A MECHANICAL EVALUATION OF IMPLANTS PLACED WITH DIFFERENT SURGICAL TECHNIQUES INTO THE TRABECULAR BONE OF GOATS

Manal M. Shalabi, DDS; Johannes G. C. Wolke, PhD; Anja J. E. de Ruijter, BSc; John A. Jansen, DDS, PhD

The aim of the study was to assess the effects of surgical technique and implant surface roughness on implant fixation. A total of 48 screw implants with machined or etched surface topographies were placed into the femoral condyles of goats. The implant sites were prepared by a conventional technique, by undersized preparation, or by the osteotome technique. Bone tissue responses were evaluated after 12 weeks of healing by removal torque testing and histologic analysis using scanning electron microscope. The cumulative removal torque value of the etched implants placed with the undersized technique (98 ± 29 Ncm) was higher (50 ± 35 Ncm) to a level of statistical significance than machined surface implants placed by the osteotome technique. Scanning electron microscope evaluation indicated that all implants showed interfacial bone contact. The torque test resulted in fracture at the bone-implant interface for all experimental conditions. Installation of etched implants using an undersized preparation of the implant bed resulted in superior bonding strength with the surrounding bone at 12 weeks after surgery. Evidently, the undersized preparation technique improved the early fixation of oral implants in this study.

Key Words: implant, surface roughness, mechanical test, surgical technique, in vivo model

INTRODUCTION

The long-term clinical efficacy of dental implants requires the establishment of a mechanically stable interface with complete apposition between the bone tissue and implant surface and without an intervening fibrous tissue layer. Besides implant surface chemical composition, surface roughness has been shown to be an important parameter in improving the bone tissue integration of dental implants. Various subtraction and addition techniques have already been used to modify the implant surface topography, such as grit blasting, acid etching, and plasma spraying. Nevertheless, contradictory results have been obtained, depending on the roughness amplitude and the method used to produce the surface roughness.

In addition to implant surface roughness, the surgical technique used for implant placement can have a major impact on initial implant stability. One surgical technique used to increase initial implant stability in low-density bone is to prepare an implant receptor site that is smaller in diameter than the implant to be placed. In this way, an osteocompressive fit between the implant surface and bone bed is achieved. Implant surface roughness can also affect interfacial shear stress, resulting in an increased resistance to loading. However, a drawback of all drilling techniques is that bone tissue is sacrificed during the drilling process. This shortcoming is exacerbated in situations where limited bone or bone...
of lesser density is available. In view of this, the osteotome technique was introduced to increase the primary stability of dental implants. This technique consists of first preparing a small-sized pilot hole, then compressing the bone tissue laterally and apically with a spreader or implant-shaped instrument. The goal of this technique is to replace the implant with a high degree of stability without removing additional bone, which is theoretically believed to improve final bone healing. This technique may hold promise for implants placed in low-density trabecular bone, for example, as present in the upper jaw; however, at the moment only a very limited number of experimental studies are available to support this suggestion about the efficacy of the osteotome technique. In addition, the available information is difficult to interpret and occasionally even contradictory. For example, Nkenke et al used a rabbit model to compare the osteotome technique with the conventional drilling technique. They showed that, 8 weeks after implant placement, the bone-to-implant contact ratio was not significantly different for the osteotome technique compared with the conventional implant placement. However, the researchers provided no mechanical data about the final fixation of the implants in the bone.

On the other hand, human clinical studies dealing with the osteotome technique suggest that a 100% success rate can always be achieved after implant loading, but the osteotome approach is mostly used for sinus elevation procedures in these studies rather than for implant socket preparation. Besides the use of the osteotome technique and the resulting osteocompression to achieve high initial implant stability, so-called “undersized drilling” can be used to create a wanted level of implant stability. The amount of required misfit between implant diameter and drill hole is determined by the bone density of the implant recipient site. This effect of drill hole diameter can be further affected by the shape and height of the implant surface roughness. In view of this, in the current study, the effects of surgical technique and implant surface roughness on final implant fixation were evaluated by mechanical testing of the implant and scanning electronic microscopic (SEM) evaluation of the bone-to-implant interface response after 12 weeks of healing.

**MATERIALS AND METHODS**

**Implant**

Forty-eight conically shaped, screw-designed oral implants (Biocomp Industries, Vught, The Netherlands) were used (Figure 1). All implants were made of commercially pure titanium, measured 10 mm in length, and had a diameter of 4.6 mm.

The implants were divided into 2 groups according to surface topography: turned (machined) group and grit-blasted and acid-etched (roughened) group.

Universal Surface Tester (UST, Wurzburg, Germany) was used to characterize the different surface topographies. The equipment included a diamond stylus, consisting of a 60° cone, which was moved across a surface with a load of 10 Nm. Three screws of each surface type were selected at random and measured.

**Animal model and implantation procedure**

Eight healthy, mature, female Saanen goats, aged 2 to 4 years and weighing about 60 kg, were used in this study. Before surgery, blood samples of the goats were taken to ensure that the animals were free of caprine arthritis-encephalitis. The animals were housed in a stable. National guidelines for the care and use of laboratory animals were observed.

General anesthesia was induced by an intravenous injection of pentobarbital and maintained by ethrane 2% to 3% through a constant volume ventilator administered through an endotracheal tube. The goats were connected to a heart monitor. To reduce the risk of perioperative infection, the goats were treated according to the following doses of antibiotics:

- During the operation—ampicillin (Albipen, Intervet BV, Boxmeer, The Netherlands) 15%, 3 mL/50 kg subcutaneously, and
- 1 and 3 days after the operation—ampicillin (Albipen LA, Intervet BV, Boxmeer, The Netherlands), 7.5 mL/50 kg subcutaneously.
To place the implants into the trabecular bone of the femoral condyles, the animals were immobilized on their backs, and the hind limbs were shaved, washed, and disinfected with povidone-iodine. A longitudinal incision was made on the medial surface of the left and right femurs, and the femoral condyles were exposed. Three holes were drilled in each femoral condyle at least 1 cm apart. The bone preparations were performed with a gentle surgical technique, using low rotational drill speeds (maximum 800 rpm) and continuous internal cooling. After preparation, the holes were irrigated and then packed with sterile cotton gauze to stop bleeding. Each femoral condyle had 3 implant sites, resulting in 6 implants, in each goat.

For installing the femoral implants, 3 different surgical approaches were used:

- **Approach 1—Press-fit technique:** After exposure of the condyle, a hole was drilled with a consecutive series of drills to a final diameter of 4.6 mm.
- **Approach 2—Undersized preparation technique:** The final drill used in the procedure had a diameter of 4 mm.
- **Approach 3—Osteotome technique:** A pilot hole was prepared with a drill of 2.55 mm in diameter. A series of consecutive osteotomes (spreaders) were then used to enlarge the diameter of the pilot hole to a diameter of 4.6 mm (osteotome diameters were 3.4, 4.0, and 4.6 mm). Each osteotome or spreader was left in place for 1 minute.

All implants were manually placed; however, in 6 goats a Digital torque instrument (MARK-10 Corporation, New York, USA) was used to measure the insertion torque value (Table 1). No significant differences in insertion torque were observed between the different implant surfaces and surgical techniques. After placement of the implants, the soft tissues were closed in separate layers using resorbable vicryl 3-0 sutures.

Evaluation of the bone fixation was planned at an implantation period of 12 weeks. At the end of the implantation period, the goats were killed by an overdose of pentobarbital (Nembutal Apharmo, Arnhem, The Netherlands) and the implants with surrounding tissue were retrieved for mechanical and SEM evaluation.

**Mechanical testing and interface evaluation**

For the mechanical testing, the goat condyles (8 condyles, 48 implants) were retrieved, and the specimens were stored on ice at a temperature of approximately 4°C. After arrival at the laboratory, implant fixation was measured using a torque removal test. The torque-measurement device detected and registered the torque necessary to remove the implant. The specimens were embedded in a mold with gypsum and placed on a support jig that was adaptable in multiple directions to ensure that a longitudinal force was placed on the implant. A tensile bench was used to slowly and gradually apply increasing torque (displacement 0.5 mm/min) to each implant until it loosened. When the peak force representing implant loosening was reached, the torque-out procedure was finished. After the mechanical testing, the torque-out specimens were divided in smaller samples containing 1 implant each. These samples were embedded in methylmethacrylate. After polymerization, the specimens were hemisectioned perpendicularly along the longitudinal axis of the implants with a diamond-blade sawing machine. Subsequently, the implant-containing surfaces of these specimens were polished, ultrasonically cleaned with 100% ethyl alcohol for 5 minutes and carbon coated for evaluation of bone-implant interface by SEM (JEOL 6310, Jeol Ltd, Tokyo, Japan) to determine the bone-implant response as well as where interface failure occurred during the torque test.

**Statistical analysis**

Mean values and SDs were calculated. One-way analysis of variance with a Tukey test was used to compare the differences between groups. Differences were considered significant when $P < .05$. All calculations were performed using GraphPad Instat 3.05 software (GraphPad Software Inc, San Diego, CA).

**Results**

**Surface topography characterization**

Surface topographic evaluation demonstrated that both experimental surfaces differed in surface rough-
The machined surface showed an average surface roughness value ($R_a = 0.45 \mu m$) that was significantly lower than that of the etched surface ($R_a = 1.47 \mu m$). The values for the parameter $R_{sk}$ (Table 2) showed that the 2 surfaces had a positively skewed surface; the surfaces consisted of more peaks than valleys. Although the data appeared to indicate that the etched implants had a higher $R_{sk}$ mean value, statistical testing revealed that the difference was not significant (Table 2).

### Experimental animals

Throughout the experimental period, the test animals appeared to remain in good health. At sacrifice, no clinical signs of peri-implant inflammation or adverse reactions were clinically observed.

### Mechanical testing

The results of the torque measurements are listed in Table 1 and depicted in Figure 2. The highest mean removal torque value (98.5 ± 28.5 Ncm) was observed for the etched implants installed with the undersized approach. Nevertheless, statistical testing showed that a significant difference existed only between etched implants placed using the undersized approach compared with machined implants placed using the osteotome approach (Table 1).

### SEM evaluation

In general, all implants showed new bone formation and interfacial bone contact. Implants with high failure values showed a lot of bone formation and a good interfacial bone contact (Figure 3). On the other hand, all implants with a low failure value showed the presence of fibrous tissue over a considerable length of the implant surface (Figures 4). The torque test resulted in a fracture at the bone-implant interface. Fracture was especially observed in the area where close bone-implant contact was achieved (Figure 5).

Machined implants showed the presence of more bone between screw threads in the coronal portion of the implant compared with the apical part. In this area, the implants were partly lined with soft tissue consisting of fibrous connective tissue. In the area where the bone was in close contact with the implant surface, bone tended to grow down to the bottom of the threads (Figure 6). In approach 1, trabecular bone was seen to be in contact with tips of the screw threads. In approach 2, the amount of bone implant contact was less prominent compared with etched implants. In approach 3, a considerable area of the implant surface showed fibrous tissue formation.

Etched implants appeared to support more bone growth than the machined implants. Bone was in contact with the entire implant surface, including the inner diameter of the screw threads. Frequently, all screw tips were in contact with bone tissue (Figure 7 and 8). In approach 2, most screw threads were filled with bone tissue, both along the superior and inferior flank as well as the root area of the screw thread.

### Discussion

The aim of this study was to investigate the effect of surface roughness and different surgical techniques on the mechanical fixation of titanium oral implants 12 weeks after installation.
The main finding of this in vivo study using the goat model was that the etched implants placed with an undersized approach showed the highest removal torque values.

To obtain information about the strength of the bone-implant interface, mechanical evaluation of retrieved implants must be performed. For threaded implants, the most appropriate choice is the use of torque testing. In addition a thorough analysis of the fractured interface is necessary after the torque testing to determine whether the torque failure is indeed caused by failure of the bone-implant interface. Reverse torque testing primarily places shear forces on the root-form implant around its cross section, although it is important to keep in mind that this method of loading may not directly relate to long-term clinical application.22

Other comparable studies have been performed by such researchers as Buchter et al,15 who placed implants with surfaces that were sandblasted with large grit and acid etched (ITI SLA, Straumann GmbH, Freiburg, Germany) in the tibial metaphysis of minipigs. They compared osteotome preparation with an undersized preparation technique in which there was a discrepancy of 0.6 mm between the last drill and implant diameter; in other words, the last spiral drill was 3.5 mm in diameter and the implant was 4.1 mm in diameter. After a healing period of 28 days, removal torques values were 111.5 and 59 Ncm for undersized and osteotome techniques, respectively. Their reported results were comparable to the etched undersized and osteotome preparation groups in the present study.

However, it has to be noted that most of the reported studies showed a wide variation in their respective animal models, as well as implant location.23–27 Further, it is known that local bone conditions (quantity and quality) vary notably between various animal species.28 Therefore, comparison and extrapolation of data with other studies is complex.
and can result in misinterpretation. As a consequence, bonding-strength data are only true for a specific experiment performed under strictly specific conditions. Basically, the difference between the undersized and osteotome technique is the degree of bone compression. Both approaches result in bone compression around the implant, but in the osteotome technique the compression is clearly higher because of force-fitting stresses, which arise when an implant is placed into an implant bed of smaller diameter. They showed that substantial stresses can be generated even when the diameter of the implant is only 100 µm smaller than the hole in the bone. In view of this, the current failure of the osteotome technique to show the best result can be attributed to the high stress on the bone surrounding the implant bed in combination with the relatively high density of the trabecular bone of the femoral condyles. It has to be emphasized that the osteotome technique is designed to be used in type 4 bone, whereas the density of condylar trabecular bone is somewhat higher. Unfortunately, no appropriate implant locations are available in large animals that both meet this bone-type requirement and provide adequate available bone for installing implants. Furthermore, it cannot be discounted that a 3-month healing time is already too long because it results in remodeling of the newly formed bone tissue and a decrease in bone volume.

In view of the present findings, some commentary is warranted on the final biological effect of implant surface morphology. Abrahamsson showed similar characteristics with resorptive and appositional events for both grit-blasted and acid-etched (SLA) and turned surfaces, but the rate and degree of osseointegration were superior for the SLA compared with the turned implant surfaces. Rosa and Beloti suggested that, for titanium implants, Ra values ranging from 0.80 to 1.90 µm optimized both intermediary and final cellular responses; however, they did not affect the initial response, whereas smoother surfaces did not favor the cellular response at all. It has been implied that surface roughness changes the type and amount of protein adsorbed to the implanted material. Further, surface roughness changes the type and amount of protein adsorbed to the implanted material.
roughness may also influence cell spreading. Some researchers have theorized that, on rough materials, cells form attachment sites on different peaks of the implanted material. In contrast, cells on a smooth material will form all their attachment sites in one plane, on the ventral side of the cells resulting in larger lateral spreading. Attachment sites are linked to the cytoskeleton, which is involved in generating mechanical tension within the cell. The degree of spreading may influence the amount of force generated within the cells, which may directly influence biochemical signals in the cell.

In this way, surface roughness may directly influence the phenotype and gene expression of cells on a titanium surface. Increase may directly influence the phenotype and gene fixation in a rabbit bone model for 12 weeks healing.

Studies, implants with an average surface roughness of 0.9 to 1.3 μm were found to be optimal for bone fixation in a rabbit bone model for 12 weeks healing.

Finally, a comparison has to be made between the current study and its predecessor, an in vitro study where similar implants and surgical techniques were used. This in vitro study showed that, directly after placement, the insertion and removal torque values for etched implants placed using an undersized technique were higher compared with machined implants, and the initial amount of bone-to-implant contact was higher for the etched implants. Although a direct cellular effect of surface roughness cannot be excluded, this initial higher amount of bone contact could still be the reason for the higher removal torque of the etched implants from undersized sites in the present in vivo study. In view of this, a thorough histologic and histomorphometric assessment has to be performed to determine the amount of bone contact 12 weeks after placement of the implants.

CONCLUSIONS

Supported by the mechanical failure data, it was concluded that etched implants placed using an undersized approach resulted in superior bonding strength with the surrounding bone and appear to improve the early fixation of oral implants.

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REFERENCES


