Effects of Implant Design and Surface on Bone Regeneration and Implant Stability: An Experimental Study in the Dog Mandible

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ABSTRACT

Background: Previous experimental studies have shown a higher degree of bone–implant contact for surface-enlarged implants compared with machined implants. Yet, there is insufficient evidence that such implants show higher stability and an increased survival rate.

Purpose: The purpose of this investigation was to study the integration and stability of grit-blasted implants with retention elements on the implant neck, with and without marginal bone defects, compared with machined implants without retention elements.

Materials and Methods: After tooth extraction of the mandibular premolars in six dogs, two grit-blasted, partly microthreaded Astra Tech implants and one standard Brånemark implant were bilaterally placed in each dog. On one side, 3 × 3 mm large buccal defects were created, to expose three to four implant threads. The contralateral side served as control, and no defects were made. The animals were sacrificed after 4 months of healing. Implant stability was measured using resonance frequency analysis at implant installation and after 4 months of healing. Histologic and histomorphometric evaluation was made after 4 months of healing.

Results: Resonance frequency analysis indicated that all implants in the test and control groups were osseointegrated after 4 months, with a tendency toward higher implant stability for the Astra Tech implants. There was a statistically significant higher increase in resonance frequency for the Astra test implants compared with their corresponding controls. Histology and histomorphometry showed well-integrated implants with varying degrees of bone repair at the defect sites. The greater bone–implant contact for the Astra implants was statistically significant. No significant difference between the implants in amount of bone filling the threads was recorded.

Conclusions: The Astra Tech implants tested showed a higher degree of bone–implant contact and higher level of bone regenerated at defect sites compared with the Brånemark implants. Resonance frequency analysis demonstrated a significantly higher increase in the Astra test implants compared with their control groups than did the Brånemark test implants versus their controls.

KEY WORDS: bone regeneration, implant design, implant stability

Adequate bone, in width as well as in height, is one prerequisite for successful anchorage and good long-term prognosis of oral implants.[1,2] Lekholm and colleagues suggested that at least 1 mm of supporting bone should be present at the linguopalatal and facial aspects of the implant to achieve a good prognosis.[2] This is sometimes difficult to obtain, owing to lack of alveolar bone that may lead to exposure of implant threads. Exposed threads have been speculated to cause mechanical irritation of the surrounding soft tissues and inferior mechanical stability of the implant.[3] However, these theories have not been proven.[4,5]

Several investigations have described techniques to facilitate placement of implants in sites with deficient bone volume. Bone grafting and guided bone regeneration (GBR) procedures have shown predictable results

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when used for this purpose.[6–15] However, healing of alveolar bone defects without the guide of membranes also has been observed.[11,16,17]

Design and surface features may have an influence on the bone healing and remodeling around implants. al Sayyed and co-workers showed that marginal bone loss occurred along a machined surface, whereas the bone level was stable along a rough implant surface.[18] Bone resorption along the machined surface was believed to be a result of lacking mechanical coupling. Other experimental studies have shown a higher degree of bone–implant contact and more bone filling the threads, for implants blasted with titanium oxide grits compared with implants with a machined surface.[19,20] However, whether these morphometric results imply higher stability for the blasted implants has not been shown.

Resonance frequency analysis (RFA) is a well-documented procedure that allows for repeated measurements of implant stability.[21–23] With this method, implant stability is assessed by measuring the resonance frequency of a transducer attached to the implant. The resonance frequency is related to the distance from the transducer to the marginal bone level, as well as to the stiffness of the surrounding bone. The technique allows for comparison between different implants as well as individual monitoring of changes in implant stability.

The objective of the present experimental investigation was to determine whether a grit-blasted implant with retention elements on its marginal third part influences the healing of marginal bone defects and the stability of the implant.

MATERIALS AND METHODS

Animals and Surgery

Six 2-year-old greyhound dogs of both sexes were used in the study. They were kept separated in purpose-designed cages and fed ad libitum with a standard laboratory diet. The animals were anesthetized with general anesthesia. Local anesthesia (3 mL 0.5% Marcain®, Astra AB, Södertälje, Sweden) was administered in the surgical area. Following a crestal incision, mucoperiosteal flaps were elevated on the buccal and lingual sides in the lower premolar regions and two of the premolars, P2 and P3, were removed bilaterally. The two extraction sockets, P3 and the posterior extraction socket P2, were used. In all cases, the implants were wider than the extraction sockets. Standard drilling procedures were used. Bone defects 3 × 3 mm, were surgically prepared on the buccal side of the implant sites in one of the quadrants (test quadrant). The other quadrant served as control, with the buccal plate left intact (Figure 1). In three animals the right side served as the test site, and in the other three animals the left side served as test. After placement of the fixtures and cover screws, the flaps were sutured for complete coverage of the wound. Analgesics (Aspromazine, Intervet, Australia) was used to reduce postoperative pain. Antibiotics (Depomycin, Intervet, 400 mg/d) were administered for 4 days. Tooth cleaning was carried out two to three times weekly. Body weight assessment was monitored monthly. At the end of the study, after 4 months, the animals were euthanized by an overdose of barbiturate. The study was approved by the local ethics committee for animal research.

Implants and Resonance Frequency Analysis

Brånemark System implants (3.75 × 8.5 mm, Nobel Biocare AB, Göteborg, Sweden) and Astra Tech implants (Fixture ST 4.5 × 9 mm and Fixture Microthread 4.0 × 9 mm, Astra Tech AB, Mölndal, Sweden) were used.

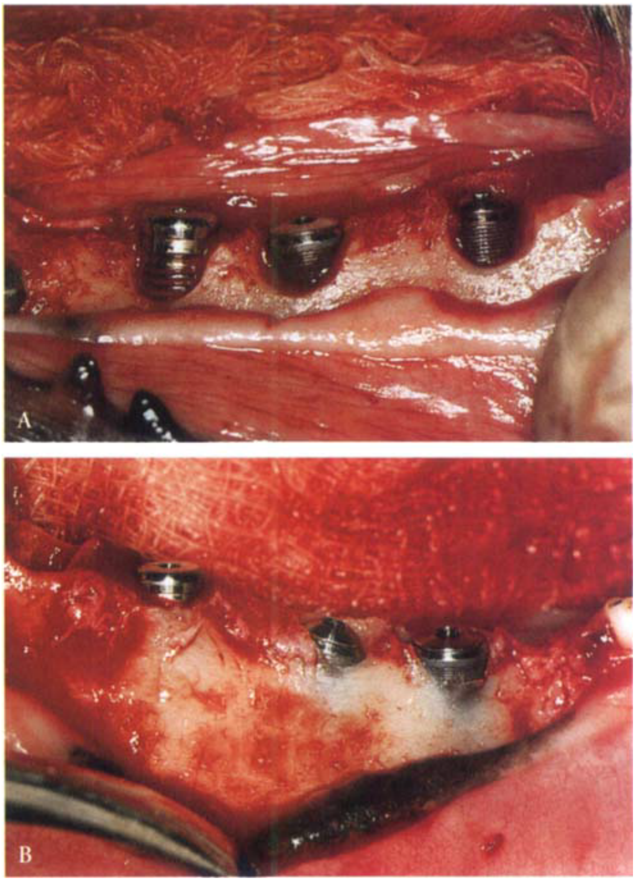

Figure 1. Clinical appearance of *A*, a test site with 3- × 3-mm buccal dehiscences, and *B*, a control site.

The Astra Tech ST fixture has a tapered marginal part with microthreads and is grit-blasted with TiO_2 (TiOblast™). The Microthread fixture is a similar microthreaded implant with the same surface but without the tapered top. All animals received six implants, three on each side of the mandible. The placement of the implants was randomized and paired. All implants were installed with good primary stability. After implant installation, RFA was performed. The transducer was attached to the implants one in turn (Figure 2). In brief, the transducer comprises a modified cantilever beam to which two piezoceramic elements are attached. The beam is vibrated by exciting one of the piezoceramic elements with a sinusoidal signal of increasing frequencies from 5 to 15 kHz by means of a frequency response analyzer and a personal computer. The second piezoceramic element measures the response of the beam. At the first flexural resonance of the beam, there is a marked increase in amplitude and change in the received signal. The resonance frequency is related to the stiffness of the bone–implant interface and the distance from the transducer to the marginal bone. A second resonance frequency measurement was made in conjunction with sacrifice.

Histologic Processing and Evaluation

After sacrifice, the implants with surrounding bone were removed en bloc, and the specimens were fixed by immersion in 4% buffered formaldehyde. The specimens were then dehydrated in a graded series of ethanol bath and embedded in light-curing plastic resin (Technovit® 7200 VCL, Kullzer and Co., Wehrheim, Germany). Following embedding in the acrylic resin, the blocks were sectioned in the buccolingual plane and through the long axis of each implant by sawing and grinding (Exakt Apparatebau, Nordstedt, Germany). The sections, about 10 μm thick, were stained with 1% toluidine blue and 1% pyronin G.

The sections were examined and photographed in a Leitz Orthoplan® microscope (Wetzlar, Germany). A Leitz Microvid® system connected to the microscope was used for histomorphometric evaluation, and the measurements were processed in an IBM® personal computer with dedicated software (MicroMacro AB, Göteborg, Sweden). A gross histologic description was made as well as morphometric measurements of the following parameters in one ground section per specimen: (i) the degree of bone–implant contact (%) along the total implant length, (ii) the bone area (%) in all implant threads, and (iii) the distance from the reference point to the most coronal implant contact with continuous bone (Figure 3). A mean figure was calculated for each implant and parameters (i) and (ii), based on measurements in one ground section and on both sides of the implant.

Statistics

Wilcoxon signed rank test was used for statistical analyses and a significant difference was considered at $p < .05$.

RESULTS

All sites healed uneventfully. No signs of infection could be observed at the time of sacrifice when the experimental areas were exposed for RFA.

Bone regeneration was evident at the defect sites after 4 months. However, complete coverage of the exposed threads could not be seen in any of the specimens (Figure 4).

Figure 2. The transducer connected to one of the implants.

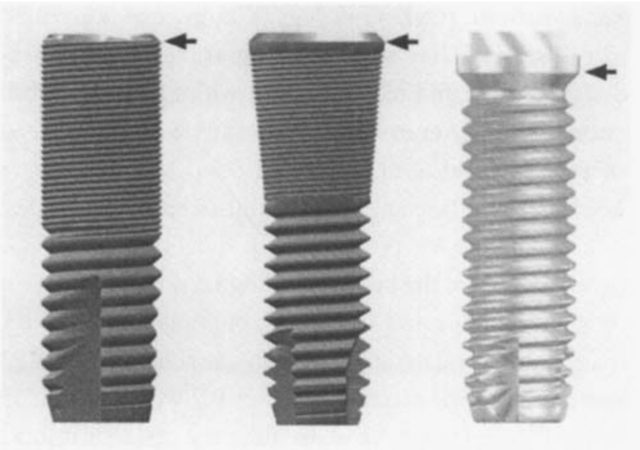

Figure 3. Reference point on each implant.

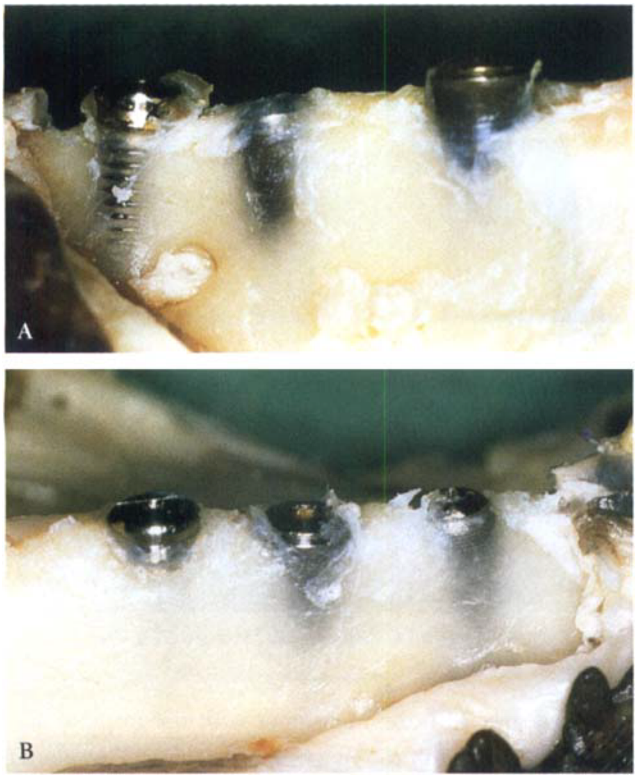

Figure 4. Clinical appearance after 4 months of healing. *A*, Note evidence of bone regeneration at the defect sites. *B*, Control site.

Resonance Frequency Analysis

There was no difference in primary stability of the test or control groups, although there was a trend toward slightly lower stability in the test groups. Resonance frequency analysis indicated that all implants in test and control groups were osseointegrated after 4 months.

There was a tendency toward higher implant stability for the Astra implants after 4 months. However, the difference was not statistically significant (Figure 5). Intraindividual comparisons showed a statistically significant higher increase in resonance frequency for the Astra ST and Microthread test implants compared to their controls ($p < .05$). The mean increase in resonance frequency for the Brånemark test implants was not significantly higher than the increase for the control implants (Figure 6).

Gross Histologic Appearance

A cross-section of the experimental site comprised the oval-shaped mandibular bone with cortical bone surrounding a bone marrow cavity. All implants were, to various degrees, surrounded by dense lamellar bone. The test implants showed signs of bone regeneration at defect sites. There seemed to be more continuous bone at the

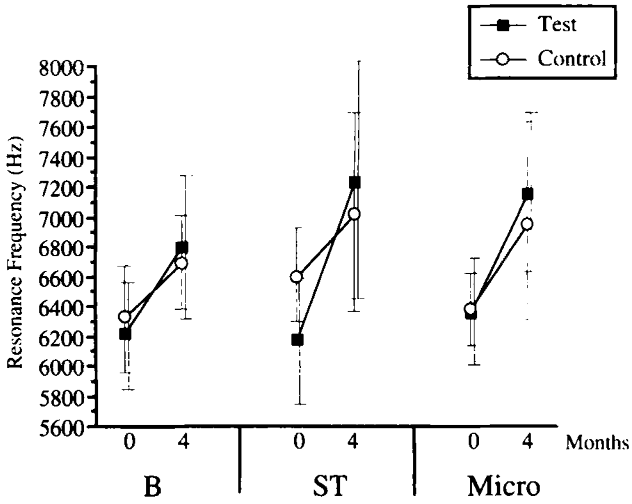

Figure 5. Resonance frequency analysis immediately after fixture installation and after 4 months of healing, showing mean values for each implant type: Brånemark System (B), Astra Tech implants ST (ST), and Microthread (Micro) fixtures.

defect sites on the smaller threads (Astra Microthread) compared with the standard-size threads (Figure 7). However, it was not possible to distinguish between original bone and regenerated bone in any specimen.

Histomorphometry

The mean degrees of bone–implant contact were 21.6 ± 17.6% and 25.5 ± 14.9% (Brånemark), 46.0 ± 17.1% and 48.8 ± 10.0% (Astra ST), and 49.7 ± 11.2% and 52.3 ± 6.6% (Astra Microthread) for the test and control implants, respectively. The Astra implants showed a statistically significant higher amount of bone–implant contact compared with the Brånemark implant ($p < .05$). Comparison between the two Astra implants showed no statistically significant difference (Figure 8, *A*).

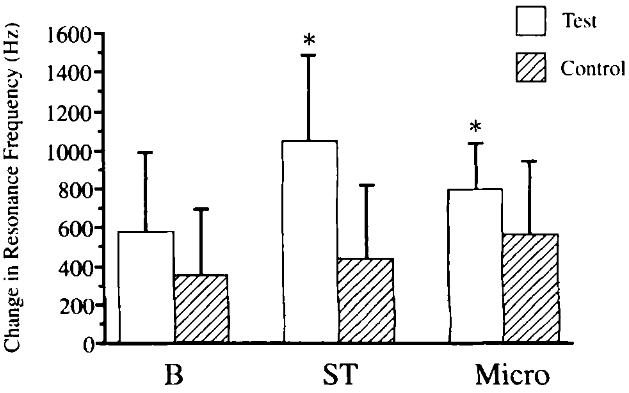

Figure 6. Increase in resonance frequency from installation to 4 months comparing test and control implants individually for each implant type. Significance level $p < .05$ between test and control for Astra ST and Microthread (B = Brånemark System).

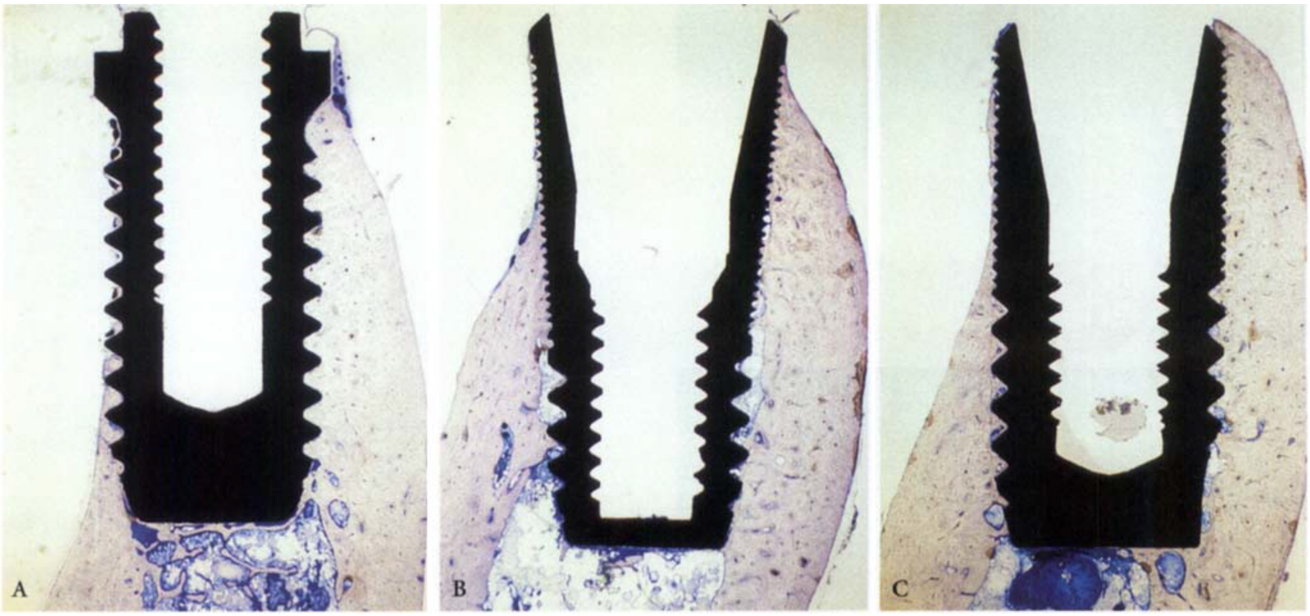

Figure 7. Histologic appearance. *A*, Brånemark fixture (test site); *B*, ST fixture (test site); and *C*, Microthread fixture (test site).

The mean amount of bone filling the threads was 32.5 ± 15.1% and 34.8 ± 13.6% (Brånemark), 38.9 ± 19.4% and 42.1 ± 13.9% (Astra ST), and 36.7 ± 12.8% and 41.3 ± 7.2% (Astra Microthread) for the test and control implants, respectively (Figure 8, *B*). There was no statistically significant difference between any of the implants.

The mean distances from the reference point to the most coronal implant contact with continuous bone on the defect sites were 2.70 ± 0.41 mm (Brånemark), 2.18 ± 0.46 mm (Astra ST), and 2.20 ± 0.32 mm (Astra Microthread). There was a statistically significant difference in distance in favor of the Astra implants, $p < .05$ (Figure 9).

DISCUSSION

The findings of the present study demonstrated that the TiO-blasted Astra implants, irrespective of design, had a higher degree of bone in contact with the implant surface compared with the machined Brånemark implants. This is in agreement with a recent histologic study in man,[20] in which titanium microimplants were inserted in conjunction with fixture installation in edentulous maxillae and mandibles. Each patient received one machined microimplant and one TiO_2 grit-blasted implant. The microimplants were retrieved in conjunction with abutment connection, after 3 and 6 months in the mandible and maxilla, respectively.

Histomorphometry showed statistically significantly more bone–implant contact and bone area in the threads for the blasted implants. In an in vitro study,[24] the initial attachment of cells to machined and grit-blasted titanium surfaces was investigated. Cells derived from human mandibular bone were used, and the attachment was determined as a ratio of the area of cell

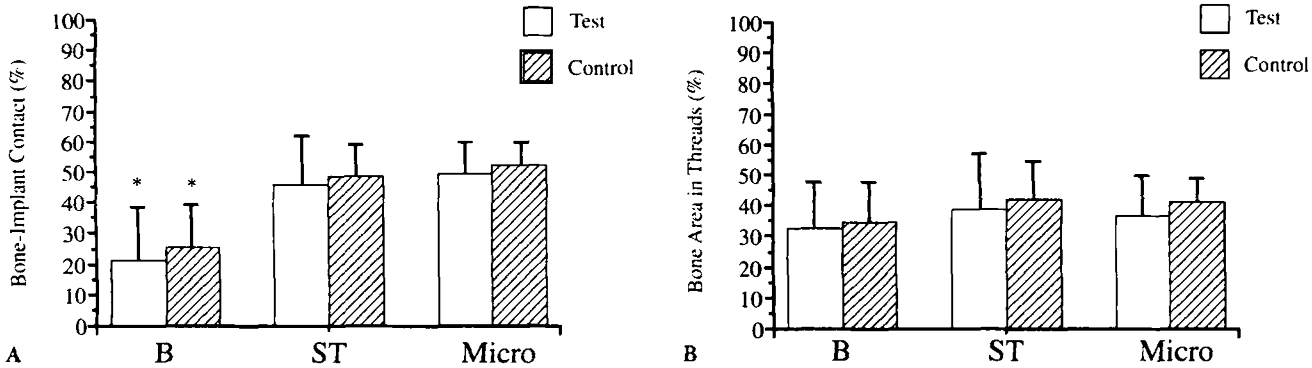

Figure 8. Histomorphometry. *A*, Percentage of bone–implant contact. Significance level, $p < .05$, between Brånemark and Astra ST and Microthread, respectively. *B*, Percentage of bone area in threads. No significance level.

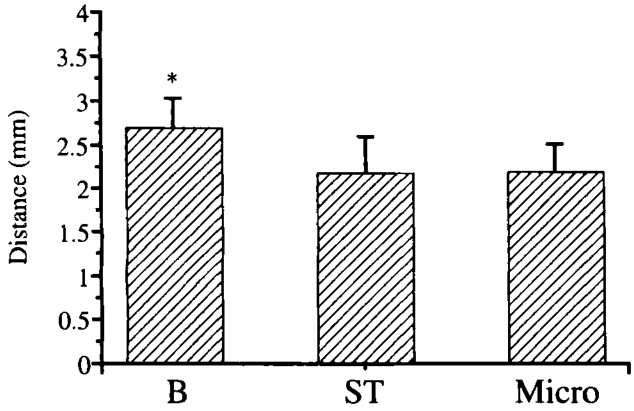

Figure 9. Distance from reference point to continuous bone. Significance level, $p < .05$, between Brånemark and Astra ST and Microthread, respectively.

profiles. After 24 hours of observation, the blasted implants had a higher rate of attachment than the implants with a machined surface. It was concluded that attachment and growth of cells are influenced by the microtexture of the implant surface. Moreover, Lundgren and co-workers studied the influence of surface roughness of barrier walls on guided bone augmentation and found that the area of mineralized bone in direct contact with the inner surface of the titanium cylinder was significantly larger in grit-blasted than in turned cylinders.[25]

In the present study, it was not possible to assess the amount of new bone in the defect zones because the original borders of the defects were distinguishable in only some of the specimens. At the defect sites, there was a statistically significant shorter distance from the reference point at the implant neck to the most coronal contact with continuous bone, for the blasted implants. More continuous bone in contact with the implant surface is believed to imply higher implant stability. There was a tendency of higher stability for the blasted implants, as measured with resonance frequency after 4 months of healing; however, the difference could not be statistically verified. These observations are important and may imply that the regenerated bone failed to enhance the stability of the implant because it was not in contact with the implant or it was not mature enough. Moreover, it is possible that the study sample was too small to statistically distinguish the differences.

In a study by Rasmusson and co-workers, a rabbit model was used to study implants that were placed with four to five threads on one side not covered by bone.[5] Test implants were subjected to barrier-induced bone augmentation, whereas control implants were left with the threads not covered. The results showed no difference between test and control implants, and the authors' interpretation was that the generated bone failed to become a load-bearing part of the implant system. However, it has been shown that the stability of screw-shaped implants is dependent not only on the amount of bone but also on the biomechanical properties of the surrounding bone (i.e., type of bone, degree of maturation, and geometry).[26,27] Therefore, the major support of the implants in the present study most likely was attributable to the integration in lingual cortical bone.

In a dog model, Carmagnola et al made buccal dehiscences with large discrepancies between buccal and lingual bone.[17] They showed some bone regrowth and osseointegration at the buccal implant surface, whereas at the lingual wall there was a compensatory resorption of the marginal bone. The degree of compensatory bone resorption is probably influenced by the size of the defect and the total width of the crest. In the present study, no compensatory resorption was noted on the lingual margin. In most of the specimens, the lingual bone reached or even extended beyond the reference point of the implants.

Hansson demonstrated that if an axial load is applied to an implant, the peak interfacial shear stress in the marginal bone can be reduced if the implant is provided with retention elements all the way up to the crest.[28] It was suggested that the retention elements would thereby counteract marginal bone resorption. In the present study, the implants were not loaded, and the possible effect of the microthreads on the Astra implants was not tested. However, it may be speculated that the higher bone level on the test side for the Astra implants was a result of both the implant design and the surface topography.

CONCLUSION

The Astra implants tested showed a higher degree of bone–implant contact and higher level of bone regenerated at defect sites than Brånemark standard implants. Resonance frequency analysis demonstrated a significantly higher increase in stability for the Astra test implants versus their controls compared with Brånemark test versus control implants.

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