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ORIGINAL ARTICLE

Combined effect of undersized surgical technique and axial compression on the primary implant stability and host bone architecture

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KEYWORDS

Surgical technique;
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Abstract *Aim:* The aim of this study was to investigate the combined effect of the lateral-compression of host-bone (undersized-osteotomy-preparation) and axial-compression of host-bone (not drilling the full length of the implant) on the primary-implant-stability and the host-bone-architecture.

Materials and Methods: In this experimental-study, 44 dental implants (diameter-4.2 mm; length-10 mm; Dyna®) were installed in the femoral-condyles of four cadaver-goats using four different surgical approaches (11 implant/surgical approach; n = 11). *Approach-1*: Standard preparation according to the manufacturer's guidelines. The bone-cavity was prepared up to 10 mm in depth and 4 mm in diameter. *Approach-2:* Preparation up to 8 mm in depth and 4 mm in diameter. *Approach-3*: Preparation up to 10 mm in depth. Approach-4: The bone-cavity was prepared up to 8 mm in depth and 3.6 mm in diameter. Insertion torque (n = 11), removal torque (n = 7) and % bone-implant contact (n = 4) measurements were recorded. Bone architecture was assessed by micro-computer tomography and histological analysis (n = 4).

Results: For approaches 2, 3, and 4 ($P < .05$), insertion-torque values were significantly higher as compared to approach 1. Regarding the bone-implant-contact percentage (%BIC), approach 3

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and 4 were significantly higher compared to approach 1 and 2 ($P < .05$). For approach 2, the %bone volume (%BV) was significantly higher as compared to approach 1 ($P < .05$) for the most the inner zone of host bone in proximity of the implant.

Conclusion: Lateral and axial compression improved the primary-implant-stability and therefore this new surgical-technique should be considered as an alternative approach especially for placing implants in low-density bone. Nevertheless, additional *in vivo* studies should be performed.

1. Introduction

Nowadays dental-implants are routinely placed in dental practices for rehabilitation of partially and completely edentulous patients. Many studies have reported 95–99% success rate of dental-implants. Nevertheless, achieving a high success rate is still challenging for clinicians in certain circumstances such as implant placement in medically compromised patients (osteoporosis, irradiation therapy and smoking), the posterior maxilla due to the low-density-bone, and in case of immediate-loading-protocol.

Primary-implant-stability is essential for optimal bone healing around implants. It has been demonstrated that the micro-movement of more than 150 μm around dental-implant during healing phase can lead to the establishment of a connective-tissue between titanium-implant and host-bone (Meredith, 1998; Lioubavina et al., 2006). Numerous factors affect the primary-implant-stability, such as (1) the surgical-technique employed for installation of the implant (Sennerby and Roos, 1998; Buchter et al., 2003); (2) surface characteristics of dental-implant (Hansson, 1999; O'Sullivan et al., 2004; Saadoun et al., 2004). (3) quantity and quality of the host-bone (Sevimay et al., 2005); and (4) loading protocol (Zhu et al., 2015).

It has been proven in many previous clinical studies that the surgical-technique for implant placement has a significant influence on the final outcome (Alghamdi, 2018). For example, high failure rates were reported for implant placement in posterior maxilla due to the presence of low-density-bone (Khang et al., 2001). Only by adopting a modified undersized surgical-protocol a success rate of 93–97% was achieved (Friberg et al., 1999; Bahat, 2000). In addition, by adopting a modified surgical-protocol immediate loading of implants in type IV bone became feasible (Friberg Östman et al., 2005). Numerous alterations of the surgical-technique have been suggested in the literature to increase the primary-implant-stability, especially in low-density-bone. Some of these modifications are: (1) using a final drill-size that is smaller than the diameter of the implant resulting in an undersized osteotomy preparation (Friberg et al., 2001, 2002).

(2) osteotome-technique, in which bone condensing is performed. After using the pilot-drill, the bone is pressed sidewise with implant-shaped instruments, called 'bone-condensers', to achieve the optimal size osteotomy, in that way the density of the surrounding bone is increased (Summers, 1994); (3) In case of insufficient-bone, it has been suggested by one of the authors to anchorage implant in at least two cortical plates (Sennerby et al., 1992). (4) vertical/axial compression of the host bone, by not drilling the full length of the implant (Bahat, 2000).

In our previous study it was emphasized that undersized/-modified surgical-technique, which results in lateral-bone-compression, has biological limits and over-compression of host-bone might lead to inferior bone healing response around implant (Tabassum et al., 2011a, 2011b). Therefore, careful surgical planning is vital as surgical-trauma has been related with host-bone necrosis and biological failures of implants (Esposito et al., 1998).

In view of above-mentioned, there is an essential need for developing an alternative technique to achieve higher primary-implant-stability without undue lateral pressure. In the present study, we proposed a novel surgical approach to enhance primary-implant-stability. In this novel surgical-technique, the osteotomy was prepaed which was smaller in diameter as well as in length compared to diameter and length of the implant. The aim of this study was to assess the combined effect of the lateral compression of host-bone (undersized osteotomy preparation) and vertical/axial compression of host-bone (not drilling the full length of the implant) on the primary-implant-stability as well as on the surrounding host-bone-architecture. In the present-study, our hypothesis is that that undersized drilling together with avoiding drilling to the full length of the implant might have a positive influence on primary-implant-stability and bone architecture as compared to the undersized surgical-technique alone.

2. Material and methods

2.1. Dental implants

Forty-four cylindrical screw-type implants (11 implants for each surgical-technique; n = 11) 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) was utilized to characterize the surface-topography of the implants (Fig. 1B).

2.2. Bone specimens

Femoral-condyles were obtained from four goats which were control animals from another study (approval Radboud University Nijmegen Ethics Committee # RU-DEC 2009-031). The bone samples were consisting of trabecular bone with an outer layer of cortical bone. The bone samples were obtained within two hours of animal death and stored on ice

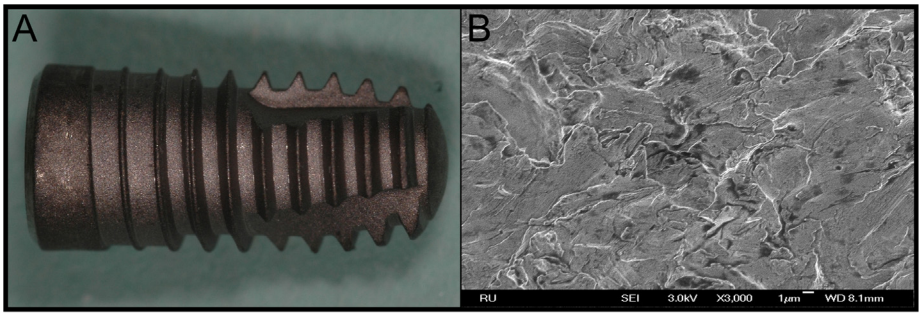

Fig. 1 A: Dyna® dental implant with the acid etched surface (dental engineering BV; Bergen op Zoom, The Netherlands). B: Surface of implant visualized by SEM showing a uniformly rough surface (magnification 3000×).

during transportation from the animal facility to the laboratory.

2.3. Implant installation

All osteotomies were prepared using a dental drill (Kavo® EWL Dental GMBH, Biberach, Germany) at a speed of 800 rpm with external cooling. Implants were placed by using four different surgical approaches:

Approach 1: standard osteotomy preparation procedure (according to the protocol of the manufacturer) was performed. Drilling was started using the pilot drill (2.0 mm diameter). Subsequently, the hole was extended by using a consecutive series of drills, i.e. 3.2, 3.6, and 4.0 mm in diameter. The depth for all drills used was 10 mm.

Approach 2: the same sequence of drills was used as for approach 1. However, the depth of 8 mm was employed for all drills resulting in a bone cavity of 8 mm in depth and 4 mm in diameter.

Approach 3: the same sequence of drills was used as for approach 1. However, the final drill (4.0 mm) was skipped. As such, the final bone cavity measured 10 mm in depth and 3.6 mm in diameter.

Approach 4: The same drilling procedure was followed as for approach 2. However, the final drill (4.0 mm) was skipped. The bone cavity was prepared up to 8 mm in depth and 3.6 mm in diameter.

2.4. Mechanical testing

Insertion-Torque Measurement: The Digital® torque gauge instrument (MARK- 10 Corporation, New York, NY, USA) was used for implant placement. The highest insertion-torque values ($n = 11$) were measured.

Removal-torque measurements: Out of 11 samples per approach, seven samples were utilized for removal-torque measurements. The bone-specimens with implants were embedded in a mould and placed on a support-jig before taking removal-torque measurements to stabilize the samples. Afterwards, a controlled and gradually increasing rotational force (displacement; 0.5 mm/min) was applied to each implant until implant was mobile. The peak-force at implant loosening was measured as a removal-torque value ($n = 7$).

2.5. Micro CT analysis

The four specimens of each surgical-technique were placed in 70% ethanol and used for micro-CT analysis. The bone samples containing one implant each were wrapped in Parafilm® (SERVA-Electrophoresis, Gmbh, Heidelberg Germany) to prevent drying of the bone during scanning. The specimens were placed on the sample holder of the micro-CT imaging system with a long axis of implant perpendicular to the x-ray beam (Skyscan-1072, Kontich, Belgium). All samples were scanned at a high resolution of 37.14 μm/pixel and a cone beam reconstruction were performed on all the projected files by using Nrecon VI.4 software (Skyscan-1072, Kontich, Belgium). Finally, a 3D model of the implant and the surrounding bone was constructed using a 3D creator software. After Micro-CT, histological preparations of the samples were performed as follows.

2.6. Histological preparations

The histological preparations were done as follows: the specimens ($n = 4$) were fixed in formaldehyde 4%, dehydrated in a graded series of ethanol (70–100%) and embedded (non-decalcified) in methylmethacrylate (MMA). After polymerization of the MMA, with a modified diamond blade sawing microtome technique, thin (15–20 μm) non-decalcified sections were obtained (Van der Lubbe et al.1988). According to previously documented protocol (Caulier et al., 1997; Tabassum et al., 2011a, 2011b), three sections were prepared from each sample. The sections were cut from the centre of the implant in a longitudinal direction parallel to the long-axis of the implant and stained using methylene-blue and basic-fuchsin.

2.7. Histomorphometrical analysis

Histomorphometrical analyses were performed, using a light-microscope (Leica-Microsystems AG, Wetzlar, Germany) and Image analysis software (Leica-qwin-pro-image, V 2.5, UK), to evaluate the bone response around the implants. Quantitative measurements were performed on both sides of the histological image for three different sections of each implant. The average of these six measurements was used for statistical-analysis. The quantitative-parameter calculated were: 1) %bone-implant-contact (%BIC) and 2)%bone-volume (%BV). %BV was calculated for three different zones around implant: the inner-zone (0–500 μm), the middle-zone (500–1000 μm), and the outer-zone (1000–1500 μm; Fig. 2B)

2.8. Statistical analysis

Data-analysis was performed by using SPSS-20.0 (IBM-product, Chicago-USA). Numerical data based on measurements of insertion-torque, removal-torque and %BIC was presented as mean & standard deviation. These data were explored for normality by checking the distribution of data for normality (Kolmogorov-Smirnov test), reveals sets of tested data following the Gaussian (or normal) distributions. One-way ANOVA was performed to compare results of insertion-torque, removal-torque and % BIC. Post-hoc Tukey's test was applied to compare pair-wise comparisons. P-value ≤ 0.05 was considered statistically significant difference of means.

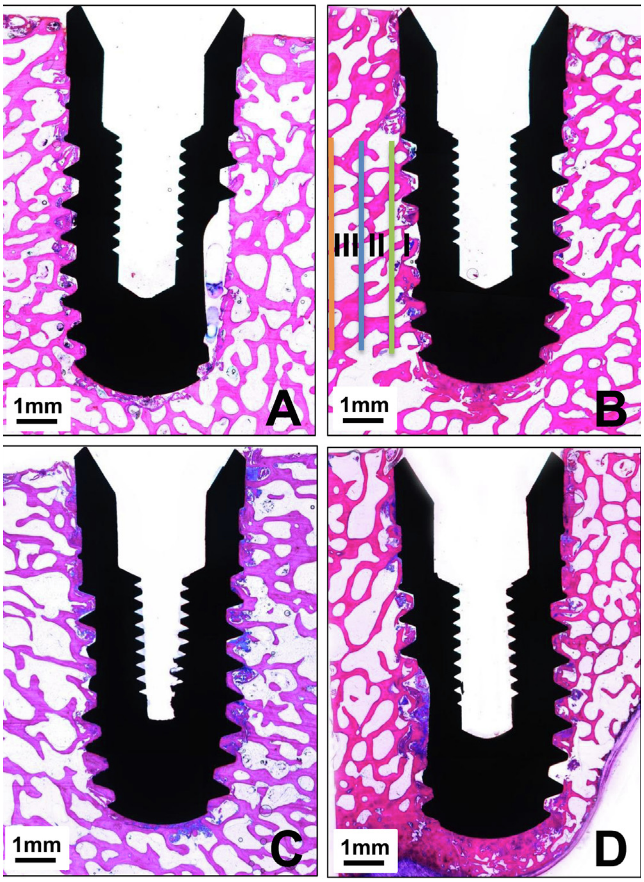

Fig. 2 An overview of histological sections of implants placed with different surgical approaches. A. Approach 1 (4, 10), B. Approach 2 (4, 8), %BV was calculated for three different zones around implant: I: the inner zone (0-500 μm), II: the middle zone (500–1000 μm), and III: the outer zone (1000–1500) μm. C. Approach 3 (3.6, 10), D. Approach 4 (3.6, 8), implant diameter and length respectively.

3. Results

3.1. Mechanical testing

The results of insertion and removal torque measurements are shown in Table 1. *Insertion-torque-values* were significantly higher for approach 2, 3 and 4 as compared to approach 1. There was no statistically significant difference between approach 3 and 4.

Removal-torque-values were significantly higher for approach 3 and 4 as compared to approach 1. There was no statistically significant difference between approach 2, 3 and 4.

3.2. Histology

In one specimen of the 16 installed implants, the bone on the left side (in close proximity to the implant) was damaged during retrieval. For this sample, histomorphometrical analysis was performed only on the right side of the three sections. The mean of these three measurements was taken. All other specimens were analyzed as initially planned. An overview of histological section of all applied surgical approaches is shown in Fig. 2(A–D). In the histological sections of approach-1, the trabecular-bone was found to be only in contact with the top of the screw threads (Fig. 3A). No bone condensation could be observed at the apex of the implant, although, some dislodged bone particles were seen at the apex of the implants (Fig. 4A). For approach 2 the implant was partially in contact with the trabecular-bone (Fig. 3B). Also, for this approach, several dislocated bone-particles could be observed between the implant-surface and host-bone. Bone densification/compression could be noticed at the apex of the implant (Fig. 4B). In approach-3 the inner area of almost all screw threads was completely filled with bone (Fig. 3C), as also the implant apex was completely in contact with the surrounding-bone. However, no clear bone-compression was observed at the apex of the implant. Some bone-debris could be observed in trabecular voids (Fig. 4C). The light-micrographs of the approach -exhibited that the screw threads were almost entirely filled with bone. Also, a lot of displaced bone-particles could be observed (Fig. 3D). Different from the other

Table 1 The mean ± SD (Ncm) of the insertion and removal torque values for four different surgical techniques are shown. Osteotomy diameter and Osteotomy length are in mm for Approach 1 (4, 10), Approach 2 (4, 8), Approach 3 (3.6, 10), Approach 4 (3.6, 8) respectively.

Group (n = 11)	Insertion-torque (Ncm)	Comparison	*P* value
Approach 1	53.5 ± 15.2	Approach 1 vs Approach 2	< 0.05
Approach 2	95.8 ± 27.7	Approach 1 vs Approach 3	< 0.05
Approach 3	92.9 ± 19.6	Approach 1 vs Approach 4	< 0.05
Approach 4	107.8 ± 22.1		
Group (n = 7)	Removal torque (Ncm)		
Approach 1	45.9 ± 13.2	Approach 1 vs Approach 3	< 0.05
Approach 2	72.9 ± 29.2	Approach 1 vs Approach 4	< 0.05
Approach 3	74.7 ± 25.1		
Approach 4	102.6 ± 22.5		

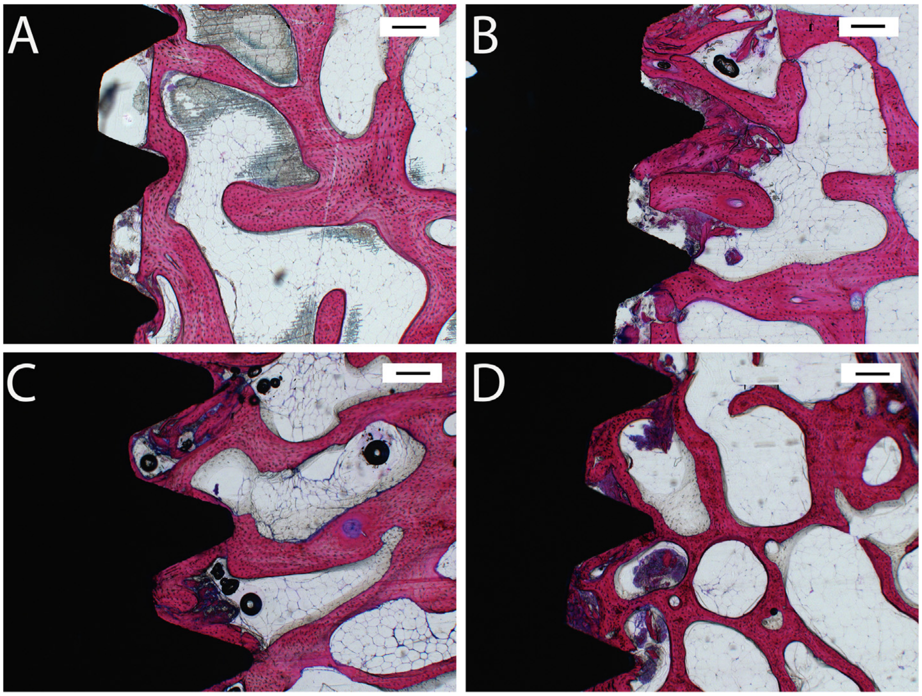

Fig. 3 Histological sections of implants placed with different surgical approaches. A: The implant inserted with the approach 1: The precise implant placement is observed. B: The implants placed with the approach 2: the implant was partially in contact with the bone. Many translocated bone particles were observed between the screw threads and in the trabecular voids. C: The implants installed with the approach 3: the bone was found in close contact with the major part of the implant and the inner area of the screw threads was filled with bone. However, no bone micro-fractures were observed. D: The implants placed with the approach 4: the implant was mainly in contact with the trabecular bone. Few translocated bone particles were also visible. No bone micro-fractures were observed.

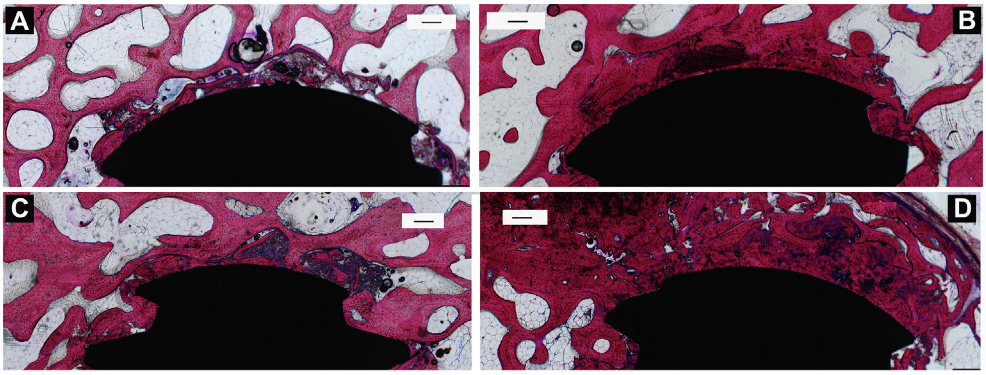

Fig. 4 Histological sections of implants placed with different surgical approaches. A: The implant inserted with the approach 1: no bone condensation could be observed at the apex of the implant. B: The implants placed with the approach 2: Significant bone condensation was seen at the apex of the implant. C: The implants installed with the approach 3: the apex of the implant was in close contact with the surrounding bone. Few translocated bone particles could also be observed. D: The implants placed with the approach 4: the compression of the trabecular bone surrounding the apex of the implant was clearly observed.

approaches especially 1 and 3, a much clear bone condensation was present at the apex of the implant. However, no micro-fractures could be observed in peri-implant-bone (Fig. 4D).

3.3. Histomorphometrical analysis

The results of %BIC are shown in Table 2. With respect to %BIC, significantly higher % BIC was measured for approach 3 and 4 as compared to approach-1 and approach-2. However, no significant difference could be observed between approach-3 and approach-4. Regarding %BV in inner-zone, significantly higher %BV was observed for approach-2 as compared to approach-1. However, no significant difference could be found between the different applied surgical-techniques for %BV in middle-zone and outer-zone (Fig. 5).

3.4. Micro CT analysis

The micro-CT 3D-image of the implant placed with approach-1 (according to the protocol of the manufacturer) is shown in Fig. 6. For the femoral-condyle of a goat, a well-defined trabecular structure was observed. The bone trabeculae were parallel to the long-axis of the implant. The apex of the implant is in contact with the surrounding

Table 2 The mean ± SD of the % bone-implant-contact (%BIC) are depicted for four different surgical techniques. Osteotomy diameter and Osteotomy length are in mm for Approach 1 (4, 10), Approach 2 (4, 8), Approach 3 (3.6, 10), Approach 4 (3.6, 8) respectively.

Group (n = 4)	%BIC	Comparison	*P* value
Approach 1	35 ± 3	Approach 1 vs Approach 3	< 0.05
Approach 2	41 ± 9	Approach 1 vs Approach 4	< 0.05
Approach 3	62 ± 12	Approach 2 vs Approach 3	< 0.05
Approach 4	58 ± 6	Approach 2 vs Approach 4	< 0.05

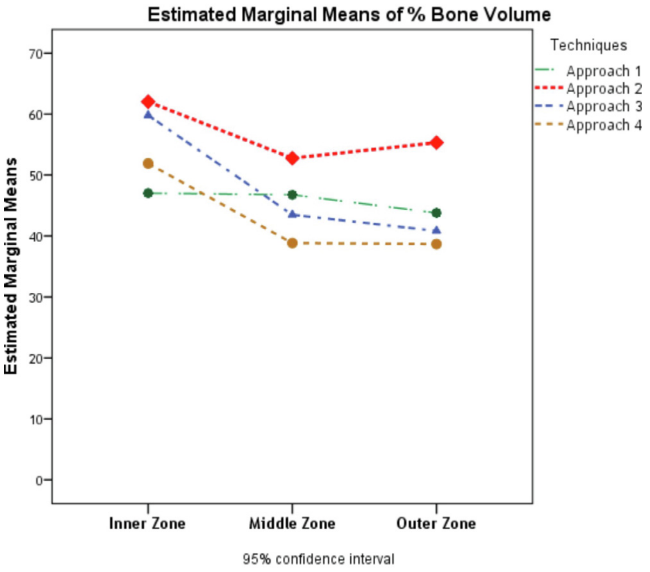

Fig. 5 The estimated marginal means of % bone volume with 95% confidence interval are presented for implants placed with the different surgical approaches.

bone indicating the accurate placement of the implant. In micro-CT-analysis, no difference could be observed between different surgical-approaches.

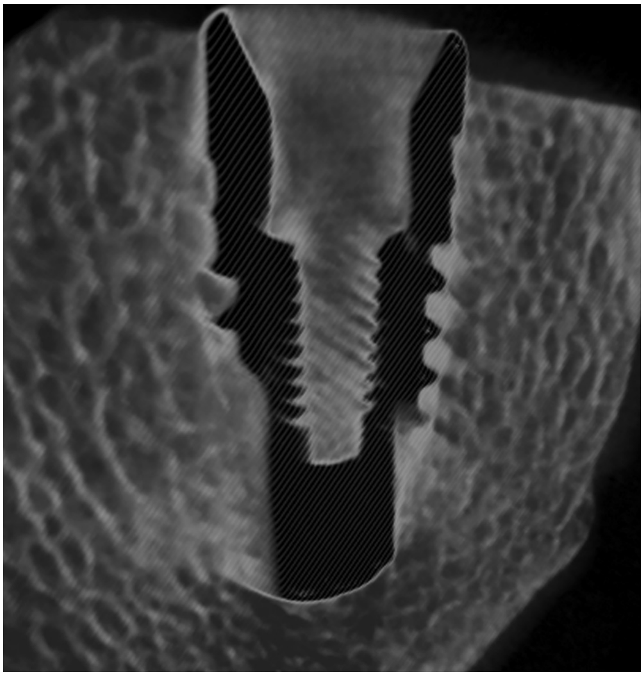

Fig. 6 Micro CT 3D image of an implant installed using approach 1. The femoral condyle of goat demonstrated a well-defined trabecular bone structure. The bone trabeculae were perpendicular to the long axis of the implant.

4. Discussion

At the time of surgical placement of the dental-implant, the mechanical engagement between the implant and host-bone ensures primary-implant-stability. Implant macro and micro design (thread-design, shape and length/diameter), drilling-protocol, and host-bone-architecture significantly impact the primary-implant-stability. In the present-study, a novel alternative surgical-approach has been introduced in which the combined effect of lateral/radial compression (size of the osteotomy smaller than the implant-diameter) and vertical/axial compression (length of the osteotomy smaller than the implant-length) of host-bone was investigated on primary-implant-stability and peri-implant-bone architecture. Data from the present study exhibited higher insertion-torques and removal-torque values for the surgical approaches 2, 3 and 4 as compared to approach-1. However, no statistically significant difference could be observed between approach 2, 3 and 4. Histomorphometrical analysis exhibited significantly higher %BIC for approach-3 (lateral compression) and approach-4 (lateral as well as axial compression) as compared to both the conventional technique (approach-1) and approach-2 (only axial compression). No micro-fractures were observed around the implant.

The present-study was designed to validate a new surgical-technique for implant placement and its effects on bone macro-architecture in vitro. The femoral condyle of goat was used in this study and this model was validated in previously published in vitro-study (Shalabi et al., 2006). It does not exemplify the structural shape of the mandible or maxilla and however, it consists of outer cortical-bone-layer and inner-cancellous-bone. Four goat samples were utilized in this in vitro study, and this did not impact the statistical model as animal-age, healing-potential, bone-quality and blood-supply mainly influence *in vivo* studies. In this study insertion and removal torque were used as indicators of primary-stability. Most common, well established methods for the measurement of primary-implant-stability for in vitro and in vitro studies are insertion-torque (IT), removal-torque (RT), pullout or push-out-test and resonance-frequency-analysis i.e., implant-stabi lity-quotient-values (ISQ) (Kay, 1992; Wong et al., 1995; Monje et al., 2019). Insertion-torque measurements is a wide-spread method for measuring primary-implant-stability due it's high reliability and good feasibility. Low insertion-torque values are considered as an indication of low primary-stability which might lead to implant failure (Martinez et al., 2001). In animal studies, removal/reverse torque testing has been widely used. The major disadvantage of this technique is that these are destructive in nature and couldn't be employed in clinical-setting (Sakoh et al., 2006; Monje et al., 2019). The resonance-frequency-analysis (RFA) have gain a lot of popularity for measurement of implant-primary-stability in recent years. Monje et al. (2019) have demonstrated that a strong positive statistical significance correlation exists between primary and secondary stability when RFA measurement tools are employed. No relationship between primary and secondary stability was observed by employing other tools of measurement such as IT. However, the study concluded that there is indecisive evidence regarding the impact of the degree of primary-stability on implant survival and marginal-bone-loss and best available method for accurate assessment of primary-implant-stability. Bayarchimeg et al. (2003) have reported a positive correlation between the IT and the ISQ values with respect to host-bone-density and cortical-bone thickness. However, regarding final-drill diameter, no correlation has been observed between IT and ISQ. Therefore, until now there is the lack of a gold standard for measuring implant-stability in clinical situation.

When inventorying only the effect of lateral/radial compression (undersized approach-3 versus conventional approach-1), it appears that lateral-compression enhanced the insertion and removal torque value as a representative of primary-implant-stability. This finding is in accordance with our earlier studies, performed on synthetic-bone-blocks (Tabassum et al., 2009; Tabassum et al., 2010a) and animal-studies (Tabassum et al., 2010b; Coelho et al., 2013; Campos et al., 2015). Also, with respect to axial-compression, higher insertion-torques were observed for approach-2 (solely axial-compression) as compared to approach-1 (conventional-technique). This indicates that engaging the apical part of the implant in host-bone resulted in higher primary-stability. Therefore, this technique might be used clinically during immediate placement of implants in fresh extraction sockets where primary-stability is mainly dependent on the apical engagement of implant. The lateral forces of compression might not influence the primary-stability significantly in this clinical situation, although axial-compressive forces might significantly improve initial stability. In a clinical study, Bahat (2000) has reported higher implant success rate in the bone of poor density by using axial-compression (only by avoiding drilling for the full length of the implant), however, exact details of the surgical-technique were not mentioned (Bahat, 2000, 1993).

With respect to conducting lateral as well as axial compression, for approach-4 higher insertion and removal torque values were reported as compared to the conventional approach-1. However, no significant difference was observed between approach 2, 3 and 4. In approach-4, lateral-compression of approximately 15% and axial-compression of about 20% were employed as compared to approach-3 where only 15% lateral-compression was induced to the surrounding bone. The interesting point to be noted is that no statistical difference of insertion-torque measurement was observed between approach-3 (15% radial-compression only) and approach-4 (radial-compression of 15% and axial-compression of 20%). These finding can be explained by the fact that the insertion-torque during implant placement depends on the interfacial pressure, p, that develops between the bone and implant (Norton, 2013) and this pressure depends on misfit between implant osteotomy and mechanical properties of bone and implant-diameter (Skalak et al., 2000; Norton, 2013). Moreover, press-fit in the cortical region of bone offers maximum stiffness and resultant higher primary-stability (Norton, 2013; Natali et al., 2009). Natali et al. (2009) has investigated the biomechanical effects of dental-implants with respect to press-fit phenomenon produced due to the difference between the implant-diameter and the drilled osteotomy. The study provided an insight into the bone-implant interaction and stress–strain induced in bone tissues, particularly, the mechanical response of bone. The implant and host-bone tissue interaction were variable in different regions of the implant such as micro-threads, macro-threads and apex of implant. Dental implant complete interaction with bone was only observed in the micro-threaded region. Around the macro-threads, bone-implant interaction was only observed at thread crests. In addition, it was reported that in the apical-region of the implant, limited interaction or no interaction was observed. In the present study, no further increase of IT was observed in approach-4 as compared to approach-3 because the misfit increase was only in the axial cancellous-bone and in the cortical compartment no further compressive forces were exerted. The high pressure especially within the cortical compartment results in unfavorable bone strain. Bone-tissue might be considered as a plastic material in its longitudinal-direction (3.1% elongation), however, this behavior is not observed in its transverse-direction (0.7% elongation) (Reilly and Burstein, 1975). Osteoclastic bone resorption always follows the micro-cracks in the bone which might occur due to excessive compression of the bone (Huiskes and Ruimerman, 2000; Verborgt et al., 2000; Guo, 2001). In a previous study, biological limits of misfit (Undersized osteotomy) in a radial-direction was observed and misfit of approximately 25% resulted in micro-fractures in the bone and lower biological or secondary stability (Tabassum et al., 2011a, 2011b). Therefore, in this study concept of combined radial and axial compression was introduced and no mico-fractures were observed in approach-4.

From biomechanical aspect, an undersized drilling is an effective method to enhance primary-stability in low-density-bone (Marin et al., 2010). Clinicians often prefer to place an implant in an undersized hole in case of type-IV quality-bone. However, sometimes they are unable to achieve optimal primary-stability by using manufacture's undersized protocol. In these clinical situations, they rely on their tactile stability perception to customize undersized drilling protocol to achieve higher primary stability (Berglundh et al., 2003). It has been demonstrated that in presence of excessive lateral compression, a profound decrease in implant stability might occur before secondary/biological stability is achieved by new bone formation (Coelho et al., 2013; Campos et al., 2015). Excessive lateral bone compression can result in inferior healing response due to rapid bone remodelling, micro-fractures and enhanced osteoclastic activity (Coelho et al., 2013; Campos et al., 2015). During early implantation period, osteotomy size plays a significant role in the healing response. A closed space between the implant threads and the host bone allows filling of blood and subsequent new bone formation compared with the situation where the bone is in very tight contact with the implant and there is little to no space (Coelho et al., 2010; Stocchero et al., 2016). The smaller the implant recipient-site as compared to the implant-diameter, the amount of remodelling at the implant-bone interface is more pronounced which might be detrimental to dental-implant-stability (Coelho et al., 2010; Stocchero et al., 2016). This is obviously against clinician's goal to achieve primary-stability which cannot be translated into long term biological or secondary stability. Therefore, by combining latera/radial and vertical/axial compression in such clinical situations, a higher primary-stability might be achieved without jeopardizing the bone healing response due to excessive lateral forces. Our goal with this approach is to achieve the rapid inception of secondary stability with minimal critical pressure to the poorly vascularized cortical-bone.

In the present-study, lateral-compression of approximately 15% and axial-compression of about 20% were employed on host-bone. This compression (solely and also in combination) contributed to increased primary-stability as compared to the conventionally placed implants. The key limitation of the present-study is that the magnitude of the stress, which is produced on the host due to this specific extent of disparity, is unknown and further animal studies should be performed to investigate the biological healing response around implants by using both vertical/axial and lateral/radial compression. In addition, other tools such as RFA should be employed for the assessment of primary as well as secondary implant-stability.

5. Conclusion

In conclusion, considering all data (insertion-torque-values, removal-torque-values, micro-CT and histomorphometric-evaluation), lateral and axial compression improved the primary-stability. Therefore, this novel surgical-technique could be considered as an option to enhance implant-stability especially in low-density bone and immediate implant-placement. Nevertheless, additional *in vivo* studies should be performed to evaluate if the enhanced stresses could not potentially frustrate a beneficial bone healing response when lateral as well as axial compression is employed. The current results warrant the continuation into further (pre)clinical studies.

Clinical relevance

Scientific rationale for study:

In our previous study, it was emphasized that undersized-surgical-technique has biological limits and over-compression of host-bone might lead to inferior bone healing response around implants.

Principal findings:

Data from the present study exhibited statistically significant higher insertion and rempval torque measurements and %BIC for the new surgical technique (in which implant osteotomy was preperad smaller in diameter and in length equated to implant diamter/length) as compared to conventional surgical technique for implant placement.

Practical implications:

This novel surgical technique could be considered as an option to enhance implant-primary-stability in clinical situations such as implant placement in Type-IV bone and immediate loading.

Ethical statement

We would like to certify that the research presented in this article is original, not under publication consideration elsewhere. The authors declare no potential conflicts of interest with respect to the authorship and/or publication of this article. In addition, Ethical approval for this study was taken from Radboud University Nijmegen Ethics Committee.

Declaration of Competing Interest

The authors declare no potential conflicts of interest with respect to the authorship and/or publication of this article.

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