CLINICAL ORAL IMPLANTS RESEARCH

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Biological limits of the undersized surgical technique: a study in goats

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Abstract
Objective: The purpose of the present study was to investigate the influence of different implant placement techniques on the early bone healing response in an animal model.
Material and methods: In the present study, 24 cylindrical-screw-type implants with a diameter of 4.2 mm (Dyna®) were installed, using three different surgical techniques; (1) *5% undersized*, using a final drill diameter of 4 mm; (2) *15% undersized*, using a final drill diameter of 3.6 mm; and (3) *25% undersized*, using a final drill diameter of 3.2 mm. After 3 weeks of implantation period, the peri-implant bone response was histologically evaluated and the percentage of bone–implant contact (%BIC) calculated.
Results: New bone formation was more pronounced for implants placed with the 5% undersized or 15% undersized technique, as compared with implants installed with the 25% undersized technique. Histomorphometrical data corroborates these findings as the %BIC was significantly higher for implants inserted with the 5% undersized (47.7 $\pm$ 11.1) or 15% undersized protocol (47.5 $\pm$ 9.5) as compared with implants inserted with the 25% undersized technique (32.1 $\pm$ 9.7). No significant difference in %BIC could be observed between the 5% undersized and 15% undersized installed implants.
Conclusion: Within the limitation of the present study, it was concluded that excessive compression of the host bone, when a discrepancy between implant and final drill diameter more than 15%, can result in an inferior tissue response in the early stage of healing. To compare research results in the future, it is advised to specify the term "undersized" by mentioning the real reduction in diameter.

Titanium implants have become a most widely used treatment option in restorative dentistry for the replacement of missing teeth. Obviously, for these implants osseous fixation is essential. To create optimal peri-implant osteogenesis many factors play a significant role, such as material surface characteristics (de Jonge et al. 2008), patient bone quality and quantity (Sevimay et al. 2005), the presence of osteogenic bone particles in the preparation site (Tabassum et al. 2010b; A. Tabassum, F. Walboomers, G.J. Meijer & J.A. Jansen unpublished data), mechanical loading (Schwarz et al. 2010), implant design (O'Sullivan et al. 2000; Lee et al. 2005) and surgical technique (Albrektsson 2001).

The critical importance of the surgical technique arises from many previous clinical studies. For example, high failure rates have been reported for bone of low density as may present in the maxilla (Khang et al. 2001). In such poor bone density, solely the modification of the surgical protocol can increase success rates up to 93–97% (Friberg et al. 1999; Bahat 2000). Therefore, careful surgical planning and execution are crucial for a successful outcome (Bahat 2000), as surgical trauma has been associated with biological failures of implants (Esposito et al. 1998). To shorten the treatment time and to decrease the surgical burden on the patient, the concept of immediate and early loading has been introduced in clinical practice. By adopting a modified surgical protocol, it is feasible to immediately load implants also in areas of poor bone density (Ostman et al. 2005). One of these surgical modifications is the undersized drilling technique, which has been introduced to locally optimize the bone density by using a final drill diameter considerably smaller compared with the implant diameter (Friberg et al. 1999).

In the past years, research was mainly focused on developing superior implant hardware, and less attention has been paid to clinical parameters like surgical technique (Albrektsson 2001). Only few studies have been performed to evaluate the biological effect of the undersized surgical technique with respect to bone response and bone-to-

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Table 1. Summary of the literature on the undersized technique with respect to discrepancy between implant diameter and final drill diameter

Study design	Implant design	Implant diameter (mm)	Final drill diameter (mm)	Percentage of diameter reduction	Reference
Clinical	Brånemark® Mk II and standard implants	3.75 4.0 and 5.0	Not mentioned 3	NA 25 and 40	Friberg et al. 1999
Clinical	Brånemark® standard and self-tapping	3 and 3. 3 3.75 4 and 5	2.0 and 2.3, respectively 2.70 to 2.85 3	35 and 30 24 to 27 25 and 40	Friberg et al. 2001
Clinical	Brånemark® implants	3.75 and 4.0 5.0	2.70 to 3.15 3.70 to 4.30	16 to 33 14 to 26	Friberg et al. 2002
Clinical	Prototype Mk IV and Standard Brånemark®	4	2.85 and 3.15	22 and 29	Friberg et al. 2003
Clinical	Brånemark® Standard and Mk IV	Not mentioned	3.15	NA	O'sullivan et al. 2004
Clinical	Brånemark® Standard and Mk IV	Not mentioned	3.15	NA	O'sullivan et al. 2004
Clinical	Brånemark® Mk III, Mk IV and Replace Select® Tapered	Not mentioned	2.85	NA	Ostman et al. 2005
Clinical	Brånemark® Mk III (n = 734) Brånemark® Mk IV (n = 171)	NP (3.3) RP (3.75 and 4) WP 5.0mm	2.70 and 2.85 2.70, 2.85 or 3.0 3.85 and 4.30	14 and 19 24 to 27 14 and 23	Ostman et al. 2006
Clinical	Brånemark® Standard, MkII, MkIII, Mk IV	Not mentioned	2.85	NA	Ostman et al. 2008
In vitro	Biocomp® Tapered	4.6	4.0	14	Shalabi et al. 2006
In vivo	Biocomp® Tapered	4.6	4.0	14	Shalabi et al. 2007a, b
In vitro	Conical and hybrid Cylindrical screw type	5	4.3	14	Sakoh et al. 2006
In vitro	Brånemark® systen Mk III	3.75	2.85, 3.0, 3.15, and 3.35	11 to 24	Beer et al. 2007
In vitro	Astra tech® AB	4	3.2	20	Fanuscu et al. 2007
In vitro	Biocomp® Tapered	4.6	4.0	14	Tabassum et al. 2009; 2010a, b

The percentage of diameter reduction was calculated based on the diameters as published in the various articles.
NA, not applicable.

implant contact (Table 1). An important issue that needs to be addressed in the field of implantology is, whether there is a biological limit for the discrepancy between implant diameter and the undersized hole, as prepared to obtain a superior healing response. For this purpose, an *in vivo* study was performed using three different surgical techniques selecting the iliac crest of the goat as an implantation model.

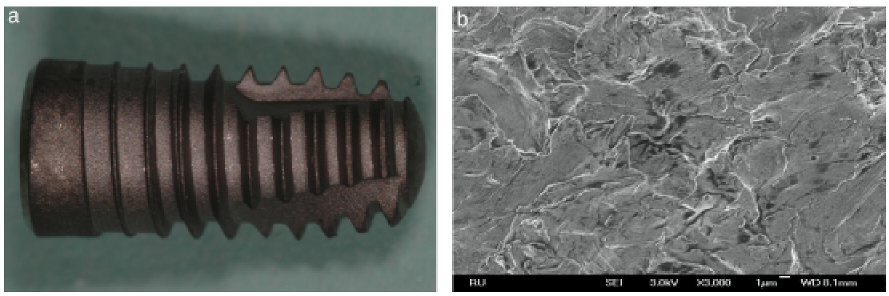

Fig. 1. (a) Dyna® implants with acid-etched surface topography (dental engineering BV; Bergen op zoom, the Netherlands). (b) Surface of implant visualized by scanning electron microscopy (SEM) showing a uniformly rough surface (magnification × 3000).

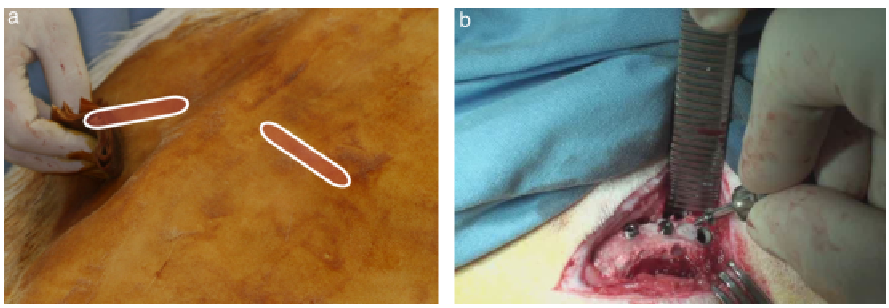

Fig. 2. (a) Animal was immobilized in a ventral position and the pelvic area was shaved and the anatomical structures were identified and marked. (b) Location of implants placed in the each iliac crest.

Material and methods

Dental implants

Twenty-four cylindrical screw type implants provided by Dyna® implants (Dyna® dental engineering BV, Bergen op zoom, the Netherlands) were used. All implants were acid-etched and measured 10 mm in length and 4.2 mm in diameter (Fig. 1a). Scanning electron microscopy (SEM) and a universal surface tester (Innowep GmbH, Wûrzburg, Germany) were utilized to characterize the surface topography of the implants.

Animal model and implantation procedure

Four healthy mature (2–4 years of age) female Saane goats, weighing approximately 60 kg, were used in the present study. Approval of the Experimental Animal Ethical Committee was obtained (RU-DEC 2009-031) and national guidelines for the care and use of laboratory animals were followed. All surgical procedures were performed under general inhalation anesthesia and sterile conditions. To reduce the risk of peri-operative infection, the goats received antibiotics pre-operatively (10 mg/kg Amoxicillin®, Centrafarm, Etten-leur, the Netherlands, intravenously), and post-operatively, at day 1 and day 3 (50 mg/kg intramuscularly Albipen® LA, Intervet BV, Boxmeer, the Netherlands). The analgesic Finadyne® (1 mg/kg, three times a day) was administered for 2 days after surgery. Before placement of the implants, the animals were immobilized in a ventral position. The pelvic area of goats was shaved and the anatomical structures marked. First, a transverse skin incision was made, starting from the upper medial side of the iliac crest, subsequently continuing towards the anterior superior iliac spine in lateral direction on both sides of vertebral column (Schouten et al. 2010). Then, the incision was continued through the underlying tissue layers until the periosteum was reached. Subsequently, the periosteum was detached and elevated aside, exposing the iliac crest (Fig. 2). Bone cavities were prepared with a gentle surgical technique, using rotational speeds (800 rpm) and continuous internal cooling with sterile saline; a total of 24 implants ($n=8$) were inserted. The distance between the holes was 4–5 mm (Fig. 2). For the installation of the implants, three different approaches were used:

Approach 1: 5% undersized; a 5% undersized preparation procedure (according to the protocol of the manufacturer) was performed. Drilling was started using the pilot drill (2 mm diameter). Subsequently, the hole was widened by a consecutive series of drills, i.e. 3.2, 3.6, and 4 mm in diameter. By installing a 4.2 mm diameter implant in a 4 mm cavity, a reduction in diameter of about 5% was achieved.

Approach 2: 15% undersized; the same sequence of drills was used as for approach 1. However, the final drill (4 mm) was skipped. By installing a 4.2 mm diameter implant in a 3.6 mm cavity, a reduction in diameter of about 15% was achieved.

Approach 3: 25% undersized; the drilling was started using the pilot drill (2 mm diameter). Afterwards, the hole was widened by a 3.2 mm diameter drill. By installing a 4.2 mm diameter implant in a 3.2 mm cavity, a reduction in diameter of about 25% was achieved.

After implant placement, the soft tissues and the skin were closed in layers with resorbable sutures (Vicryl® 2.0, Ethicon Products, Amersfoort, the Netherlands). After 3 weeks of implantation, all four goats were euthanized with an overdose of Nembutal® (Apharmo, Arnhem, the Netherlands). Hereafter, the iliac wings were harvested and excess tissue was removed. By using a diamond blade saw, the iliac crests were divided into smaller pieces. As a result, each specimen contained just one implant with surrounding bone.

Histological preparations

The specimens for histology were fixed in formaldehyde 4%, dehydrated in a graded series of ethanol (70–100%), washed with acetone, and embedded (non-decalcified) in methylmethacrylate (MMA) for 4 weeks. After polymerization of the MMA, thin (10 μm) non-decalcified sections were prepared with a modified diamond blade sawing microtome technique (Van der Lubbe et al. 1988). According to routine procedure (Caulier et al. 1997; Shalabi et al. 2007a), three sections were made through the middle part of the implant, but at least 350 μm apart in distance. The sections were made in a longitudinal direction parallel to the long axis of the implant and subsequently stained using methylene blue and basic fuchsin.

Histological and histomorphometrical evaluation

To evaluate the bone response around the implants, histological as well as histomorphometrical analyses were performed using a light microscope (Leica Microsystems AG, Wetzlar, Germany). Image analysis software (Leica qwin pro-image, V 2.5, Cambridge, UK) was used for histomorphometrical evaluation. Quantitative measurement on the percentage bone–implant contact (%BIC) was performed on both sides of the histological image for three different sections of each implant.

Statistical analysis

All data were expressed as a mean ± SD. One-way analysis of variance (ANOVA), with subsequent Tukey–Kramer multiple comparisons testing was conducted to compare the difference between groups. All calculations were performed with Instat software V.3.05, (GraphPad® Software Inc., San Diego, CA, USA). Differences were considered significant when $P<0.05$.

Results

Surface characterization

Surface evaluation demonstrated an average surface roughness of $R_a=0.815 \pm 0.05$ μm and a height distribution of $R_q=1.28 \pm 0.37$ μm. SEM showed a uniformly roughened surface topography (Fig. 1b).

Experimental animals

All animals remained healthy after the surgery. At sacrifice no signs of inflammation or other adverse tissue reactions could be observed. Of the 24 installed implants, two implants were damaged during preparation and had to be excluded from further evaluation.

Histology

Light microscopic examination of all the implants demonstrated no signs of inflammation. The iliac crest of the goat mainly consists of trabecular bone. At the upper border of iliac crest, the bone seems to be more compact. All sections showed that the drilling procedure was accurate, as the apical parts of all implants were in contact with the surrounding bone. No intervening fibrous tissue layer was observed between any implant and the surrounding bone.

Approach 1: 5% undersized, histological examination demonstrated that most of the screw vents were completely filled with newly formed bone (Fig. 3a). The bone was in close contact at the top of the screw threads and bone in-growth was visible from the top of the screw threads into

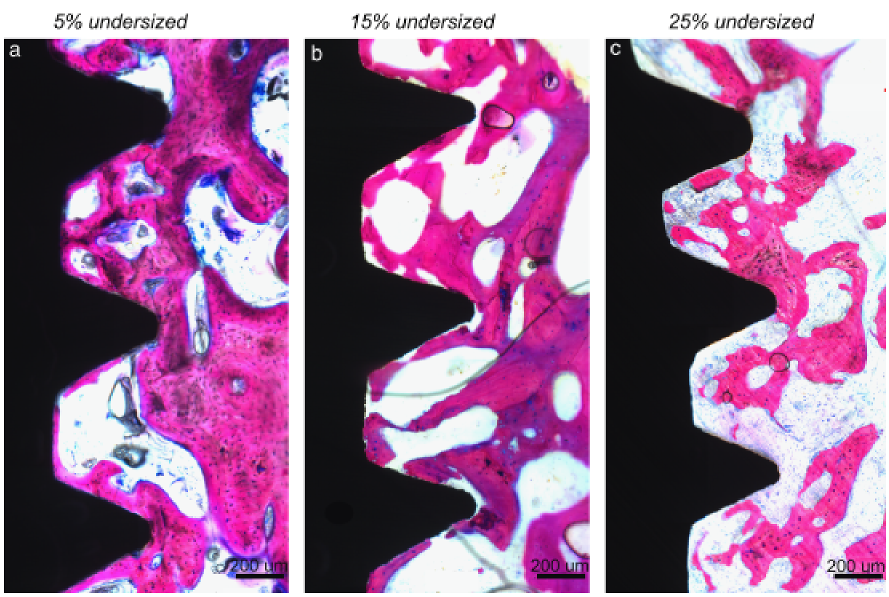

Fig. 3. Histological overview of all three groups: (a) implants inserted with the 5% undersized technique; (b) implants placed with the 15% undersized technique; (c) implants installed with the 25% undersized technique. Magnification of all images is × 10. Histological examination revealed that new bone formation was more pronounced in implants placed with the 5% undersized or 15% undersized surgical technique. Implants placed with the 25% undersized technique demonstrated only a limited bone-to-implant contact.

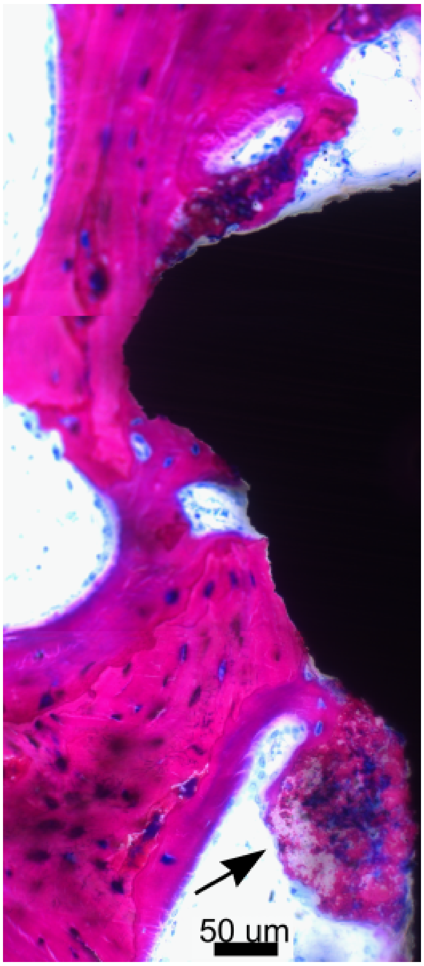

Fig. 4. Light micrographs of an implant placed with the 25% undersized technique (magnification × 40). Osteoblasts (OB) and osteoclast (OC) are visible on the surface of newly formed bone. Remodelling lacunae with obvious signs of resorption can also be observed (see arrow).

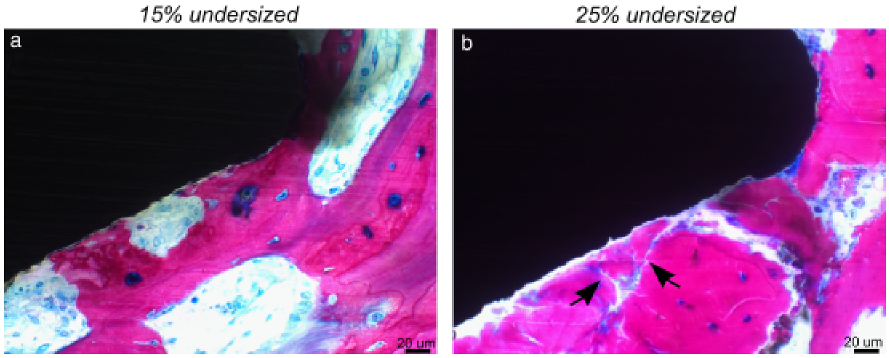

Fig. 5. Light micrographs of an implant placed with the 15% undersized and 25% undersized technique (magnification × 40). The micro-fractures of the trabecular bone are clearly visible in implants placed with 25% undersized technique (see arrows). However, implants placed with the 15% undersized technique have not shown such micro-fractures.

Table 2. **Mean ± SD of histomorphometrical data and statistical analysis performed for implants placed with 5% undersized, 15% undersized and 25% undersized after 3 weeks of implantation**

Group	%BIC	Comparison	*P*-value
5% undersized	47.78 ± 11.13	5% vs. 15% undersized	$P > 0.05$
15% undersized	47.5 ± 9.57	5% vs. 25% undersized	$P < 0.05$
25% undersized	32.1 ± 9.73	15% vs. 25% undersized	$P < 0.05$

P-values for the overall ANOVA was $P = 0.013$.
BIC, bone–implant contact.

the screw vents. In the calcified tissue, many large rounded osteoblasts and osteocytes were visible. Newly formed bone could easily be distinguished from the old host bone, as the newly formed bone contained more irregularly arranged osteocytes and was lighter in color (pink).

Approach 2: 15% undersized, the implants showed a bone healing response almost similar as observed for the implants installed with the 5% undersized technique (Fig. 3b). New trabecular bone formation was noticed filling the screw vents. Most of the implant surface was in intimate contact with the host bone. Bone marrow spaces between the implant surface and host bone were also visible.

Approach 3: 25% undersized,examination demonstrated that the trabecular bone was only partially in contact with the implant surface (Fig. 3c). The ingrowth of newly formed bone into the screw threads was less abundant as compared to the implants inserted with the 5% undersized or 15% undersized surgical technique. Many bone particles were observed in the proximity of the implant surface as also in the trabecular voids. Functional repair (modelling and remodelling) was evident along with the presence of osteoblasts, osteoclasts and remodelling lacunae (Fig. 4). Some micro fractures of the host bone trabeculae could clearly be observed (Fig. 5).

Histomorphometrical analysis

Paired samples correlations testing showed that all measurements can be treated as independent observations, and thus there is no goat effect to model. Mean data ± SD regarding the %BIC is depicted in Table 2 and Fig. 6. Implants placed with a 5% undersized or 15% undersized surgical technique demonstrated a significantly higher %BIC as compared with implants installed using the 25% undersized technique. No statistically significant difference could be observed between the 5% undersized and 15% undersized surgical technique.

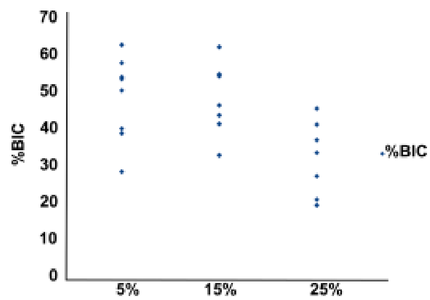

Fig. 6. The scatter plot of histomorphometrical data calculated for implants placed 5% undersized, 15% undersized and 25% undersized after 3 weeks of implantation.

Discussion

The present study focused on the effect of the surgical technique on the early biological stability of titanium implants. It was shown that BIC was significantly reduced with the 25% undersized technique. No differences could be observed between the 5% undersized and 15% undersized inserted implants.

Regarding our study set-up, first the choice of surgical model should be clarified. The surgical technique of ''choosing a smaller drill diameter than implant diameter'' is particularly recommended for type IV bone. To evaluate the healing response of titanium implants, specifically in locations with poor bone density, we recently introduced the ''iliac crest of goat'' as a model (Schouten et al. 2010). This iliac crest mainly consists of porous trabecular bone with almost no cortical layer, showing a bone volume fraction of 20.8 ± 6.1% (A. Tabassum, F. Walboomers, G.J. Meijer & J.A. Jansen unpublished data). This is significantly lower than reported for example, the femoral condyle (57.4%) (Schouten et al. 2010), and therefore makes the iliac crest model highly appropriate to evaluate the bone healing response in low-density bone. The immediate and early loading protocols has been often used in clinical practice, therefore, the present study especially focused on the initial bone response i.e., 3 weeks of implantation period. In addition, from a histological point of view the bone healing around titanium implants is characterized by the direct BIC visualized by a light microscope (Albrektsson et al. 1981), the percentage of BIC was calculated.

The term ''press-fit'' should be utilized when ''implant diameter is equal to diameter of the implant bed''. In contrast, undersized drilling technique demonstrates a discrepancy in implant diameter and the implant bed. This can be confusing, as drill and implant diameters given by various manufacturers are not always fully accurate and ''press-fit'' in practice often involves a small percentage of undersized drilling. Moreover, with respect to the nomenclature used for undersized drilling no consistent term or definition is used in literature. Several paraphrases such as *adapted bone-site preparation* technique (Friberg et al. 1999); *undersized surgical* technique (Shalabi et al. 2006, 2007a, 2007b; Tabassum et al. 2009, 2010a, 2010b); *adapted surgical* protocol (Ostman et al. 2005), *under-dimensional* drilling (Sakoh et al. 2006) and *adapted preparation* technique (Beer et al. 2007) have been utilized. One specific author baptized the undersized technique as ''drilling osteotome technique'' (Fanuscu et al. 2007), in which the discrepancy between final drill diameter (3.2 mm) and implant diameter (4 mm) was 20%. The exact reduction of diameter is not always mentioned, although this parameter seems critical.

The data from the present study exhibited no significant difference between implants placed with a 5% undersized and 15% undersized surgical technique. These results are in accordance with a previously performed study, in which tapered screw-type implants were inserted into the femoral condyle of goat. Also these authors could not observe a significant difference between press-fit and undersized technique after 12 weeks of implantation. However, the tendency of a higher bone response for the undersized technique (diameter reduction of 14%) was reported (Shalabi et al. 2007b). In the present study, no such trend was observed. Such difference may be explained by the different animal model but more likely due to a different healing time points (12 vs. 3 weeks in our study) and different implant design (tapered vs. cylindrical). The theory behind the use of tapered implants is to induce a degree of compression on the cortical bone in a poor quality bone (O'Sullivan et al. 2004) as an higher implant stability can be ensured by engaging even a few threads of the implant into the cortical layer (Sennerby et al. 1992). In case of a cylindrical implant, compressive forces induced on the cancellous bone are higher as compared with tapered implants (Eser et al. 2010). However, in view of the high number of different implant designs that are currently in clinical use (O'Sullivan et al. 2000); it is still impossible to determine whether one specific implant design can be preferred over another (Astrand et al. 2004).

The surprising outcome of the present study was the negative effect of the 25% undersized technique as compared to both the 5% undersized and 15% undersized technique in terms of BIC in the early healing phase. In addition, the 25% undersized technique was found associated with microfractures of the trabecular bone. Our findings corroborate earlier performed studies in which the so-called osteotome technique also induced trabecular bone fractures (Nkenke et al. 2002; Buchter et al. 2005). During implant placement into an undersized prepared hole, compressive forces are generated along the implant/bone interface, which are dependent on the density of the bone and the mismatch between the hole and the implant diameter (O'Sullivan et al. 2004). When the compression of trabecular bone is higher than the visco-elasticity of the trabecular bone, microdamage might occur (Nagaraja et al. 2005). A relationship between micro-damage and disturbed bone remodeling due to osteocyte apoptosis and osteoclast activation has been revealed in rats (Verborgt et al. 2000). In addition, if significant numbers of trabeculae have been lost or damaged, it is difficult to recuperate the original properties of trabecular bone (Niebur et al. 2002). In addition, previous studies established that tight contact between implant and host bone could result in poor bone formation (Futami et al. 2000) or even host bone resorption (Zubery et al. 1999). The key question is how much compression is advantageous and is there any biological limits of inducing compression on the trabecular bone? Based on the results of the present study, a reduction of the diameter of the last drill of more than 15% compared with the implant diameter can result in low biological stability in terms of less BIC.

Optimal BIC is the final goal of implant healing. To enhance the primary implant stability undersized drilling is a strong option, but the outcome of the present study indicates that there is a biological limit even in low-density bone. Therefore, within the limitation of this animal study, it can be concluded that ''undersizing'' has a biological limit and excessive compression of the host bone can result in inferior tissue response in early stage of healing. Implants that were placed 5% undersized or 15% undersized, showed a significantly better bone healing response as compared with the 25% undersized inserted implants. In addition, researchers should mention the precise discrepancy between the final drill diameters and implant diameter.

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