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Primary stability and healing outcomes of apically tapered and straight implants placed into fresh extraction sockets. A pre-clinical in vivo study

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Abstract

Objectives: To compare the stability of apically tapered and straight (non-tapered cylindrical) implants at the time of immediate placement and to histologically evaluate the healing outcomes after 6 weeks.

Materials and Methods: The second maxillary incisors were extracted bilaterally in nine dogs. After randomization, apically tapered and straight implants with a 3.3 mm shoulder

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diameter were inserted into the extraction sockets. The implant stability quotient (ISQ) of the implants were recorded after placement. Peri-implant defects on the buccal aspect were filled with deproteinized bovine bone mineral and covered with resorbable type I/III porcine collagen matrix. After 6 weeks of healing, sections were prepared for histological and morphometric analysis.

Results: All implant sites healed uneventfully. The apically tapered implants had significantly higher ISQ values compared to straight implants at placement ($p = 0.009$). The histomorphometric outcomes 6 weeks following implant placement in both experimental groups were similar, except in the apico-palatal region. Apically tapered implants demonstrated significantly less percentage bone-to-implant contact ($p = 0.035$) in the apico-palatal region. At both implant types, substantial corono-apical resorption of the buccal bone wall was noted in the coronal 2 mm of the implant.

Conclusion: Apically tapered implants had significantly higher ISQ values at immediate placement compared to straight implants. The healing outcomes and remodeling of the buccal bone wall were similar for both implant designs. In the apico-palatal region, there was less %BIC at the implant surface at apically tapered implants compared to straight implants.

Key words: apically tapered implant, straight implant, cylindrical implant, primary stability, ISQ, immediate implant, bone healing, grafting

Introduction

Primary stability is a prerequisite in achieving osseointegration. Sufficient stability is required to enable the implant to resist micromovements until osseointegration has been achieved. A number of measures have been employed to increase primary stability of implants including drilling protocols in which the osteotomy is underprepared (Friberg, Ekestubbe, Mellstrom, Sennerby, 2001, Friberg, Ekestubbe, Sennerby, 2002) and modifications in implant design (Albrektsson & Wennerberg 2004a; Albrektsson & Wennerberg 2004b; Chong, Khocht, Suzuki, Gaughan, 2009). One feature of implant design that may influence the initial stability of implants is the taper of the implant body. A tapered implant may be defined as an implant in which the endosseous part narrows in diameter towards the apex. The taper may occur continuously from the implant shoulder to the apex (also referred to as a fully tapered implant), or it may be confined to the cervical, middle or apical parts of the implant (Jokstad & Ganeles, 2018). It has been demonstrated that implants with a tapered body achieve greater primary stability compared to non-tapered cylindrical designs (O'Sullivan, Sennerby, Meredith, 2004; Akkocaoglu, Uysal, Tekdemir, Akca, Cavit Cehreli, 2005; Sakoh, Wahlmann, Stender, Al-Nawas, Wagner, 2006). Tapered implants have therefore been recommended for placement in fresh extraction sockets.

Type 1 (immediate) implant placement refers to the placement of an implant following tooth extraction and as part of the same procedure (Hämmerle, Chen, Wilson, 2004). With this approach, primary stability of the implant is achieved by intimate contact between the implant and the walls of the socket apically and laterally. However, the morphology of the socket may influence the ability of the clinician to obtain sufficient mechanical stability of the implant (Hämmerle et al. 2004).

As primary stability is positively associated with secondary stability from new bone regeneration (Davies 1998), the increased stability of a tapered implant may positively influence the initial bony healing.

To date, there are few preclinical studies that have investigated the primary stability and healing outcomes of tapered implants. The aim of this study was to compare the stability of apically tapered implants and straight (non-tapered cylindrical) implants when placed immediately into extraction sockets in a canine model. The secondary objectives were to

histomorphometrically evaluate the healing of the extraction sockets with these two implant designs 6 weeks after their placement.

Material and methods

The study protocol was approved by the animal ethics committee of the University of Melbourne (ethics ID no. 1413179.1). Nine healthy female Greyhound dogs, weighing between 25 to 40 kilograms and aged 2-4 years were used. This study complies with the Equator guidelines and the study report has been written according to the ARRIVE guidelines (Kilkenny, Brown, Cuthill, Emerson, Altman, 2010).

Surgical procedures

All procedures were performed by two experienced clinicians under general anaesthesia with bilateral infra-orbital nerve blocks. The surgical steps are depicted in figure 1. Scaling with an ultrasonic scaler was performed prior to surgery if plaque and calculus were present at the maxillary incisor area. An intrasulcular incision was performed around the second maxillary incisors. These were extracted using luxators and forceps. Following successful delivery of the tooth, the depth and bucco-lingual width of sockets as well as the thickness of crestal bone at the mid-buccal point were measured using a Michigan O probe with Williams markings (Hu-Friedy, Chicago, IL, USA) and recorded by rounding off the measurements to the nearest half a millimetre. Sockets were cleaned of any remnants of soft tissue and checked for any possible dehiscence and/or fenestration of the buccal bone.

Randomization was performed by a third clinician, using a coin toss for each dog to determine the side to receive one apically tapered and one straight dental implant (10mm Straumann Roxolid® narrow CrossFit NC with SLActive® surface; 3.3 mm shoulder diameter; Straumann Dental Implant System, Institut Straumann, Basel, Switzerland). The implants were identical in dimension, and body and screw geometry in the coronal 5 mm, and only differed in the apical 5 mm for the tapered implant, reducing from 3.3 mm to 2.0 mm at the apex. The osteotomy was initiated at the apico-palatal aspect of the socket, and completed in accordance with the manufacturer's recommendation. The osteotomy was prepared to allow the implant to be placed with the shoulder at the same apico-coronal level as the buccal bone crest (Fig. 1c). Primary stability was achieved by engaging the

apical, palatal and proximal bone walls, as well as the cortical bone at the floor of the nasal cavity. Resonance frequency analysis was used to record implant stability, recorded as an implant stability quotient (ISQ). Three readings were taken and averaged (Osstell ISQ Instrument Kit, Osstell, Gothenburg, Sweden). Using the same periodontal probe, the width and the depth of the intrabony peri-implant defect were measured at the mid-buccal point from the implant shoulder to the nearest half a millimetre. A closure screw was connected to the implants. The peri-implant defect was then filled with deproteinized bovine bone mineral (DBBM) with a particle size of 0.25-1 mm, (Bio-Oss®, Geistlich Pharma, Wolhusen, Switzerland) (Fig. 1d). A resorbable type I/III porcine collagen matrix (CM) (Mucograft®, Geistlich Pharma, Wolhusen, Switzerland) was placed to cover the socket entrance and grafted area. 4-0 synthetic bio-resorbable sutures (Monosyn®, B. Braun, Australia) were used to secure the collagen matrix in position (Fig. 1e). An occlusal radiograph was taken to record the implant position (Fig. 2).

During the first two weeks, wounds were inspected daily and a plaque control regimen including once daily application of Hexarinse® (chlorhexidine gluconate supported by cetylpyridinium chloride and zinc gluconate, Virbac, Regents Park, NSW, Australia) was provided. Thereafter, gentle mechanical brushing of the implant site and the adjacent teeth was undertaken with a soft toothbrush soaked in Hexarinse® three times a week for the remainder of the experimental period. Soft food was prescribed in the first week followed by a normal diet thereafter. At 6 weeks all nine dogs were sacrificed using an intravenous injection of Lethabarb® (Pentobarbitone, Virbac, Regents Park, NSW, Australia).

Histological preparation

The pre-maxillae were resected en block and immediately placed in 10% buffered formalin (Orion, Balcatta, WA, Australia). The fixated bone blocks were dehydrated in a series of graded ethanol solutions and defatted in xylol. Specimens were then infiltrated and embedded in resin (Sigma-Aldrich, Hamburg, Germany) and polymerized according to the manufacturer's instructions. The samples were cut just prior to the central orientation of the implant in the bucco-lingual direction using a low-speed rotary diamond saw (EXAKT 300 & 310/ CL & CP, EXAKT Advanced Technologies GmbH, Norderstedt, Germany). Two central sections of 400 µm thickness were obtained from each implant. Sections were mounted

onto methyl methacrylate slides and ground and polished to a final thickness of approximately 40-60 μm on a rotating grinding plate (EXAKT 400 CS, EXAKT Advanced Technologies GmbH, Norderstedt, Germany). Subsequently, sections were stained with Paragon toluidine blue (Amresco, VWR International AG, Dietikon, Switzerland) and basic fuchsine, (Merck KGaA, Darmstadt, Germany) covered with liquid cover glass (MERCKOGLAS[®], Merck KGaA, Darmstadt, Germany) and examined under a standard light microscope for histological analysis.

Histomorphometric measurements

Imaging was performed with a light microscope (Olympus BX43, Olympus Europa Holding GmbH, Hamburg, Germany) equipped with a digital colour camera (Olympus XC30, Olympus Europa Holding GmbH, Hamburg, Germany). Histomorphometry was conducted with imaging software (Olympus cellSens, Olympus Europa Holding GmbH, Hamburg, Germany).

The following landmarks were identified on each slide (Fig. 3a-d):

- IS: implant shoulder
- S: surface of the implant at the buccal aspect
- C: crest of the regenerated buccal bone
- OC: the outer contour of the buccal bone, ignoring those superficial particles of DBBM that were not in contact with bone and were only embedded in soft tissue
- ROB: the most coronal remnants of the original buccal bone as stained light magenta
- fBIC: the first bone-to-implant contact at the site of the implant shoulder

In the para-sagittal plane, the following measurements parallel to the long axis of the implant were obtained (mm):

- IS-fBIC: distance from implant shoulder to first bone-to-implant contact
- IS-ROB: distance from the implant shoulder to the most coronal remnants of the original buccal bone
- IS-C: distance from the implant shoulder to the most coronal point of the regenerated crestal bone
- C-fBIC: distance from the most coronal point of the regenerated crestal bone to the first bone-to-implant contact

In the same para-sagittal plane, the following measurements orthogonal to the long axis of the implant were obtained (mm):

- S-OC: distance from the surface of the implant to the outer surface of the buccal bone at 1mm intervals along the length of the implant
- S-C: distance from the surface of the implant to the crest of the regenerated buccal bone
- IS-IC: distance from the surface of the implant to the inner aspect of the buccal bone at the level of the implant shoulder

To evaluate the percentage of bone-to-implant contact (%BIC) and the composition of the bony tissue around implants, four areas of interest were determined around each implant (Fig. 3b); corono-buccal, apico-buccal, corono-palatal and apico-palatal.

The %BIC within each region of interest was calculated by dividing the length of the implant surface in direct contact with bone by the total length of the implant. The area of newly formed bone, remnants of original bone and residual graft material were calculated as percentages of the total area of the region of interest (Fig. 3b). Contrast measurements were used to separate newly formed bone and residual bone using image analysis software (Olympus cellSens, Olympus Europa Holding GmbH, Hamburg, Germany). The residual graft material was manually marked; these areas were summed and excluded from the contrast measurement.

Data analysis

Power analysis for this project resulted in a minimum sample size of 8 animals. This was based on the ISQ variable with a standard deviation of 4, a statistical difference of 5 and power of 0.8. Nine animals were selected in case of implant loss in one of the treatment groups. Descriptive statistics for the mean and standard deviation, median and 25th/75th percentiles, and the range for each of the measured parameters were calculated. The Wilcoxon signed rank test was used to test for significance in differences between groups for each variable. The results were presented in the text as median and interquartile range (IQR) (Minitab 19; Minitab Inc, State College, PA, USA). The level of significance was set at 0.05.

Results

Following extraction, all sockets were found to be intact with no fenestrations or dehiscences present. There was no statistical difference in the dimension of the sockets between the 2 groups (apico-coronal socket dimension 10.3 ± 0.71 mm; mesio-distal dimension at the crest 5.8 ± 0.44 mm). There was no statistical difference in the residual peri-implant defect on the buccal aspect of both implant types. Following implant placement, the bucco-palatal defect dimension from implant shoulder to the buccal socket wall was 2 mm at all sites, whereas the apico-coronal defect was 5.4 ± 1.01 mm for apically tapered and 6.0 ± 1.50 mm for straight implants ($p = 0.142$).

At placement, apically tapered implants had significantly higher median ISQ values compared to straight implants (median 66.6, IQR 6.8 and 60.0, IQR 5.4 respectively) ($p = 0.009$) (Table 1). After 6-weeks of healing, all implants were submerged beneath the mucosa with no signs of biological complications.

Histological observations

During histological processing, no artefacts occurred and no tissues blocks were destroyed. One apically tapered and one straight implant from two different animals were found to be encapsulated in fibrous tissue, indicative of non-osseointegration. These samples were eliminated from further morphometric analysis. Hence, the apically tapered and straight groups each yielded seven paired samples for histometric analysis. The histological outcomes following implant placement in both experimental groups were similar. The apices of all implants just breached the floor of the nasal cavity. Healing was characterized by close proximity of the implant surface to the original bone on the lingual and apical aspects of the implant. On the buccal aspect, the gap between the buccal socket wall and the implant was filled with DBBM particles and newly formed bone. In all specimens, no DBBM particles were found to be in direct contact with the implant surface. An intervening layer of newly regenerated bone was always present. In the majority of the specimens, the original buccal crest had resorbed apically, and was replaced by a newly regenerated bone wall consisting of DBBM particles surrounded by newly formed bone. In most specimens, a gap was present between the newly regenerated buccal bone and the surface of the

implant near the implant shoulder. The bucco-palatal thickness of the regenerated bone crest on the buccal aspect was less than the original orofacial dimension.

Morphometric analysis

The results for variables IS-fBIC, IS-C, C-fBIC, IS-ROB and IS-IC are depicted in Table 2. The median distance of implant shoulder to bone crest (IS-C) was significantly different between groups (apically tapered group: 0.8, IQR 1.4 vs. straight: -0.2, IQR 1.6), $p = 0.022$) (Table 2). Two implants in the apically tapered implant group and five implants in the straight group had a regenerated bone crest that was located coronal to the implant shoulder (represented as a negative value). There were no statistically significant differences between groups for IS-fBIC, C-fBIC, IS-ROB and IS-IC.

The %BIC for each area of interest is summarized in Table 3. A zero value for %BIC was recorded in the apico-palatal region of one specimen, and in the corono-palatal region of another specimen. The individual value plots for the variable %BIC are shown in figure 4.

In the apico-palatal area, the apically tapered group had significantly less bone to implant contact compared to the straight group (23.7, IQR 28.8 vs 51.9, IQR 31.5 respectively, $p = 0.035$). There was no statistical difference in %BIC between the apically tapered and straight groups in the other areas of interest.

The percentage of new bone formation within each area of interest is presented in Table 4. The percentage of new bone formation in the corono-buccal and corono-palatal was similar in both groups. There was a trend for a greater percentage of new bone formation in the apico-buccal and apico-palatal regions of the straight group compared to the apically tapered group ($p = 0.076$).

S-OC, which represents the bucco-palatal width of the regenerated buccal bone, is shown in Table 5. There were no differences in S-OC between groups at each of the 1 mm increments. Of the 14 implants analysed, there was no buccal bone present in 10/14 and 6/14 at 0 and 1mm apical to the implant shoulder respectively. All 14 implants had a buccal bone wall at 2 mm apical to the implant shoulder. At 0 mm from IS, the S-OC was on

average $1.5 \pm 0.3\text{mm}$ (range 1.3 - 1.7 mm) and $1.6 \pm 0.7\text{mm}$ (range 1.0 - 2.2mm) for apically tapered and straight implants respectively.

Discussion

The results of the current study demonstrate a statistically significantly higher median ISQ value for apically tapered implants compared to straight implants (median 66.6, IQR 6.8 vs. 60.0, IQR 5.4 respectively; $p = 0.009$). These findings are in agreement with a human cadaver study (Akkocaoglu et al. 2005) and a multicentre randomized-controlled clinical trial (Lang, Tonetti, Suvan, Bernard, Botticelli, 2007). In the human cadaver study, implants were placed immediately following extraction of teeth. The authors reported higher ISQ and installation/removal torque values for tapered implants compared to cylindrical implants of the same shoulder diameter (Akkocaoglu et al. 2005). Similarly, the multicentre randomized-controlled clinical trial demonstrated increased ISQ values for tapered implants compared to cylindrical implants at immediate implant placement (Lang et al. 2007). In contrast, however, a prospective cohort study of tapered and straight implants in extraction sockets did not identify a difference in ISQ values between the two implant designs at placement (West & Oates 2007). The contrast in findings between these clinical studies may be attributed to the heterogeneity in tooth sites and extraction socket morphology. In the present study, the second maxillary incisor sockets provided dimensionally and morphologically comparable extraction sockets. Thus, the higher ISQ values for apically tapered implants compared to straight implants may be attributed to the difference in geometry between the implant designs rather than the socket morphology. In this context, it should be noted that ISQ values derived from resonance frequency analysis are often used as a surrogate measure for implant stability. Although ISQ values are not well correlated with histomorphometric measurements of bone to implant contact (Schliephake, Sewing, Aref, 2006; Degidi, Perrotti, Piattelli, Iezzi 2010), there is a positive correlation with micromotion (Trisi, Berardini, Falco, Podaliri Vulpiani, 2016). In a recent study, micromotion of implants was measured with a digital micrometer on the opposite side to a standardized applied force of 25 N/cm. Micromotion was significantly correlated to ISQ values, as well as reverse torque value, %BIC and crestal bone loss (Trisi et al. 2016). This study confirms that ISQ may represent a valid surrogate measure for implant stability.

The histological outcomes following implant placement in both experimental groups were similar in the corono-buccal, apico-buccal and corono-palatal regions of interest. In the corono-buccal and corono-palatal regions, this may be attributed to the similarities in geometry of the two implant designs in their coronal half. The test implant in this study was tapered in the apical region i.e. the coronal 5 mm of the implant had a cylindrical geometry that was identical to that of the control straight implant. There were, however, differences between the two implant groups in the apico-palatal region. At 6 weeks post insertion, the apically tapered group had significantly less %BIC in comparison to the straight group (23.7, IQR 28.8 vs 51.9, IQR 31.5 respectively, $p= 0.035$). This suggests a relatively delayed integration of bone at apically tapered implants compared to straight implants in this region. It may be postulated that the higher initial stability in the apically tapered group is achieved by greater compression of the bone. It has been observed that regions of high bone compression are associated with necrosis of the bone in the early phase of healing, and hence reduced bone to implant contact (Cochran, Schenk, Lussi, Higginbottom, & Buser, 1998). It should be noted, however, that a zero value for %BIC was recorded in one specimen in the apico-coronal region for a straight implant and the corono-palatal region for an apically tapered implant in another specimen. With the relatively small sample size, these two outliers could skew the results, and therefore the results should be interpreted with caution.

It was interesting to note a trend for greater percentage of new bone formation in the apico-palatal and apico-buccal regions, suggesting that initial bone resorption and reduced %BIC may be accompanied by a greater volume of compensatory bone formation in the adjacent bone. Studies with larger sample sizes to specially examine the effect of implant taper on the bone response in the apical region would be required to clarify this.

A confounding factor and a limitation of the study was the apical position of the implants in relation to the nasal floor. In all specimens, a minor breach of the nasal floor was observed which could have resulted in fibrous tissue in contact with the apical part of the implants. This would be anticipated to be evident at both apico-buccal and apico-palatal regions of the implant. However, %BIC was different between groups only in the apico-palatal region and not in the apico-buccal region, which suggests that implant geometry rather than

fibrous encapsulation was the predominant influencing factor on BIC. The placement of slightly shorter implants would have overcome this limitation of the study.

The location of the regenerated bone crest (C) varied considerably (range for apically tapered group -0.3 to 1.6 mm vs. range for straight -1.0 to 0.8 mm). Only 2 implants in the tapered implant group and 5 implants in the straight group had a regenerated bone crest that was located coronal to the implant shoulder. The median distance of implant shoulder to crest (IS-C) was statistically significantly different between groups (apically tapered group: 0.8, IQR 1.4 vs. straight: -0.2, IQR 1.6; $p = 0.022$). In contrast the ROB was similar between groups, suggesting the implants were placed at a similar apico-coronal level and the sockets underwent similar apico-coronal resorption of the buccal bone crest. Therefore, the variation in regenerated bone crest (C) is more likely due to variability in healing and bone regeneration rather than the geometry of the implants themselves or the manner of their insertion.

There was also considerable variability in fBIC on the buccal aspect of the implants, ranging from 0.5 – 4.3 mm for the apically tapered group and 0 – 3.9 mm for the straight group, even though the marginal gap was filled with DBBM particles. The lack of new bone contact to the implant surface in this marginal region may reflect the relatively short observation period of 6 weeks in this study. This timeframe was based on the observations by Berglundh et al. (2003) and Abrahamsson et al. (2004). They demonstrated that new bone deposition onto the implant surface occurs between 1 and 6 weeks after implant placement in healed sites in a canine model, while bone remodelling commenced after 6 weeks. However, immediate implant placement is a more challenging situation compared to implant placement in healed sites, since a large part of the implant is not in contact with bone on the buccal aspect. Therefore, healing periods longer than 6 weeks may be required to fully evaluate the bone regenerative potential in this model. In a study of immediate implants in mandibular premolar sockets in a canine model, specimens were examined at time intervals of 4 hours, 1, 2, 4 and 8 weeks after implant placement. The authors observed that BIC increased over the observation period (Vignoletti, Johansson, Albrektsson, De Sanctis, San Roman et al. 2009).

Of note was the observation of diminished bone dimensions compared to the original socket dimensions in the shoulder region of the implant after 6 weeks of healing (fig. 5). For all sites combined, the bucco-palatal bone width was 0.6 mm, 1.4 mm and 2.0 mm at 0, 1 mm and 2 mm apical to the implant shoulder. In addition, the regenerated bone crest was apical to the level of the implant shoulder in 8/14 implants. This finding is consistent with a previous study of immediate implants in a canine second incisor model in which submerged and non-submerged healing protocols were compared following flap reflection and implant placement (Mellati, Chen, Davies, Fitzgerald, Darby, 2015). The authors found that in one-third of the sites, the regenerated buccal crest was apical to the implant shoulder. Taken together, these observations support the concept that the buccal bone crest undergoes rapid resorption in the first few weeks of immediate implant placement, following which the particles of DBBM are no longer contained by the buccal bone wall and may become displaced. The result is a reduction in the bone dimensions in the coronal 2 mm of the implant (Araujo, Sukekava, Wennstrom, Lindhe, 2006).

In a clinical context, it has been proposed that the bone graft may be placed coronal to the implant shoulder in the region between the supracrestal soft tissue and the implant abutment/provisional crown to compensate for the crestal bone resorption in the buccal marginal position at immediate implants placed without flap elevation (Tarnow, Chu, Salama, Stappert, Salama et al, 2014). While there is clinical evidence to suggest that this technique maintains peri-implant soft tissue volume, there is lack of histological evidence to demonstrate if this technique compensates for the crestal bone resorption. Another approach is to place the implant with its shoulder 1 to 2 mm apical to the buccal bone crest in anticipation of crestal bone resorption (Buser, Chappuis, Belser, Chen, 2017). It should be noted that the ability to compensate for bucco-palatal resorption of the buccal bone is limited when a flapless surgical approach is utilized.

In conclusion, the maxillary second incisor model in the canine was found to be a viable model for immediate implant studies, as has been reported previously (de Santis, Botticelli, Pantani, Pereira, Beolchini, Lang, 2011; Mellati et al. 2015). Within the limitations of this study, apically tapered implants have significantly higher ISQ values when placed immediately into the second maxillary second incisor sockets compared to straight implants

in a canine model. The higher ISQ values imply that the apically tapered implants are at less risk of micromovement, and may be suitable for immediate placement where attainment of primary stability can sometimes be difficult to achieve. The healing outcomes and remodeling at the buccal bone wall were similar for apically tapered and straight implants. However, there was less %BIC in the apical palatal region of the apically tapered implants compared to the straight implants.

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Conflicts of interests:

The authors report no conflicts of interest.

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Table 1. Resonance frequency analysis for apically tapered and straight implants (ISQ)

	Apically tapered (ISQ)	Straight (ISQ)	
Mean \pm SD	65.5 \pm 4.2	59.6 \pm 4.1	P = 0.009* (n=9)
Range	57.3 - 72	53.0 - 65.3	

* Statistically significant ($p < 0.05$) using the Wilcoxon signed rank test.

Table 2. Histomorphometric results for IS-fBIC, IS-C, C-fBIC, IS-ROB and IS-IC

	IS-fBIC		IS-C		C-fBIC		IS-ROB		IS - IC	
	Apically tapered	Straight	Apically tapered	Straight	Apically tapered	Straight	Apically tapered	Straight	Apically tapered	Straight
Mean ± SD (mm)	2.7 ± 1.3	1.9 ± 1.4	0.7 ± 0.7	-0.2 ± 0.7	2.0 ± 1.0	2.1 ± 1.0	1.4 ± 0.7	1.5 ± 0.7	0.8 ± 0.5	0.5 ± 0.3
Range (mm)	0.5 - 4.2	0 - 4.2	-0.3 - 1.7	-1.0 - 0.8	0.7 - 3.4	0.8 - 3.9	0.7 - 2.1	0.5 - 1.9	0.4 - 1.4	0.2 - 0.9
p-value	0.108		0.022*		0.673		0.933		0.151	

Data based on 7 paired specimens.

* denotes statistically significant ($p < 0.05$)

Table 3. Mean percentage of bone-to-implant contact (%BIC) within each area of interest

	Corono-buccal		Apico-buccal		Apico-palatal		Corono-palatal	
	Apically tapered (%)	Straight (%)	Apically tapered (%)	Straight (%)	Apically tapered (%)	Straight (%)	Apically tapered (%)	Straight (%)
Mean ± SD	14.8 ± 12.6	28.6 ± 27.5	45.9 ± 22.7	47.9 ± 21.1	26.4 ± 20.7	45.5 ± 24.7	29.2 ± 22.1	40.1 ± 25.1
Range	0.6 - 55.3	3.01- 80.5	7.1 - 76.0	22.3 - 86.0	2.0 - 66.0	0 - 76.2	0 - 54.3	9.4 - 68.2
p-value	0.108		0.076		0.035		0.205	

Data based on 7 paired specimens.

*Statistically significant (p < 0.05).

Table 4. Mean percentage of new bone within each area of interest

	Corono-buccal		Apico-buccal		Apico-palatal		Corono-palatal	
	Apically tapered (%)	Straight (%)	Apically tapered (%)	Straight (%)	Apically tapered (%)	Straight (%)	Apically tapered (%)	Straight (%)
Mean ± SD	17.0 ± 3.9	20.2 ± 13.1	33.2 ± 10.6	23.8 ± 10.6	32.1 ± 5.3	24.7 ± 6.9	41.8 ± 7.2	39.9 ± 14.6
Range	10.6 - 28.3	6.9 – 41.0	15.7 - 48.4	9.4 - 36.9	17.2 - 41.2	13.0 - 35.4	28.5 - 50.3	15.2 - 49.9
p-value	0.612		0.076		0.076		0.800	

Data based on 7 paired specimens.

*Statistically significant ($p < 0.05$)

Table 5. Bucco-palatal dimension of the buccal bone (S-OC) at 1mm intervals apical to the implant shoulder (IS)

Intervals apical to the implant shoulder (IS)	Apically tapered		Straight	
	Mean \pm SD (mm)	Range (mm)	Mean \pm SD (mm)	Range (mm)
0 mm	1.5 \pm 0.3	1.3 - 1.7	1.6 \pm 0.7	1.0 - 2.2
1 mm	1.9 \pm 0.5	1.2 - 2.4	1.8 \pm 0.6	1.0 - 2.1.2
2 mm	1.8 \pm 0.4	1.4 - 2.4	2.1 \pm 0.5	1.4 - 2.8
3 mm	1.8 \pm 0.3	1.3 - 2.0	2.1 \pm 0.2	1.5 - 2.6
4 mm	1.4 \pm 0.5	0.5 - 1.9	2.0 \pm 0.6	1.1 - 2.8
5 mm	1.5 \pm 0.4	1.2 - 2.0	1.8 \pm 0.6	1.0 - 2.6

6 mm	1.2 ± 0.5	0.5 - 1.8	1.5 ± 0.6	0.6 - 2.3
7 mm	1.0 ± 0.5	0.3 - 1.4	1.1 ± 0.6	0.2 - 1.9
8 mm	1.2 ± 0.1	0 - 1.2	1.1 ± 0.7	0.3 - 1.9

No significant difference between groups at all levels - Wilcoxon signed ranked test

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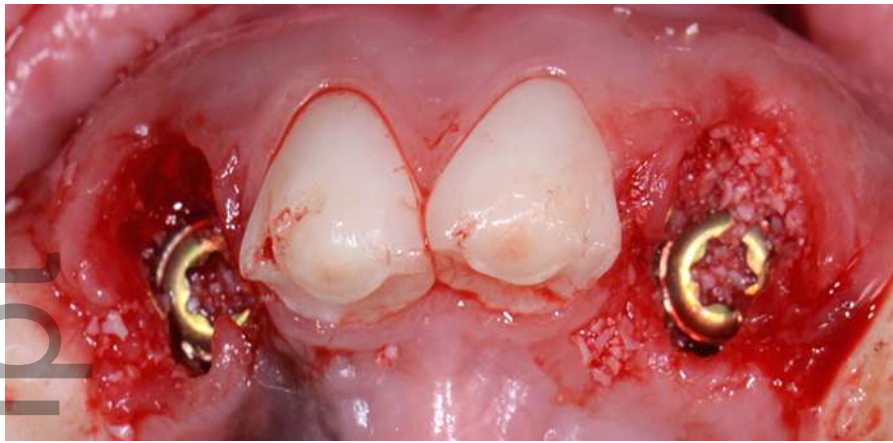
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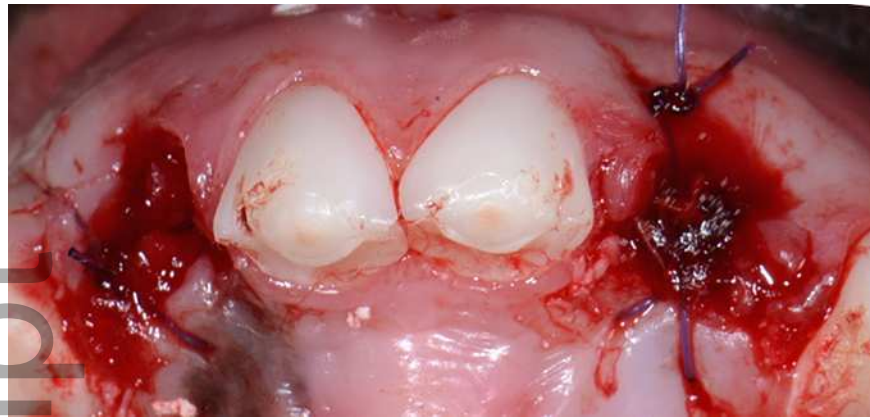
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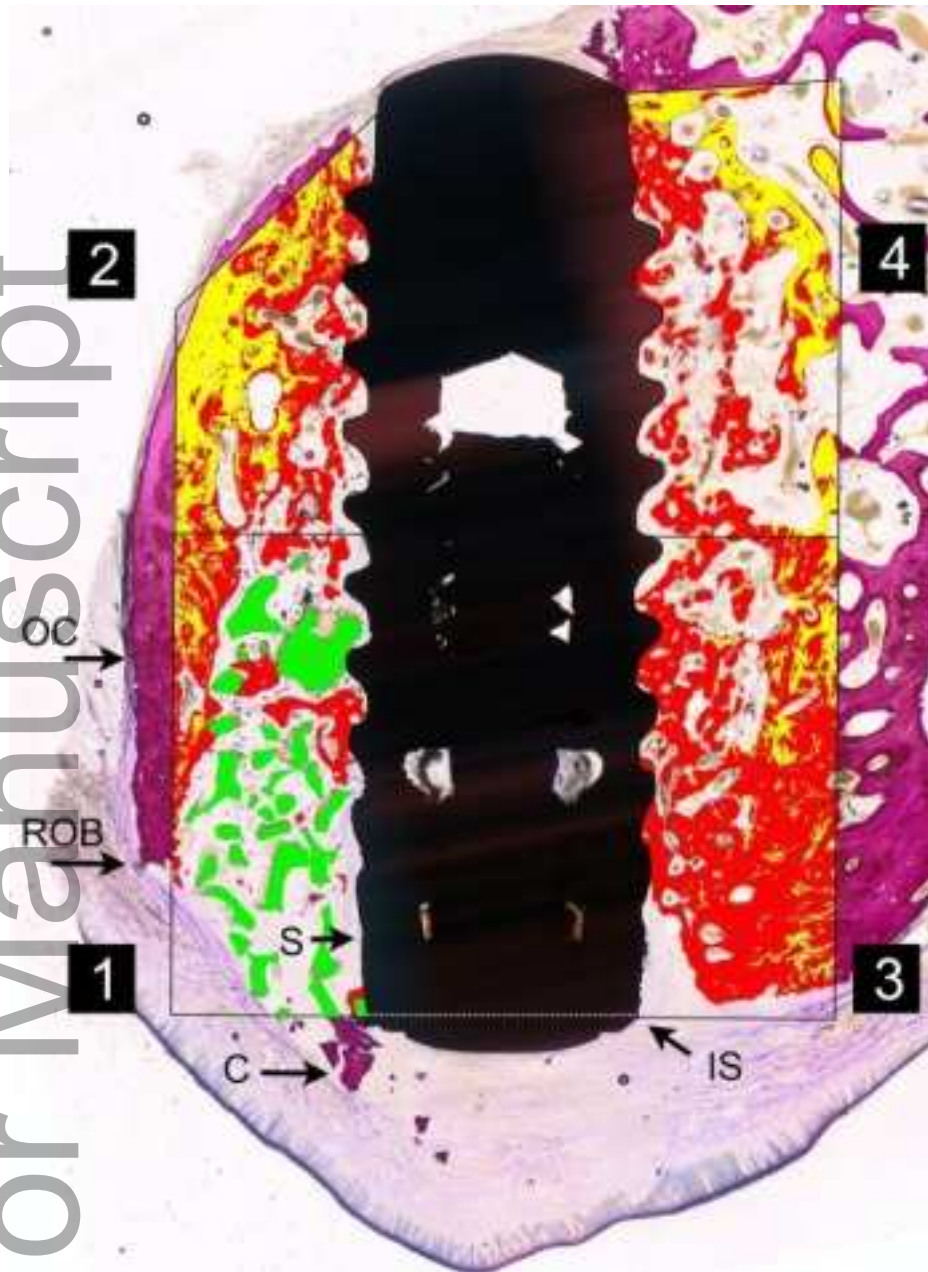


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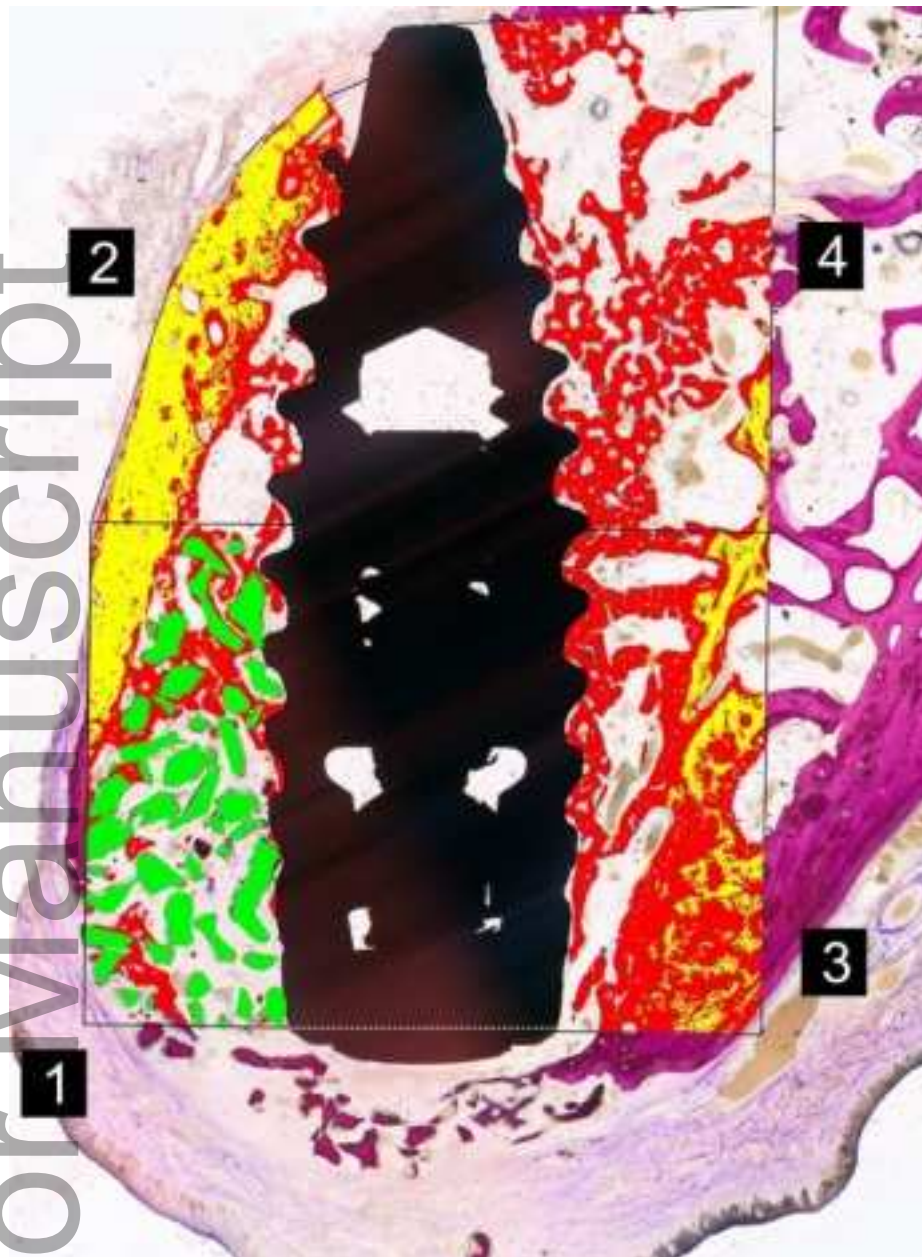
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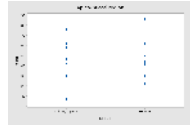


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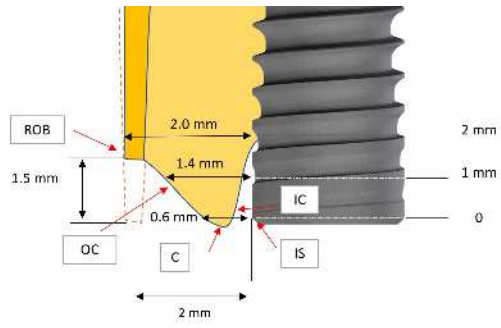


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