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Histological and Biomechanical Aspects of Surface Topography and Geometry of Neoss Implants. A Study in Rabbits.

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This experimental study showed evidence of surface mediated bone formation on the bimodal titanium surface as previously described for other commercially available surface modified implants. Removal torque tests showed increased stability by adding a modified surface and vertical flutes as compared to turned control implants without flutes.

INTRODUCTION

Osseointegrated implants are clinically successful if a direct bone-implant contact can be established and maintained (Albrektsson et al. 1981). The bone-implant interface is biomechanically challenged in rotational, axial and lateral directions during healing, the prosthetic phase and clinical function. The ability to withstand loading is decisive for the clinical outcome and factors of importance are (i) type and magnitude of loading, (ii) the quality of the bone-implant integration and (iii) the mechanical properties of the surrounding bone. Implant integration is time dependent and the biomechanical properties of the bone-implant interface improve with time (Johansson et al. 1987, Sennerby et al. 1993, Friberg et al. 1999). Therefore, the use of a two-stage procedure with three to six months of healing usually ensures a mature bone-implant interface and good clinical results. However, the trend today is to use immediate/early loading protocols, which make great demands on the bone-implant interface since the implants will be loaded during initial healing.

The first generation of osseointegrated implants had a relatively smooth (machined, turned) surface (Brånemark et al. 1969). Good long-term clinical outcomes have been reported on all indications when used in good bone qualities and using a two-stage procedure (Albrektsson & Sennerby, 1991). However, in more challenging situations such as low bone densities, bone grafting and immediate loading, increased failure rates have been reported (Friberg et al. 1991, Becktor et al. 2004, Glauser et al. 2001). Surface modification is one way of improving implant integration and stability, as shown in numerous experimental studies (Albrektsson & Wennerberg 2004). It is believed that the surface irregularities ensure a firm contact with the blood clot allowing primitive cells to migrate to the interface, differentiate to osteoblasts and form bone directly on the surface (Davies 2003). For a smooth surface, shrinkage of the blood clot will create a gap at the interface and cells cannot reach the surface (Miranda-Burgos et al. 2007). Thus, implants with a moderately rough surface integrate more rapidly and with more bone contacts than smooth surfaced implants (Ivanoff et al. 2001, Zechner et al. 2003).

A second means of improving implant integration is by geometric features. Most dental implants are self-tapping and have an apical configuration including cutting edges and bone chambers. Bone ingrowth into such voids is most likely to increase the rotational stability of the implant. Recent research has indicated that grooves at the thread flank may lead to improved healing by guided bone formation as well as to an improved interlock with bone (Hall et al, 2005). The Neoss implant is a self-tapping implant with apical bone chambers and vertical flutes. It has a bimodal surface topography which is produced by blasting with two different sizes of ZrO and Ti-based particles. The influence of the surface topography and geometry on the bone tissue response and stability is presently not known.

The present study was conducted to examine the early tissue responses to the bimodal titanium surface. The aim was also to evaluate the effect of surface topography and geometrical features on rotational stability.

MATERIALS AND METHODS

Implants

A total of 96 implants, 7 mm long and 4.0 mm in diameter were implanted in the study. These were both original and modified Neoss implants (Neoss Ltd, Harrogate, UK) as follows (fig. 1);

- 48 implants with a bimodal surface created by blasting with 100 to 300 µm wide ZrO_2 spheres followed by irregularly shaped Ti-based particles, 75 to 150 µm wide (Fig 2).
  - 36 with vertical flutes (original surface and geometry)(B+)(Fig 3a)
  - 12 without flutes (B-)(Fig 3b)
- 24 implants with turned surfaces
  - 12 with two vertical flutes (original geometry) (T+)
  - 12 without flutes (T-)
- 24 other implants used for another investigation.

FIgure 1. The four types of implants used in the study; (L to R) bimodal surfaced fluted and non-fluted and two with turned surfaces.

Animals, anaesthesia and experimental protocol

A total of 12 female New Zealand white rabbits were used in the study, after the protocol had been approved by the animal ethics committee of the Gothenburg University.. General anesthesia was induced by intramuscular injections of fluanisone-fentanyl (0.7 mL, Hypnorm™, Helsingborg, Sweden) and intraperitoneal injection of diazepam (0.25 mg/kg, Apozepam™, Alpharma AB, Stockholm, Sweden). Local anesthesia was induced at both proximal tibial metaphyses and distal femoral condyles by injections of lidocaine (about 2 mL, Xylocaine®,Astra Zeneca AB, Södertälje, Sweden).

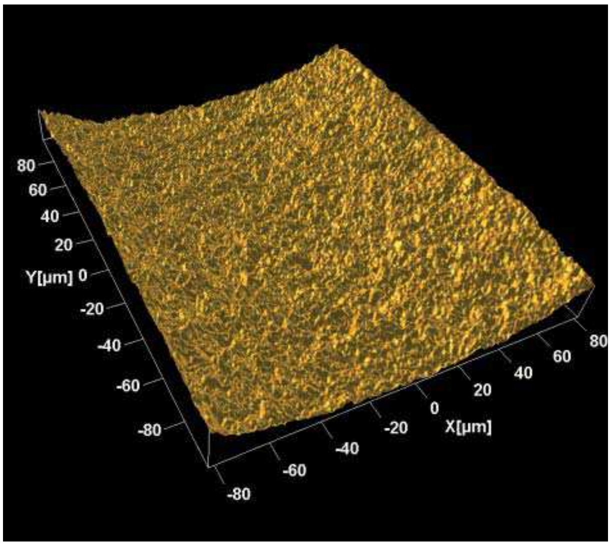


FIgure 2. Three-dimensional view of the bimodal surface topography at a thread flank.

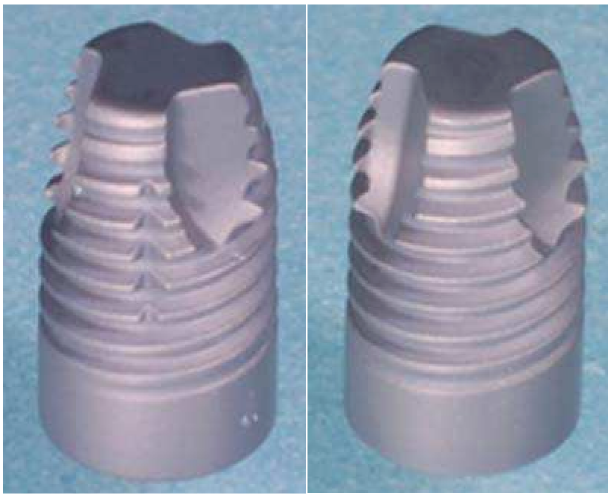


Figure 3a. Close up of an implant with bimodal surface and vertical flutes (B+). 3b. Non-fluted bimodal implant (B-)

The distal femoral condyles and proximal tibial metaphyses were used as experimental sites. The bone was exposed via incisions through skin and fascia. Two implant sites were prepared in each femur and tibia; each animal receiving 8 implants. Implants were selected by a rotational scheme, so that one each of T+, T-, B+ and B-implants were placed in the femora of each animal. Two B+ and two B- implants were placed in the tibiae of each animal. Cover screws were placed and the flaps were closed with resorbable sutures. The animals were allowed to heal for three (n=4) and six (n= 8) weeks after surgery.

Removal torque

After six weeks of healing, the femoral implants in eight animals were subjected to removal torque (RTQ) test. The tests were performed in a specially designed rig using a motor-driven device. A linearly increasing torque was applied until failure of integration occurred; the peak value in Newton-centimeters

(Ncm) was recorded. A mean value was calculated for each of the four implant types. The percentage difference from that of turned implants without vertical flutes was calculated for each of the other groups. The Wilcoxon Signed Rank test was used for statistics and a difference was considered if $p < 0.05$.

Histology
All implants and surrounding bone tissues were retrieved and fixed by immersion in a 4% buffered formaldehyde solution. The specimens were then dehydrated in a graded series of ethanol and embedded in light curing methacrylate (Technovit® 7200 VCL, Kulzer, Friedrichsdorf, Germany). Ground sections, approximately 10 µm thick, were prepared using a sawing and grinding technique (Exakt Apparatebau®, Norderstedt, Germany). One central section was taken from each implant site, stained with Toluidine Blue and examined in a Nikon light microscope.

RESULTS

Light microscopy of the three-week specimens of the bimodal implant surface revealed bone formation directly onto the implant surface (Fig. 4a). This could be seen as thin rims of bone following the contour of the implant threads (Figs. 4a and b) and as solitary islets with no obvious connection to existing bone surfaces (Fig. 5). Osteoblastic seams were often seen on the bone rims, facing the adjacent soft tissues (Figs. 4b and 6). Non-bone areas consisted of a loose connective tissue rich in cells and vessels and devoid of signs of inflammation (Figs. 4a-b, 5 and 6). A more mature bone-implant interface was seen in the six-week specimens and a larger proportion of the implant surface was in contact with bone (Fig. 7).

The removal torques were found to be correlated with surface topography and the absence or presence of vertical flutes (Fig. 8); the lowest torques were recorded for machined implants without flutes and the highest for bimodal surface implants with vertical flutes ($p<0.05$)(TABLE 1).

DISCUSSION

The present study indicated that the bimodal topography induced bone formation directly at the implant surface as previously described for other commercially available surface modified implants (Piattelli et al.

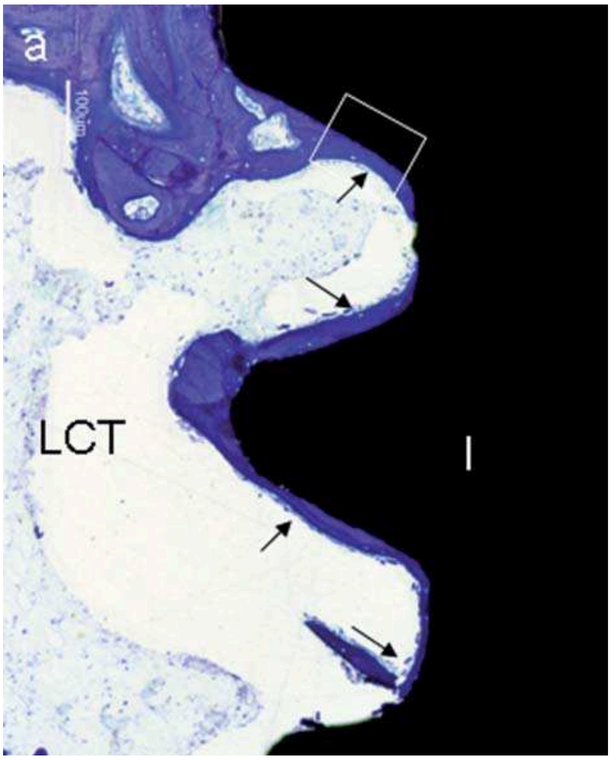
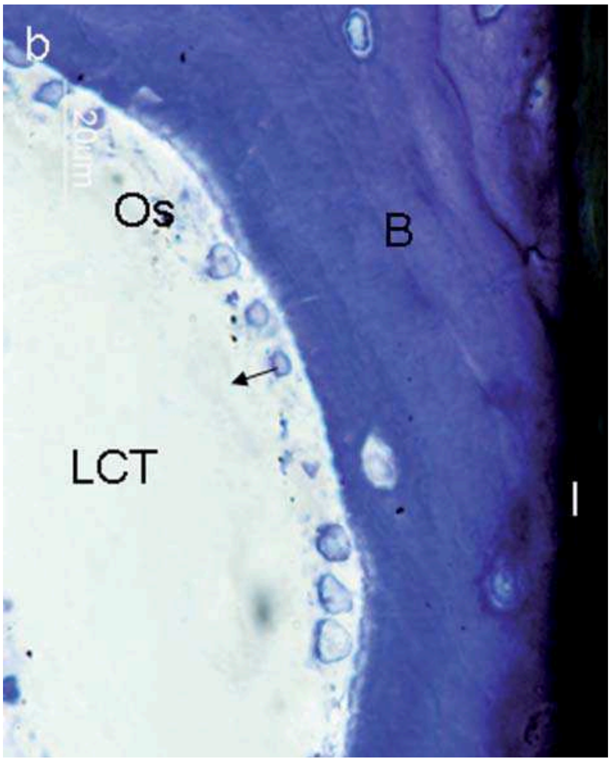


FIgure 4. Light micrographs showing Neoss implants after three weeks of healing.
a/ Overview showing thin rims of bone following the contour of the threads (Arrows), I = implant, LCT = loose connective tissue.
b/ Close up of a. Bone (B) has been formed directly on the implant (I) surface. Osteoblasts (Os) and osteoid can be observed on the surface of the bone facing a loose connective tissue (LCT).



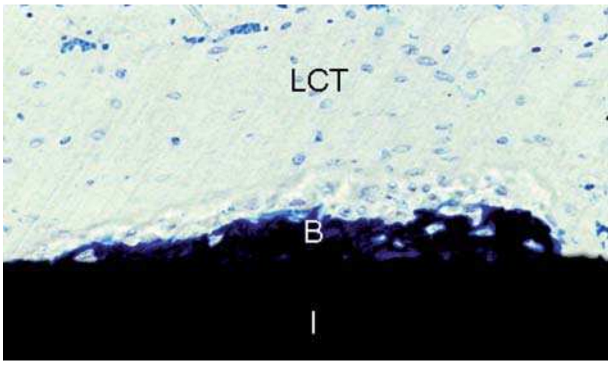
Turned (T-)	Turned with flute (T+	Bimodal (B-)	Bimodal with flute (B+)
42.4 (15.4)	44.4 (15.0)	46.9 (13.2)	58.5 (13.2)*

* P<0.05 compared with T- implants

Table 1. Results from removal toruqe measurements.

1996, Ivanoff et al. 2001, Rocci et al. 2003, Berglundh et al. 2003). This was seen as seen thin rims or solitary islets of bone at the surface with osteoblastic seams facing the adjacent bone marrow. Previous descriptions of the healing of smooth, turned implants have reported bone formation from the adjacent tissues and towards the implant surface (Sennerby et al 1992, Palma et al. 2006, Miranda-Burgos et al. 2007). The mechanisms behind the different integration pathways are probably related to the integrity of the blood clot-implant interface during the early events of bone healing (Davies 2003). With a rough surface, the clot can maintain a firm contact in spite of shrinkage, whereas a gap may be formed at a smooth implant surface. In the former case mesenchymal cells can migrate to the implant surface, differentiate and start to produce bone matrix. The influence of surface modification on the clinical outcome is not clear. For instance, clinical studies comparing titanium-plasma sprayed and turned surfaces or TiO2 blasted and turned surfaces could not find any statistically significant differences with regard to survival rate and marginal bone loss (Åstrand et al. 2004a, 2004 b). However, other non-comparative studies have indicated better survival rates for surface modified than for turned implants in challenging clinical situations such as bone grafting (Brechter et al. 2005) and in immediate loading (Glauser et al 2001, 2003).

Figure 5. Light micrograph after three weeks showing solitary bone formation (B) at the apical part of the implant (I) facing a loose connective tissue (LCT) rich of cells.



Since the trend today is to use immediate/early loading, the use of surface modified implants is preferable.

The removal torque tests revealed an improved resistance to torque with modified topography and a vertical flute added. This is best explained by ingrowth of bone into micro- and macroscopic undercuts at the surface. Hall et al (2005) showed that a macroscopic

Figure 6. Light micrograph showing bone formation at the bottom of a thread after three weeks of healing. New bone (NB) is formed by osteoblasts (Os) on previously formed bone (PB) and separated by a cement line (white arrow). LCT = loose connective tissue

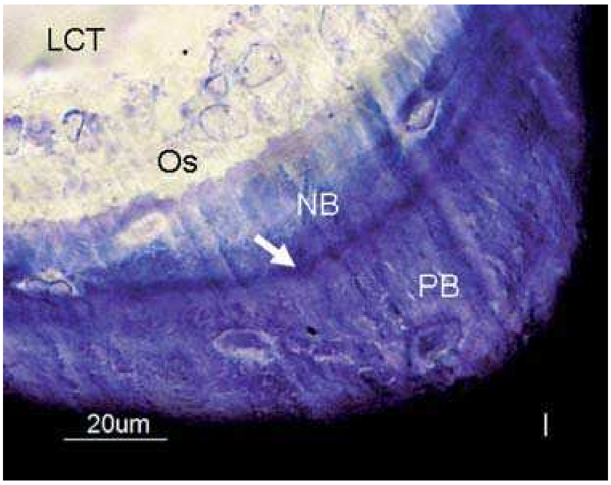
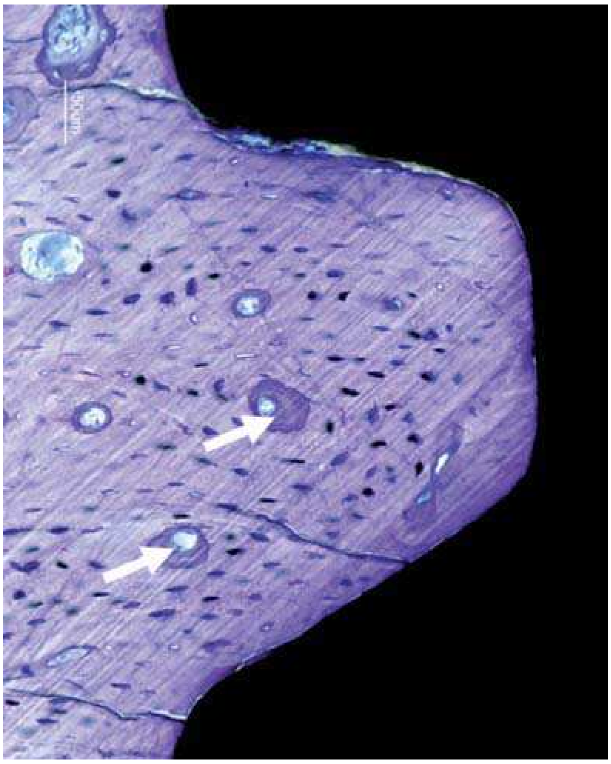


FIgure 7. Light micrographs after 6 weeks of healing showing almost complete bone filling of a thread with mature bone. Arrows point at newly formed secondary osteons indicative of remodelling.



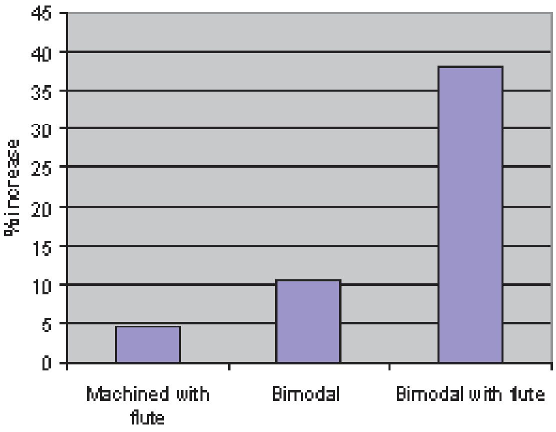


Figure 8. Graph showing the percentage change of removal torque in comparison with turned implants without vertical flutes (T-). * p< 0.05

groove added to the thread flank can stimulate bone formation over the implant surface. The relatively small effect of surface topography may be explained by the design of the test implants, since they all had apical undercuts, i.e. cutting edges and bone chambers.

CONCLUSION

The present experimental study showed evidence of surface mediated bone formation at the bimodal surface as previously described for other commercially available surface modified implants. Removal torque tests showed increased stability with the modified surface and adding vertical flutes when compared to turned control implants without flutes.

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