

Effect of Crown to Implant Ratio and Implantoplasty on The Fracture Resistance of Narrow Dental Implants with Marginal Bone Loss. An In Vitro Study.

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Research article

Keywords: Peri-implantitis, Dental implants, Compressive strength, Titanium, Implantoplasty

Posted Date: June 29th, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-37995/v1>

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Version of Record: A version of this preprint was published on November 19th, 2020. See the published version at <https://doi.org/10.1186/s12903-020-01323-z>.

Abstract

Background: Perimplantitis is a biological complication that affects soft and hard tissue around dental implants. Implantoplasty polishes exposed implant surface aiming to decontaminate it and make it less prone to bacterial colonization.

This study aims to analyze macroscopic changes after implantoplasty (IP), whether a higher crown-to-implant-ratio (CIR) reduces implant fracture resistance and if implants are more fracture-prone after IP and in the presence of 50% vertical bone loss.

Methods: Narrow platform (3.5mm) 15mm long titanium dental implants with a rough surface and hexagonal external connection were placed in standardized bone-like resin casts leaving 7.5mm exposed. Half were selected for IP. Macroscopic changes were observed using plain standardized x-rays and ImageJ software. The IP and control groups were each divided into 3 subgroups with different clinical CIR (2:1, 2.5:1 and 3:1). A static load test was performed and scanning electron microscopy (SEM) was used to evaluate failure loads and implant fractures.

Results: IP effect was similar across the sample in all reference points and no perforations were observed. Only 2.5:1 group showed a significant reduction in fracture resistance between the IP and control implants. Significant reductions in mechanical resistance in the 2.5:1 and 2:1 group, compared to 3:1 group, were found.

Conclusions: Our results suggest that implants with higher CIR are more prone to fracture in the presence of 50% vertical bone loss; Fracture resistance does not differ significantly between IP and intact implants and CIR seems more relevant than IP considering implant fracture resistance.

Background

There seem to be several causes of implant failure: biological, mechanical or iatrogenic[1–3]. Peri-implantitis (PI) is one of the major concerns among clinicians, as it may affect 28–56% of patients and 12–46% of implants and lead to implant loss[4, 5].

For implant surface decontamination several approaches have been studied. They include air-powder abrasion, ultrasonic and manual debridement (using plastic, carbon stainless steel, graphite or titanium curettes), implantoplasty (IP), laser therapy and sterile saline rinses, among others[6–9]. Mechanical debridement has also been complemented by the use of several substances, such as: citric acid, hydrogen peroxide, cetylpyridinium chloride, tetracycline, EDTA or chlorhexidine[10].

IP is a common procedure that consists of polishing rough implant surfaces outside the bony envelope, making them less prone to bacterial accumulation as surface roughness may be risk factor perimplant disease. IP is effective in the long term to arrest bone loss caused by PI, both alone and in combination

with surgical regenerative procedures[10–13] and does not seem to be associated with any biological or mechanical complication of importance[14].

Thermal increases during the procedure that could affect the bone; lower resistance to fractures due to reducing the thickness of the implant walls; and the local and systemic biological repercussions that the dispersion of titanium particles might have in the long term have been pointed as potential problems of IP performance[15–20].

Tawil et al.'s[21] definition of anatomical and clinical CIR takes the position of the fulcrum into account. For the anatomical ratio, the fulcrum is at the interface of the implant shoulder and the crown/abutment system, while for the clinical ratio the fulcrum lies at the most coronal bone-implant contact. It is clear that both definitions can represent the same ratio in an early phase, but increasing bone loss due to PI will increase clinical CIR which in turn, reportedly reduces the resistance to fracture of intact dental implants, although CIR between 0.9 and 2.2 has not been associated to high occurrence of biological or technical complications[22]. Implant connection design also seems to affect the overall strength[23] and IP seems to weaken the strength of narrow implants[16] although it has not been linked to increased marginal bone loss or added biomechanical risks in recent publications[24].

The effect of the CIR increase on the strength of dental implants treated with IP has not been addressed yet in any published paper, to the best of the authors' knowledge. Therefore, the aim of this research was to analyze macroscopic changes after IP using the presented protocol, whether an increased CIR reduces the fracture resistance of implants with or without IP, and whether implants subjected to IP are more prone to fracture in comparison with intact implants, regardless of the CIR in the presence of 50% bone loss.

Materials And Methods

An *in vitro* study was conducted using 48 type V titanium narrow platform implants. Similar *in vitro* protocols have been described by previously, although with different implants, bone insertion and loading abutments[16, 23, 25].

The dental implants were 3.5 mm in diameter and 15 mm long, with a rough surface and a hexagonal external connection (Ocean E.C., Avinent Implant System S.L., Santpedor, Spain). Half of the sample was randomly allocated to the IP group. The apical half of each implant was inserted in standardized bone-like resin casts (EA 3471 A and B Loctite®, Henkel AG & Company, Düsseldorf, Germany) with a ≥ 3 GPa modulus of elasticity in accordance with International Organization for Standardization (ISO) standard 14801:2016 (third edition)[26]. The choice for 15 mm long implants related to the resin retention capacity during fracture tests and the 50% exposure of the implant relates to the fact that IP is usually considered safe up to 50% of total implant length. On the other hand, 3.5 mm wide implants were selected exactly because previous reports show that narrower implants must be addressed carefully for IP[16]. The fact is, narrow implants are used widely and vertical bone loss from PI can affect any implant. As such, we found it valuable for understanding the threshold of fracture resistance.

Both groups were divided into 3 subgroups of 8 implants each, which received screwed hemispherical loading abutments of one of three heights: 7.5 mm, 11.25 mm and 15 mm, simulating clinical CIR of 2:1, 2.5:1 and 3:1, respectively (Fig. 1). One may argue that a 15 mm long implant with a 15 mm long restoration is not normal in the clinical practice. This is true, but considering a bone level type implant, represents a standard 1:1 CIR. In the same line of thought, a 10 mm long implant with a 10 mm restoration that, through PI, loses 5 mm vertical bone will go from a clinical CIR of 1:1 to a clinical CIR of 3:1, just like the 15 mm abutment group in this experience.

Implantoplasty

IP of the exposed implant surface was performed using a high-speed air-powered hand piece (Bora Blackline LED, Bien-Air Dental SA, Langgasse, Switzerland) with an abutment protecting the connection. After removing the threads of the exposed portion of the implants, using an oval-shape tungsten carbide bur (H379 314 023; Komet Dental, Lemgo, Germany), the surface was polished with two-step silicon carbide polishers (9618 314 030 and 9608 314 030; Komet Dental, Lemgo, Germany) until it was macroscopically flat and smooth. A new set of burs was used for each sample. The procedure was performed by an experienced surgeon with 2.8x magnification loupes (Galilean HD and Focus™ LED 6000 k, ExamVision ApS, Samsø, Denmark), under copious water irrigation and adequate light conditions, similar to a clinical scenario, although the cast was held by the operator and turned by hand. The time spent on each procedure was recorded. When the IP procedure was finished, the surface was cleaned with water and dried with air.

Macroscopic changes

The macroscopic changes were evaluated through plain x-ray examination of all the samples, in the initial position and rotated through 120° and 240°, using standardized mounts. All the measurements were made using ImageJ v.1.51 (National Institutes of Health, Bethesda, Maryland, USA), based on a fixed 1.9 mm reference provided by the manufacturer. A calibrated investigator performed the examination with 400X amplification. The variables were defined, taking the prosthetic screw hole as the reference (length at the middle of the first and tenth threads and at its end, perpendicularly to the long axis of the implant), as shown in Fig. 2.

The mean value of the three measurements (one for each exposure) was recorded for each variable and sample. The measurements in the IP group were subtracted from those of their control analogues, thus obtaining the thinning of the implant for each variable.

STL files for subtractive analysis of the three-dimensional changes of the implants were not predictable to obtain due to the polished surface of the IP samples.

Fracture tests

Metallic hemispherical load abutments (n = 48) were digitally designed, milled and screwed onto each implant according to group, using prosthetic screws (Avinent® Implant System, Santpedor, Spain) at

32 N/cm, as recommended by the product manufacturer.

Tests in order to find the maximum compression force ($F_{\max}$), *i.e.* maximum force reached before implant fracture, were performed at a constant speed of 1 mm/min with a universal servo-hydraulic mechanical testing machine (MTS Bionix 370 Load Frame, MTS®, Eden Prairie, USA), applying a compression load to the implants with a 661.19H-03 MTS Load Cell of 15kN capacity. All the samples were held in the same device, a manufactured stainless-steel clamping jaw that allowed compression loads to be applied at a constant angle of 30° from the vertical axis (Fig. 3), in accordance with UNE-EN ISO 14801:2016 (third edition) ("Dynamic fatigue test for endosseous dental implants") except for the supracrestal 50% of the total implant length (previously referred to). The tests were controlled by MTS Flextest 40 (MTS®, Eden Prairie, USA), measuring $F_{\max}$ and recording real-time data.

Scanning electron microscopy (SEM) (Quanta 200→, FEI, Hillsboro, Oregon, United States) screening of the fractured implants was used to determine the location of fracture.

Statistical analysis

Previous results[23] were used in the sample size calculation using Stata v.14 software (StataCorp®, College Station, USA). Considering $F_{\max}$ as the primary outcome measure, the analysis of variance with an α risk of 0.05 and a statistical power of 80% aimed to detect the following differences between the means of resistance to fracture according to different crown heights: $\mu_{8\text{mm}} = 1504\text{N}$ $\mu_{10\text{mm}} = 814\text{N}$ $\mu_{12\text{mm}} = 491\text{N}$ $\mu_{14\text{mm}} = 325\text{N}$. Assuming a standard deviation of 500N and groups all being the same size, the sample size was established as 8 implants per group.

The implant characteristics were presented as absolute and relative frequencies for categorical outcomes. The normality of the scale variables ($F_{\max}$ and implant width) was explored using the Shapiro-Wilk test, P-P scatterplot graphs and box plots. Where normality was rejected, the interquartile range (IQR) and median were calculated. Where the distribution was compatible with normality, the mean and the standard deviation (SD) were used.

To analyze the effect on $F_{\max}$ of the procedure (IP or control), the crown length (7.5, 11.25 or 15 mm) and the interaction between these two variables, a two-way ANOVA was performed. The ANOVA assumptions were assessed using the Shapiro-Wilk test for normality and Levene's test for homoscedasticity. Pairwise comparisons between groups, using Tukey's correction for multiplicity of contrasts, were used for each procedure and CIR.

An unpaired *t* test was used to identify differences in implant width between the control and IP groups at every reference point. In each area of interest, Pearson correlation coefficients were computed to quantify the correlation between implant width and $F_{\max}$.

The associations between categorical variables were assessed with either Pearson's χ^2 test or Fisher's exact test.

The statistical analysis was carried out with Stata14 software (StataCorp®, College Station, TX, USA). The level of significance was set at $P < 0.05$.

Results

Macroscopic Changes

The mean reductions in implant width after IP are summarized in Table 1. In all the groups and subgroups, the procedure was associated with a statistically significant reduction in width at reference points 1–3 ($P \leq 0.05$, independent samples t test). More important, a similar amount of change was found at each reference point ($P > 0.05$ in all cases; one-way ANOVA), regardless of the crown length group of the implant.

Table 1
Mean implant diameter (mm) in IP and control samples at each reference point (n = 48)

	Control	IP			
Reference point	Mean (SD)	Mean (SD)	MD (95%CI)	Independent samples t-test P-value	ANOVA P-value
Coronal					
2:1	3.44 (0.02)	3.03 (0.04)	0.41 (0.37 to 0.44)	< 0.001*	0.103
2.5:1	3.44 (0.01)	3.03 (0.04)	0.41 (0.38 to 0.45)	< 0.001*	
3:1	3.45 (0.02)	3.08 (0.04)	0.37 (0.33 to 0.40)	< 0.001*	
Middle					
2:1	3.32 (0.03)	2.86 (0.03)	0.46 (0.42 to 0.49)	< 0.001*	0.949
2.5:1	3.31 (0.02)	2.86 (0.04)	0.45 (0.41 to 0.49)	< 0.001*	
3:1	3.34 (0.03)	2.89 (0.06)	0.46 (0.41 to 0.50)	< 0.001*	
Apical					
2:1	3.07 (0.03)	2.62 (0.06)	0.45 (0.40 to 0.50)	< 0.001*	0.163
2.5:1	3.07 (0.05)	2.64 (0.04)	0.43 (0.38 to 0.47)	< 0.001*	
3:1	3.07 (0.02)	2.68 (0.04)	0.40 (0.36 to 0.43)	< 0.001*	
*Statistically significant difference					
MD: Mean difference (Control - IP)					

No correlations were observed between implant wall width and $F_{\max}$ at any of the reference points (Fig. 4) and there was no perforation of the inner threads of the implants.

Static test

Significant reductions in resistance to fracture between IP and control implants were only found in the 2.5:1 CIR group, although all the IP samples showed less resistance to fracture than their respective

controls (Table 2, Fig. 5).

Table 2
Mean fracture strength (N) of the three crown-to-implant ratios in the IP and control samples

	Control	IP		
CIR	Mean (SD)	Mean (SD)	MD (95%CI)	P-value
2:1	1276.16 (169.75)	1211.70 (281.64)	64.46 (-117.17 to 246.09)	0.478
2.5:1	815.22 (185.58)	621.68 (186.28)	193.54 (11.91 to 375.17)	0.037*
3:1	606.55 (111.48)	465.95 (68.57)	140.60 (-41.03 to 322.24)	0.126
Total	899.31 (323.58)	766.44 (379.19)	132.87 (-71.95 to 337.69)	0.198
*Statistically significant difference				
MD: Mean difference (Control - IP)				

In both the IP and control groups, the implants with a 2:1 CIR showed more resistance to fracture than those with 2.5:1 or 3:1. No differences were observed between the 2.5:1 and 3:1 subgroups (Table 3, Fig. 5).

Table 3
Mean fracture strength (N) of the IP and control samples in the three anatomical crown-to-implant ratio groups

Group	Ratio1	Ratio2	MD (95%CI)	P-value
Control	2:1	2.5:1	460.94 (242.27 to 679.60)	< .001*
		3:1	669.60 (450.94 to 888.27)	< .001*
	2.5:1	3:1	208.67 (-9.99 to 427.33)	.064
IP	2:1	2.5:1	590.02 (371.36 to 808.68)	< .001*
		3:1	745.75 (527.09 to 964.41)	< .001*
	2.5:1	3:1	155.73 (-62.93 to 374.39)	.206
Total	2:1	2.5:1	525.48 (363.58 to 687.38)	< .001*
		3:1	707.68 (545.78 to 869.57)	< .001*
	2.5:1	3:1	182.20 (20.30 to 344.10)	< .001*
*Statistically significant difference				
Ratio: Crown-to-implant ratio				
MD: Mean difference (Ratio1 - Ratio2)				
Figure Subtitles				

The effect of IP was similar in each CIR group, meaning that the interaction between group and CIR was not significant (Fig. 5).

Location of fracture

Fracture patterns were apparently similar in the IP and control groups and within each CIR subgroup. However, in the 2.5:1 and 3:1 groups the fractures always occurred in the platform (Fig. 6a, 6b), whereas in the IP group with a 2:1 CIR, 4 of the samples fractured in the implant body (Fig. 6c) and 1 in the prosthetic screw (Fig. 6d).

Discussion

The lower resistance to fracture in the IP group of narrow platform titanium implants with an external hexagonal connection was significant only in the 2.5:1 CIR group. Besides, the mean total values show no significant difference in fracture resistance between the control and test samples (Table 2). CIR seems to be a much more relevant variable than IP since both the IP and the control implants show significant reductions in mechanical resistance in the 2.5:1 and 3:1 CIR groups when compared to the 2:1 (Table 3).

Indeed, while IP reduced the mean fracture strength by 132.87 N, a higher CIR (2.5:1 or 3:1) led to a mean difference of 525.48 N or 707.68 N, respectively. These results are relevant since clinicians must be aware that performing IP in narrow diameter implants with an unfavorable CIR might lead to fractures.

In order to increase the external validity of the study, the pressure, time and number of strokes needed to perform the IP were not standardized.

Surface roughness was not an outcome in this study and has not been addressed, although the IP test and control surfaces were recorded with SEM (Figs. 6e, 6f respectively). Using the same IP protocol, significant differences were reported between the test and control surfaces, with a mean height of 0.1 μm ($\sigma = 0.02$) for tests and 0.76 μm ($\sigma = 0.08$) for controls[25].

With no surprise, significant differences due to the IP procedure were observed at all the reference points in the macroscopic analysis and there was no perforation of the inner threads. The implant diameter at each of the 3 reference points showed a reduction that ranged from 0.37 mm (95% CI: 0.33 to 0.40 mm) to 0.46 mm (95% CI: 0.42 to 0.49 mm) in the IP test samples. Other authors[25] with similar IP protocols have reported lower reductions. These discrepancies might be explained by differences in the degree of polishing, but are more likely to be the result of different implant geometry, namely thread depth and model. Thus, further studies with different implants should be carried out, since their design and material are likely to affect the implant's resistance to fracture.

A similar amount of change was found at each reference point ($P > 0.05$ in all cases; one-way ANOVA), regardless of the crown length group of the implant, thus showing that the implantoplasty was similar across all these groups. These seem to show the procedure to be easy to reproduce.

Previous reports have claimed that implant diameter affects stress fatigue behavior and that when subjected to IP, dental implants will attain a critical stress point at lower loadings[16, 27, 28]. The present results corroborate this finding, as lower resistance to fracture was observed in the IP groups (Table 2). All the IP groups showed less resistance to fracture than the control groups, but this difference proved to be significant only for one of the CIR groups (2.5:1). Hence, narrow platform implants seem to be structurally weakened by IP procedures, although the most relevant risk factor for mechanical complications in the presence of 50% vertical bone loss seems to be CIR, as the mean fracture resistance values dropped to almost half from CIR 2:1 to 2.5:1 (mean difference 590.02N, 95% CI: 371.36N to 808.68N) and by 61.6% from CIR 2:1 to 3:1 (mean difference 745.75N, 95% CI: 527.09N to 964.41N) (Table 3).

In both the IP and the control groups, resistance to fracture decreased with increasing CIR, although the differences were only significant between CIR 2:1 and the other two groups (Table 3). No significant differences were observed between CIR 2.5:1 and 3:1 despite the resistance to fracture of the latter being lower in both the IP and the control implants (Control: 815.22 N vs. 606.55 N; IP: 621.68 N vs. 465.95 N).

In the present study the area mostly affected was the platform, and all the control implants broke at this point, suggesting that the platform is more fragile than the body in narrow fixtures. In the IP group with a

2:1 CIR, some fractures occurred in the body ($n = 4$) and prosthetic screw ($n = 1$), suggesting that IP reduces the mechanical resistance of the implant body. However, when higher CIRs were tested the stress seemed to be directed towards the platform and the prosthetic connection, and therefore all the fractures occurred in this area. Other studies using regular platform implants have found that implants subjected to IP usually break at the implant body, and although IP does not seem to decrease the maximum compression force of regular diameter external connection implants significantly, it clearly weakens the implant body[25].

The present study has some limitations related to its *in vitro* design. Firstly, the IP procedures were performed by hand to simulate real-life conditions, instead of using a milling machine. Although this might compromise the standardization of the implant reduction slightly, it increased the external validity of the outcomes.

In addition, static compressive loads at a 30° angle do not replicate the daily complex oral function of patients[29]. However, the methodology employed complied with guideline UNE-EN ISO 14801:2016 (third edition), allowing comparison with previous studies, except for the implant vertical exposure. Nevertheless, future research should include dynamic fatigue tests to determine the clinical relevance of the fracture resistance.

According to Gibbs et al.[30] the maximum human clenching force covers a wide range, from 98N to 1243N, and is affected by several factors including age, gender and tooth support. The top of this range would fracture all the samples except for the controls with a 1:2 CIR (1276.16N ($\sigma = 169.75$)).

Bite force seems to decrease from molar to premolar and to incisor. Maximum bite forces measured in male subjects are higher than those of female subjects according to Umesh et al.[31]. The same authors found maximum bite forces of 744N in molars, 371N in premolars and 320N in incisors.

Considering these outcomes and comparing them with the present data, IP procedures with an CIR of 2:1 (mean fracture strength 1211.70 N $\pm$ 281.64) would present a low fracture risk regardless of implant position, and fracture risk would be of concern after IP in molar regions with an CIR of 2.5:1 (mean fracture strength 621.68 N $\pm$ 86.28 N) or 3:1 (mean fracture strength 465.95 N $\pm$ 68.57 N).

However, it is important to stress that, although no statistically significant differences were found between IP and control groups with a 3:1 CIR, the mean resistance value of narrow implants in this situation was the lowest (465.95 N $\pm$ 68.57 N). Thus, clinicians should consider doing a risk-benefit analysis in such cases since implant fractures are more likely to occur. Nevertheless, as the Young modulus of different titanium alloys and ceramic implants is variable, further research is needed to determine the resistance to fracture of new materials used for dental implants.

Conclusions

In the test conditions, narrow (3.5 mm) dental implants with unfavorable CIR (2.5:1 and 3:1) are more prone to fracture than with a CIR of 2:1 in the same conditions. Considering the mean total values, and in the test conditions, there is no significant difference in resistance to fracture between implants with and without IP.

Declarations

Consent for publication

Not applicable

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests:

The authors declare non-financial support from Avinent (Santpedor, Spais) for this study. The authors would like to declare the following interests outside the work presented:

BLA reports personal fees (sponsored lectures) and non-financial support from Megagen (Daegu, South Korea) outside the submitted work.

RF reports personal fees (sponsored lectures) from Inibsa Dental (Lliça de Vall, Spain). In addition, has also participated as a sub-investigator in a randomized clinical trial sponsored by Mundipharma (Cambridge, UK) and in another clinical trial for Menarini Ricerche (Florence, Italy).

AC reports personal fees (sponsored lectures) from Straumann (Basel, Switzerland).

JMM reports no conflicts of interest.

OCF reports grants, personal fees (sponsored lectures) and non-financial support from MozoGrau (Valladolid, Spain), and personal fees (sponsored lectures) from BioHorizons Ibérica (Madrid, Spain), Inibsa Dental (Lliça de Vall, Spain), Dentsply implants Iberia (Barcelona, Spain) and Araguaney Dental (Barcelona, Spain) outside the submitted work. He has also participated as a principal investigator in a randomized clinical trial sponsored by Mundipharma (Cambridge, UK) and in another clinical trial as a sub-investigator for Menarini Ricerche (Florence, Italy).

EVC reports personal fees (sponsored lectures) and non-financial support from MozoGrau (Valladolid, Spain), and personal fees (sponsored lectures) from BioHorizons Ibérica (Madrid, Spain), Inibsa Dental (Lliça de Vall, Spain) and Dentsply implants Iberia (Barcelona, Spain) outside the submitted work. In addition, Dr. Valmaseda-Castellón has also participated as a sub-investigator in a randomized clinical trial sponsored by Mundipharma (Cambridge, UK).

Funding:

The present research was conducted by the Dental and Maxillofacial Pathology and Therapeutics research group at IDIBELL and the Center of Interdisciplinary Research in Health of Universidade Católica Portuguesa (Viseu, Portugal) also supported this study with non-financial aid.

Author's contributions

BLA performed all experimental protocol and wrote this paper; RF supervised protocol execution and did critical review; OCF performed statistical analysis; JMM did critical review; EVC did critical review and editing.

Ethical approval:

This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent:

For this type of study, formal consent is not required.

Acknowledgements

The authors wish to thank Anton Galigrov (Compression tests. Industrial engineer at Avinent® Implant System, Santpedor, Spain), the staff of *Centres Científics i Tecnològics* of the University of Barcelona (SEM screening), Mary Georgina Hardinge (English language editing assistance) and Professor Mário Vaz (Critical review. School of Engineering, Oporto University, Portugal).

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Figures

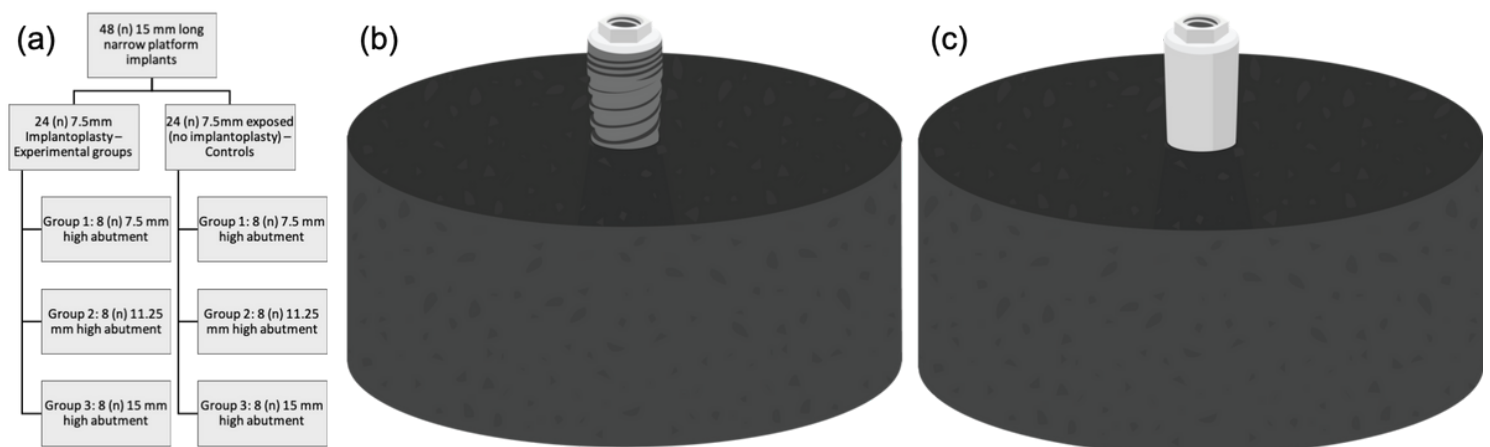


Figure 1

(a) Study design and groups; (b) Sample before implantoplasty; (c) Sample after implantoplasty

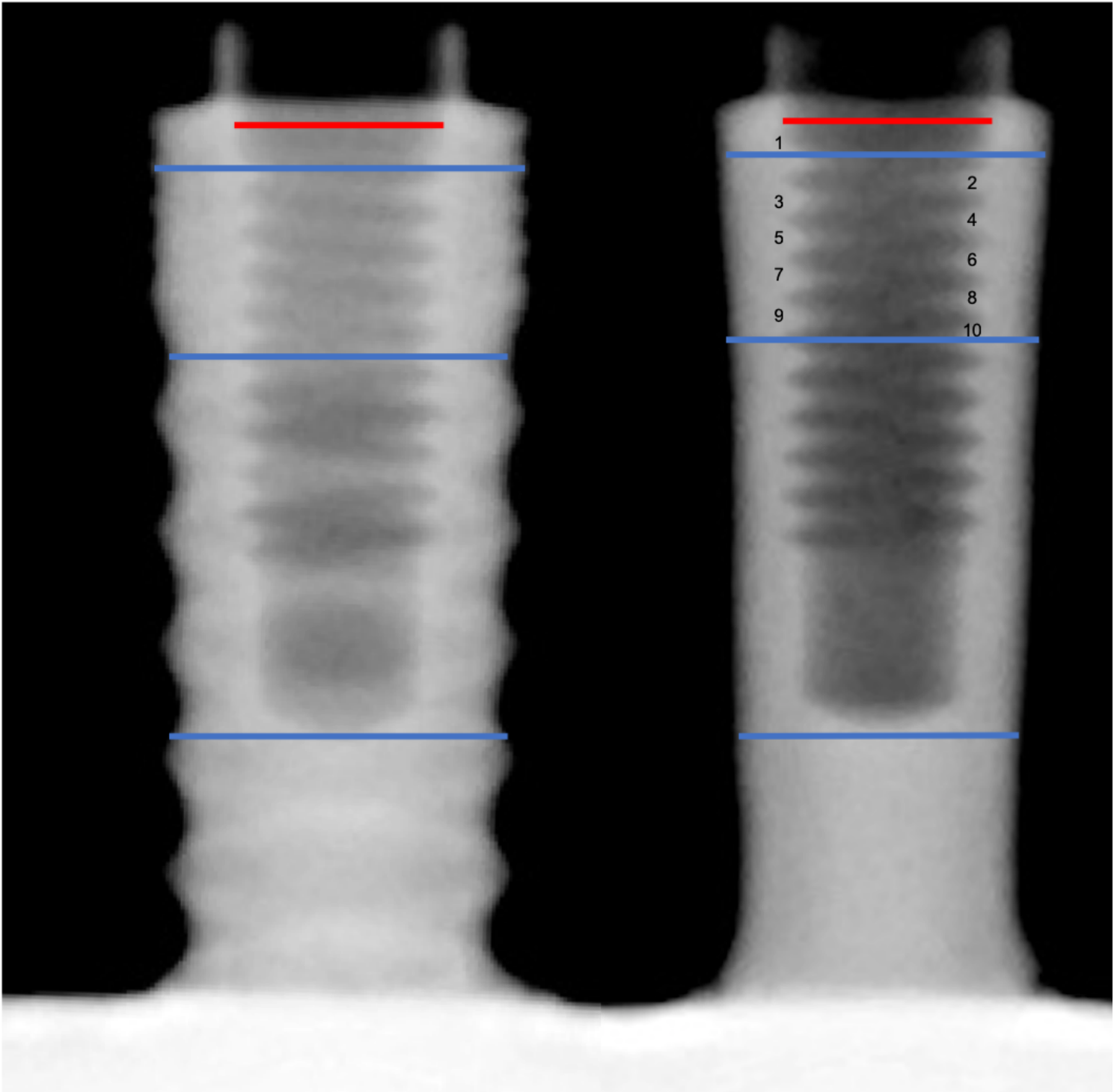


Figure 2

Macroscopic variables Left: control implant; right: IP implant. Blue lines: length at middle of the first and tenth threads and at the end of the prosthetic screw hole, perpendicularly to long axis of the implant; red line: 1.9mm reference

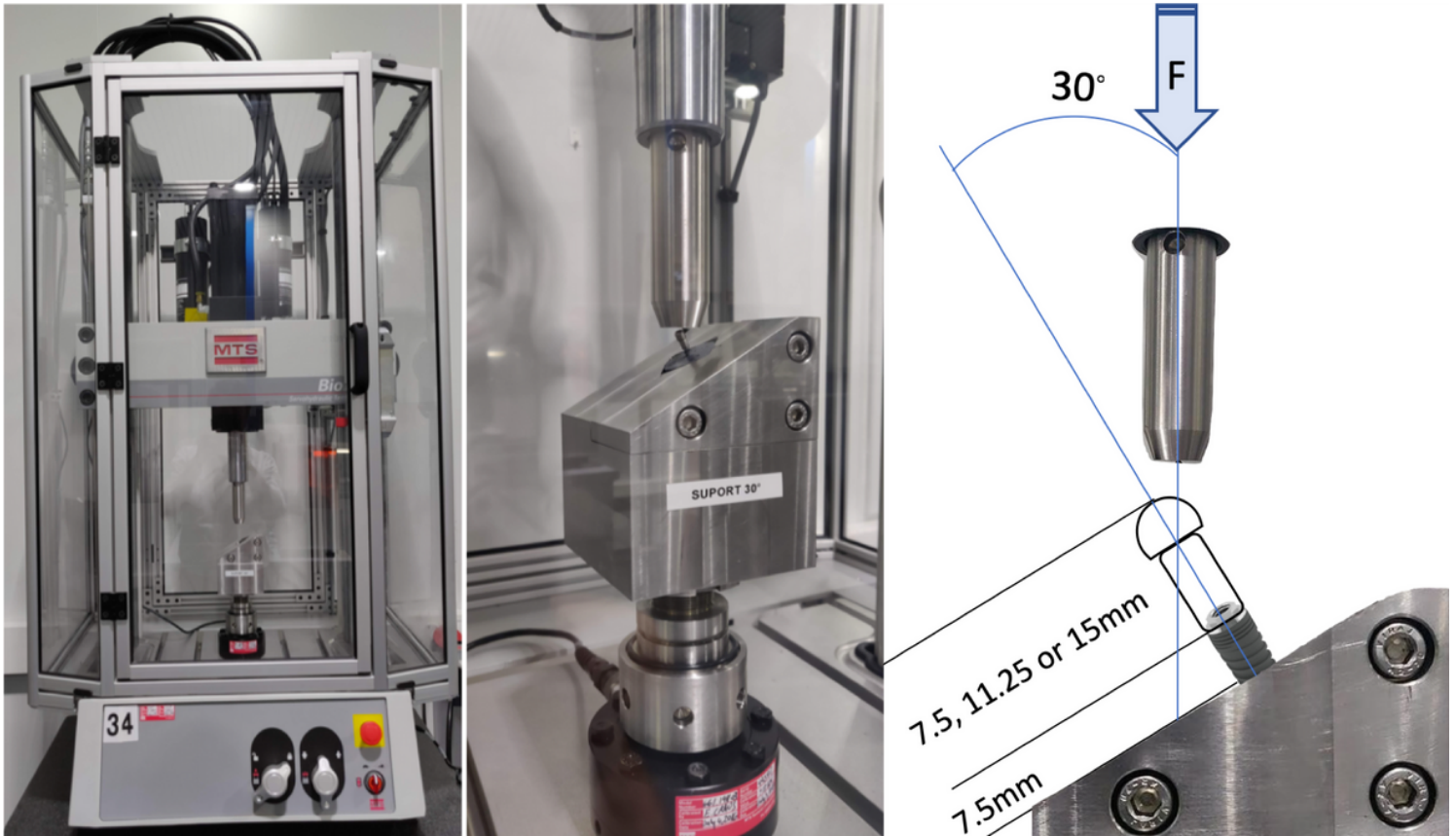


Figure 3

Fracture test equipment and diagram

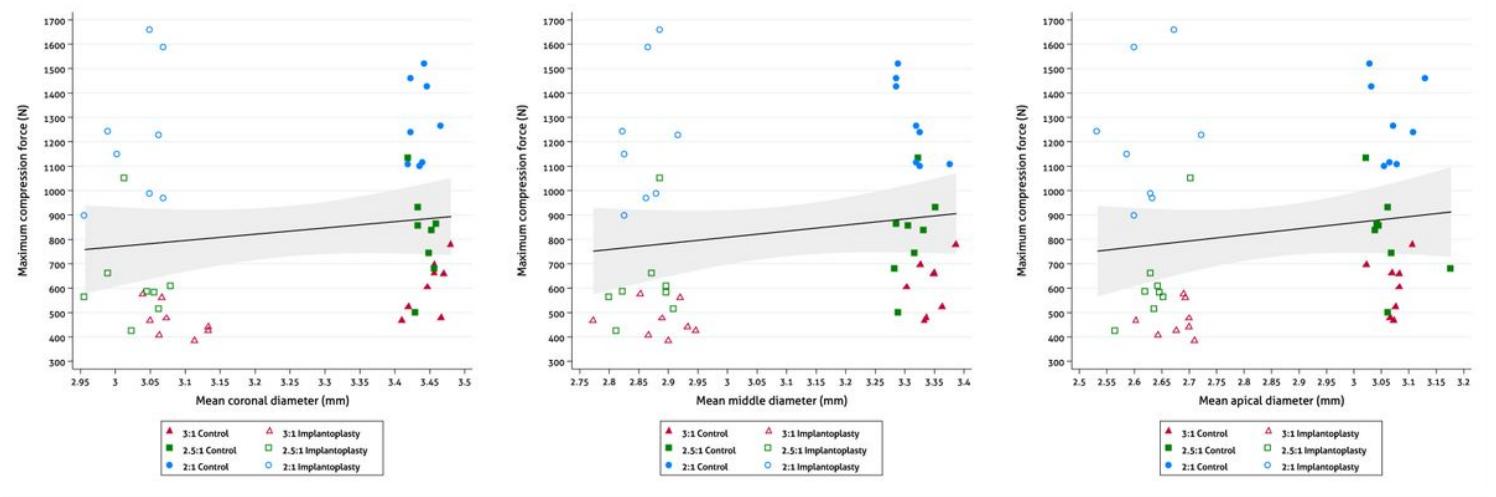


Figure 4

Fracture strength (N) and coronal, middle and apical implant widths of the crown-to-implant ratio subgroups of the IP and control groups

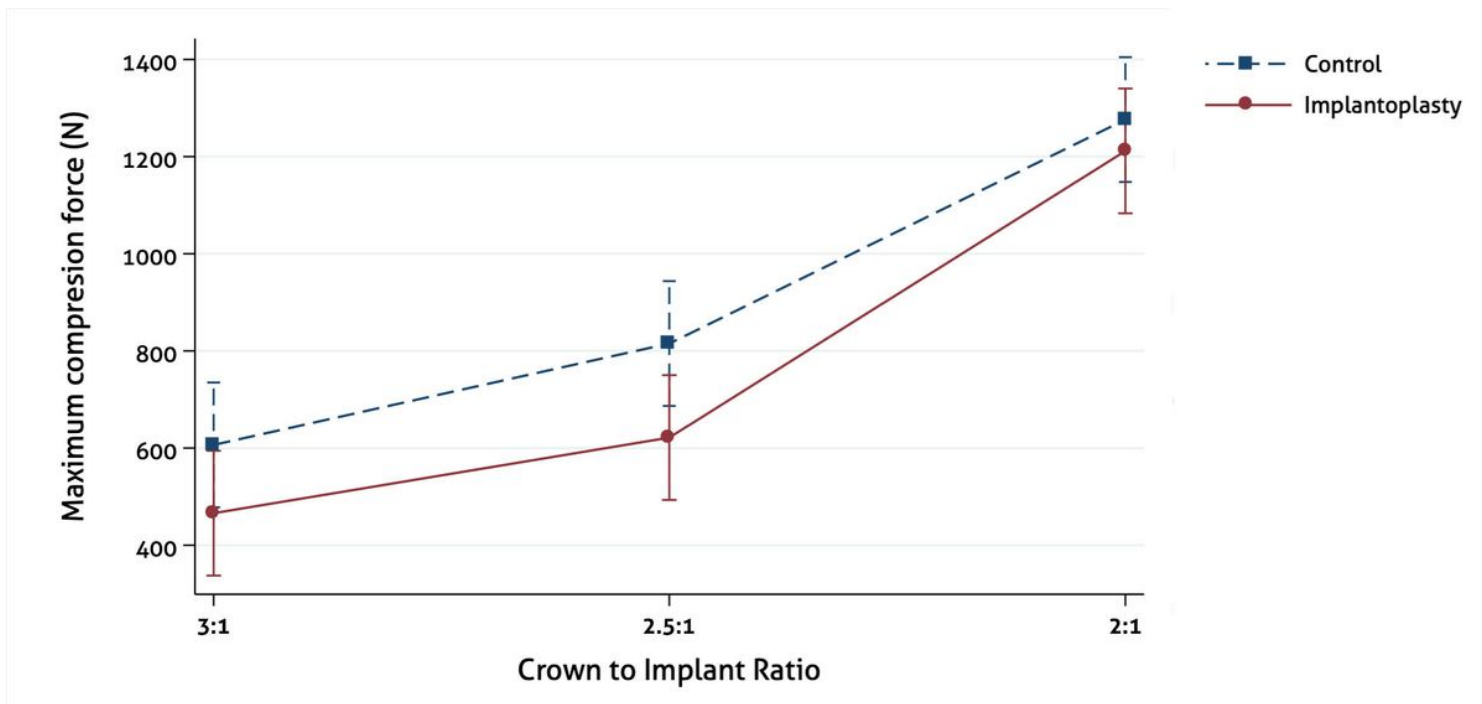


Figure 5

Mean fracture strength (N) of the three crown-to-implant ratios in the IP and control samples

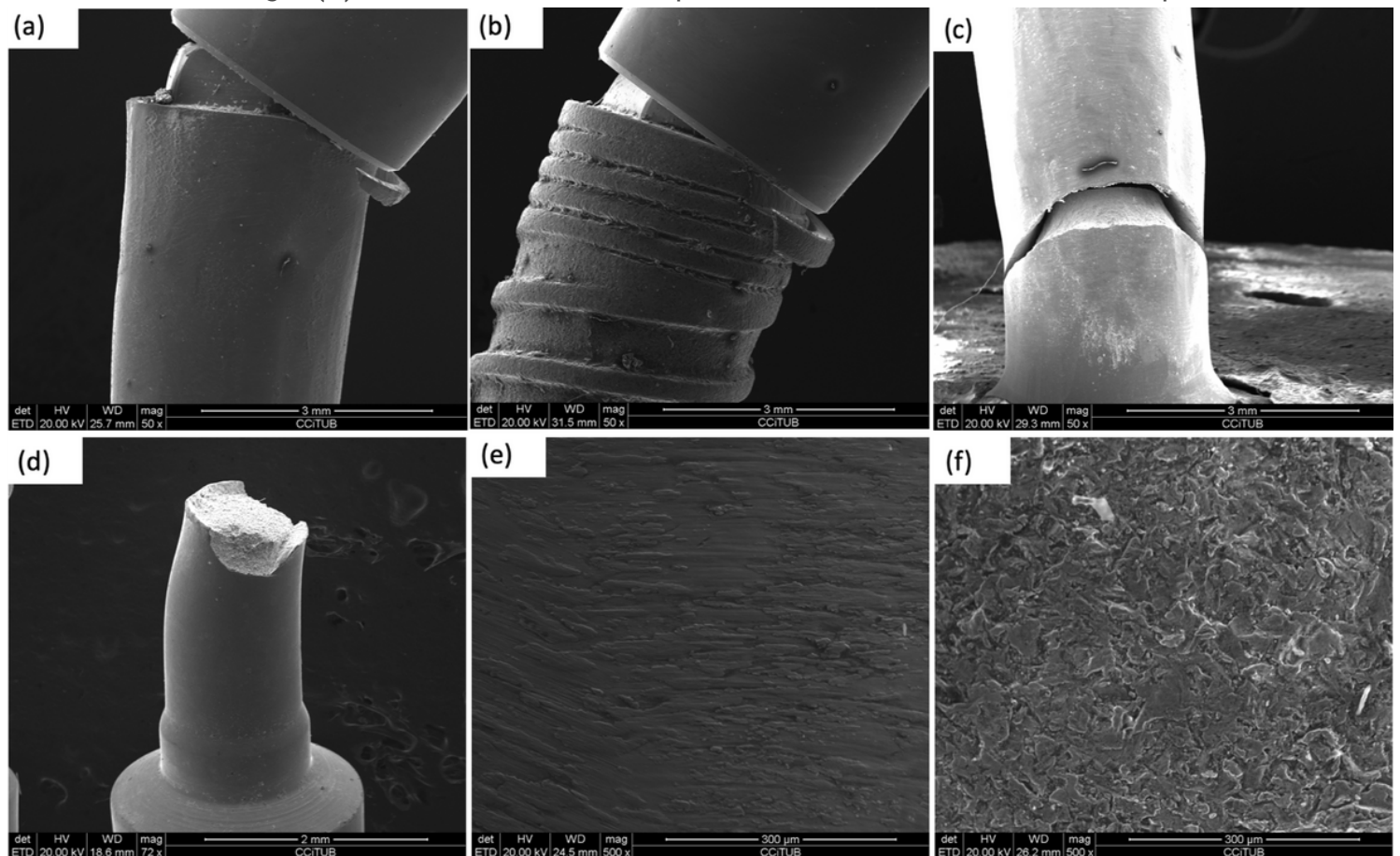


Figure 6

SEM screening: (a) IP sample platform fracture; (b) Control sample platform fracture; (c) IP sample body fracture; (d) Prosthetic screw fracture; (e) Detail of IP surface; (f) Detail of control surface.

Supplementary Files

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