparing the mean ultimate failure strength of the Astra OsseoSpeed 3.0mm (367.2N) to Astra OsseoSpeed 3.5mm (568.8N). Increasing the diameter of Astra OsseoSpeed implant by 0.5mm, led to 55% increase in the failure resistance.

![Image of implant abutment connection designs](image)

Figure 18: Implant abutment connection designs: a) Astra OsseoSpeed 3.0mm, b) Biomet 3i Full OSSEOTITE Certain 3.25mm, c) Straumann Bone Level 3.3mm, d) Astra OsseoSpeed 3.5mm, e) Noble Biocare Speedy Replace 3.5mm and f) Zimmer Tapered Screw-Vent 3.7mm.

The implant abutment connection design seems to also significantly influence the ultimate failure resistance of the complex. This design feature includes the geometrical shape of the connecting parts, length of the engaged part of the abutment and the thickness of the thinnest part of the implant collar (Figure 11). The Noble Biocare Speedy Replace 3.5mm abutment connection design seems to significantly diminish the failure
resistance of the system. All Noble Biocare Speedy Replace 3.5mm samples broke, while other systems with the same biomaterial composition, CPT grade 4, showed only deformation without any obvious crack or fracture lines. Those systems include Astra OsseoSpeed 3.0mm and 3.5mm and Straumann Bone Level 3.3mm. It seems that the triangular connection design with the thin rim connection at the apex makes it more prone to fracture compared to the thicker continuous wall in the other systems. Even though the Straumann Bone Level 3.3mm is narrower than Noble Biocare Speedy Replace 3.5mm by 0.2mm, it shows higher level of failure resistance. It is very obvious that the internal connection design of the Noble Biocare Speedy Replace 3.5mm implant inversely overcomes the advantage of increased diameter. The long-term performance of 3.5mm Noble Biocare Speedy Replace single tooth prostheses has not been reported in the literature.

Interestingly, the connection design of Biomet 3i Full OSSEOTITE Certain 3.25mm implant significantly influences the fracture resistance compared to Zimmer Tapered Screw-Vent 3.7mm. Both systems are made of Titanium alloy (Ti-6Al-4V). Even though, the diameter of the 3.25mm Biomet 3i Full OSSEOTITE Certain implant is smaller than 3.7mm Zimmer Tapered Screw-Vent, by 0.45mm, the failure resistance of both systems showed no statistically significant difference (p-value <0.05, and 1-β err prob. =0.47). This observation could be explained by the fact that Biomet 3i Full OSSEOTITE Certain implant collar has a continuous band on the top, without any form of indentation or sharp pointed corners. On the other hand, the sharp corner of Zimmer Tapered Screw-Vent’s internal hexagon and collar may make it easier for the crack to start and propagate. It is noteworthy that the fracture occurred at the Biomet 3i Full OSSEOTITE Certain implant
level, which corresponds to the thinnest cross section between the second and third threads (Figure 12).

![Figure: 19 The thinnest cross section of the 3i implant between 2nd and 3rd thread.]

In addition to the implant size and design, the type of metal used to manufacture the implant must be taken into consideration. The Biomet 3i Full OSSEOTITE Certain and the Zimmer Tapered Screw-Vent implants are manufactured with titanium alloy (Ti-6Al-4V). However, the Astra OsseoSpeed, Straumann Bone Level and Noble Biocare Speedy Replace implants systems are manufactured with grade 4 CP Ti. Titanium alloy has higher level of tensile strength than commercially pure titanium, nearly twice as much (20). The alloy is more brittle, which is reflected in the failure mode pattern of both Biomet 3i Full OSSEOTITE Certain 3.25mm and the Zimmer Tapered Screw-Vent 3.7mm implants. The decreased resistance to failure of the CP Ti manufactured implants could be related to the design, size and material or a combination of them all. Grade 4 CP Ti implants with proper collar design showed ductile deformation, rather than brittle fracture behavior. Given the small diameter of the two-piece implant, the advantage of titanium alloy may reduce its failure potential. However, at least equally important to the
implant size and design, the forces applied in the clinical situation need to be carefully controlled.

Other studies have stated that under fatigue testing ($10^6$ load cycles), titanium and titanium alloy specimens fractured at approximately 50% of the ultimate force required to break the same specimen under static loading. (18) The mean loading force in the human incisal region is approximately $150 - 206$ N (16,21). This range may exceed the 50% mean peak load values of the Astra OsseoSpeed 3.0mm implant. Though this study measures the peak load value at a crown height of 13mm, the clinical situation might also necessitate a crown height of more than 13mm, generating even more clinical load. Clinical crown height space (“CHS”) should be taken in to consideration during the treatment planning stage, because the increased crown height space creates a greater challenge on the clamping force of the joint and preload of the screw. This may have negative effects on the stability of the implant/abutment assembly. Clinically, it is very common to face scenarios with potential increased CHS after extraction of maxillary lateral or mandibular incisors due to buccal plate dehiscence, fenestration or advanced periodontal defects. In those cases, it may be recommended to augment the extraction site, reduce the size of the potential ridge defect and improve the CHS factor, rather than risk immediate implant placement with high potential of compromising the lever arm.

Pedroze et al reported significantly higher ultimate failure strength of the Zimmer Tapered Screw-Vent 3.7mm implant (mean of 1197N compared to 802N) than in this study, most likely because their experiment model was set at 10 mm crown height space. (23) On the other hand, Jacob et al reported significantly lower ultimate failure strength of the Astra OsseoSpeed 3.0mm implant (mean of 187N compared to 367.2N in
this study) most likely because their experiment model was set at 17.5 mm crown height. (16) A shorter crown height space should result in a shorter moment arm and would normally require more force to induce failure. Increased clinical crown height space, especially in periodontally compromised mandibular incisors, is a common scenario. The clinician might consider using the 3.25mm Biomet 3i Full OSSEOTITE Certain implants in areas where heavy forces are expected, but the bone is narrow. The mean ultimate failure resistance, 679N, of this 3.25mm Biomet 3i Full OSSEOTITE Certain implant is well above the average value of the biting force of a normal individual in the incisor area.

Unfortunately, studies on implants of small diameters have produced contradictory results. The research protocols and methods used have been too diverse. Most of these studies used the external hex or Morse taper connection systems, which are outside the scope of this study. (24-30) Moreover, newly published articles recommend the use of mini root form implants (even smaller diameters than studied in this project) for implant supported definitive prosthesis. The rationale behind these recommendations seems to be based on the simplicity, minimally invasive procedures and the claim that the failure causes less bone destruction compared to the normal implant. (31, 32) However, these authors only consider failure to occur when the implant fails to osseo-integrate. Obviously, this is only part of the potential problem. There is also the potential risk of implant fatigue fracture and the associated bone damage in the event that a broken implant portion needs to be trephined out of the bone. Any small-diameter implants should be indicated only after careful evaluation of occlusal forces. Only further
long-term clinical trials will provide information on the specific reliability of small-diameter implants.

Though studies show high biting forces in the incisal region, the implant crown may not be subjected to the same load as the natural dentition. When selecting two-piece, small diameter implants one must pay close attention to the final occlusal scheme. It may make sense that the implant should have light contact in centric occlusion and be equilibrated to avoid premature contact in eccentric movements. MD Gross, recommended flatten or round-out protrusive and working guiding inclines to reduce lateral forces to anterior implants when possible. Using small diameter implants outside of the manufacture’s recommendations and/or with disregard to final occlusal scheme, may put the implant at risk for fracture. This research only dealt with the one element of comparison between two-piece small diameter implants of different companies. Resistance to failure is only one parameter of success. Operator implant positioning, framework fit and patient bite force should also be taken into consideration when selecting implants.

However, given the findings of this research, there may be some concern that long-term use of these two-piece implants, particularly those with small diameters and made from CP Ti, may be at a risk of failure in high stress areas. Careful patient selection and attention to the occlusal scheme should be used when placing small diameter implants. However, if used in the correct setting, the small diameter implants would be expected to withstand normal function. Additional clinical research is needed to evaluate the strength characteristics of the small diameter implants
Chapter 5
Conclusions

Within the limitations of this study, it can be concluded that:

Zimmer Tapered Screw-Vent 3.7mm diameter showed significantly higher amounts of load to failure in comparison to the other groups tested in this study (p-value <0.05). However, no significant difference was observed between Zimmer Tapered Screw-Vent 3.7mm and Biomet 3i Full OSSEOTITE Certain 3.25mm with 3.25 mm diameter (1-β err prob. =0.47). In addition, Astra OsseoSpeed with 3.0 mm diameter showed the lowest amount of load to failure (p-value <0.05) in comparison to the rest of test groups in the current study. No statistical difference was observed between Astra OsseoSpeed 3.5, Straumann Bone Level 3.3mm, Biomet 3i Full OSSEOTITE Certain 3.25mm and Noble Biocare Speedy Replace 3.5mm. Generally, implants with larger diameters showed higher amount of load to failure, in comparison to narrower diameter implants. Ti alloy implants generally took more force to cause failure than CP Ti implants. As always, laboratory results should be verified by clinical trials.
References


