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# Improved Retention and Bone-to-implant Contact with Fluoride-modified Titanium Implants

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Wennerberg A.  
Holmén A.

Int J Oral & Maxillofac  
Implants  
2004;19:659–666.

Products:  
TiOblast  
OsseoSpeed

**Purpose:** This study set out to compare the bone-to-implant contact and interfacial strength of TiO<sub>2</sub>-blasted implants with and without fluoride modification, in the rabbit model.

**Materials and Methods** Twenty male New Zealand white rabbits were used in the study. All implants were 3.5 x 8.0mm in dimension and were TiO<sub>2</sub> grit-blasted to produce the TiO-blast surface (Astra Tech). The test implants were further cleaned with diluted hydrofluoric acid. Test and control implants were subject to surface analysis using 3D profilometry (Topscan 3D) to measure Sa, Scx, and Sdr values using a 50 x 50µm Gaussian filter.

Animals were anesthetized for osteotomy preparation according to protocol in the tuberosities of the tibia. Two test implants were inserted into one tibia and two controls into the contralateral tibia. Implants were spaced 5mm apart and with 1 or 2 exposed threads. Tissues were then closed in layers for submerged healing.

The animals were split into 2 groups. Group A were left to heal for 1 month and group B were left to heal for 3 months. At the end of these periods the animals were euthanized and one test and one control implant were subject to torque removal. The remaining implants were harvested en bloc and prepared for histologic evaluation of 10µm sections stained with toluidine blue. Histologic measurements were made of percentage bone-to-implant contact (%BIC) and the bone area within threads (%BAT) both for the total implant length and for the 3 best consecutive threads in the cortical region.

Finally the interfacial shear strength (ISS) was calculated from the data. Wilcoxon signed rank test was used to evaluate statistical significance.

**Results** Fluoride modification resulted in a slightly less rough surface Sa = 0.91µm compared to 1.12µm for the unmodified TiOblast surface with increased waviness.

At 1 month, mean peak values for control implants measured 27Ncm and for test implants measured 31Ncm, NS. At 3 months there was a significant increase in removal torque and there was also a significant difference between test and control implants, 85Ncm compared to 54Ncm respectively, p < 0.005.

At 1 month the %BIC measured 35% compared to 26% for test and control implants, p < 0.05, which increased to 39% and 31% at 3 months, p < 0.05. When comparing %BIC for the 3 best threads a highly significant difference existed at 3 months, p = 0.005. In contrast the mean %BAT was better for controls at 3 months compared to test implants, measuring 39% and 31% respectively, p < 0.05, and 68% compared to 54% for the 3 best threads, p < 0.05.

When calculating the ISS at 3 months the value for control implants was 18N/mm<sup>2</sup> compared to 23N/mm<sup>2</sup> for test implants, p < 0.05.

**Discussion and Conclusion** In this experiment, test implants were modified by the incorporation of fluoride ions on to the surface of the implant. The modification process resulted in a small reduction in surface roughness although there was an increase in waviness. This may have contributed to a significant increase in %BIC, mean peak removal torque values and interfacial shear stress, which supports previously published experimental data. In addition alterations to the surface chemistry by incorporation of fluoride has been shown to result in conditions suited to bone bonding by seeding of calcium and phosphate which may stimulate osteoprogenitor cells and result in an elevation of alkaline phosphatase activity and this may explain the improved retention of test implants in the presence of a smoother surface, which was also lower in total surface area when compared to the conventional TiOblast surface.

# Increasing Biocompatibility by Chemical Modification of Titanium Surfaces

Ellingsen J.E.  
Lyngstadaas S.P.

**Bio-Implant Interface;  
Improving Biomaterials  
and Tissue Reactions:**  
CRC Press  
2003:323-340.

**Products:**  
OsseoSpeed  
TiOblast

Titanium is well suited to use for intraosseous medical and dental devices due to its low corrosiveness, favorable mechanical properties that are capable of withstanding functional load, and its highly stable oxide layer, which has low toxicity and solubility and is biologically passive. This oxide layer is known to be the surface apposed to bone during osseointegration but a number of methods have been investigated with a view to improving the biological properties and interfacial strength between implant and bone involving surface modifications.

**Electrochemical Oxidation** Anodization is a process by which the oxide layer is thickened in a controlled manner, and can be used to influence not only thickness but crystallinity and porosity of the oxide layer. In particular studies have shown that by increasing the voltage at which the anodic process is carried out will lead to an increase in these characteristics, and in particular porosity and hence surface roughness and this has been shown to have clinical consequences with respect to increases in bone-to-implant contact and implant interfacial shear strength. However some studies have also indicated that these effects may not be long-lasting.

**Effects of Surface Roughness** Surface roughness may be influenced at the macro-, micro- and nanometer scale. Mechanical interlocking of bone is known to increase implant retention and it has been shown that pits as small as  $100\mu\text{m}$  can still allow formal bone ingrowth and interlocking. However it may be that changes in surface roughness on the micro- and nanometer scale also influence implant retention by manipulating cellular response, and the percentage of bone-to-metal contact. In particular studies have shown that cellular activity, orientation, matrix formation and deposition as well as mineralization are all influenced by surface roughness on the micrometer scale. To this end theoretical and experimental studies would seem to suggest that a surface roughness value (Sa) of  $1.0\text{-}1.5\mu\text{m}$  appears optimal. Certainly the roughness created by a high voltage anodic oxidation process would fall into this magnitude. One explanation for these observations is that the large pores of very rough surfaces may actually appear smooth to the somewhat smaller rugophile bone cells.

It is very probably that further modifications on the nanoscale will lead to additional enhancements, and this requires further study.

**Ion Implantation of Oxide** In addition to anodic oxidation it has also been demonstrated that it is possible to incorporate ions such as Ca and P into the oxide layer, which in turn has been shown to influence tissue response and bone integration. Other studies have used sulphur based acids to increase surface roughness, yielding increases in implant retention values. Certainly the alteration in surface roughness would have a positive effect on retention but so too might chemical modifications within the surface. Again this has been demonstrated by the incorporation of Ca ions by ion implantation within the anodized oxide layer forming complex oxides such as  $\text{CaTiO}_3$ . Such technology has been proposed as a natural supersedant to HA coatings which have been deemed to be fraught with problems of delamination and biodegradation.

**Fluoride-Modified Oxide** Recent work by Ellingsen et al, has also indicated the value of implanting fluoride ions into the titanium surface to provide an enhanced stimulation of the osseointegration process with an improved biological response.

The modification of titanium using fluoride based acids can result in the incorporation of low concentrations of fluoride ions onto the implant surface, with a very slight net reduction of the Sa roughness value of around 20%. Such implants have been shown to result in the binding of P ions, with nucleation and precipitation of Ca-P on the implant surface. Such reactions did not appear to occur for c.p. titanium even if it had a defined surface roughness of  $1.0\text{-}1.5\mu\text{m}$ . It is believed that this indicates that such implants would be highly beneficial in their ability to react with calcified tissues. Indeed in experimental studies using fluoride-modified implants compared to controls it was possible to show a higher pull-out strength and the attachment of tissue remnants due to the fracture of bone at a distance from the interface, compared to the unmodified controls for which no tissues was seen to remain attached after pull out.

**Experiments with Blasted Implants** The use of fluoride modification has also been combined with grit-blasting to enhance both the chemical structure as well as the microtopography of the implants. In a key experimental study by Ellingsen machined implants, were compared to titanium grit-blasted implants and grit-blasted implants with fluoride modification for peak removal torques when integrated into rabbit tibias. After a defined period of healing there was a statistically significant increase in the peak removal torque not only for the fluoride modified and unmodified grit-blasted implants compared to controls, but also between the modified and unmodified blasted implants ( $p < 0.005$ ). In this experiment a distinct crack was heard on removing the fluoride modified implants, and on histologic examination it was apparent that this was due to the fracture of bone at a distance from the interface with bone tissue remnants still tenaciously attached to these implants and filling the troughs of the thread profiles. This would suggest that the fracture resistance of the interface is higher than the fracture resistance of bone itself. In addition the histology confirmed a much tighter bone-to-implant contact for these implants with apparent bone formation on the implant surface even in the very porous cancellous compartment, where little bone was evident for the other groups. These observations would tend to reinforce the view that fluoride modification enhanced the biological tissue response compared to both machined as well grit-blasted implants.

**Clinical Perspectives** The goal in implantology must be to achieve more rapid and predictable integration of endosseous devices for early loading even in bone of lower density such as the posterior maxilla. The application of fluoride modification of titanium would seem to yield very promising results with higher bone-to-implant contact and peak removal torque values at earlier time frames.

# On the Properties of Surface-modified Titanium

Ellingsen J. E.

## Bone Engineering

Davies, J.E (ed),  
em Sqaered Inc, Toronto  
2000:183–189.

## Products:

OsseoSpeed

**Introduction:** A variety of biomaterials have been used for load bearing implants, each with unique properties, which result in a different tissue response. Of these, titanium is unique since it demonstrates a superior biocompatibility and strength. The spontaneous formation of an inert  $\text{TiO}_2$  layer, which has a thickness of 4nm would seem to be responsible for its apparent tissue compatibility. Since this layer presents with negatively charged oxygen the layer is able to undergo ion exchange and bind calcium when exposed to body fluids and as such acts more like a ceramic such as hydroxyapatite. This in turn optimises the ability for these materials to adsorb proteins and glycosaminoglycans.

It has also been shown that the surface of an implant can be influenced by treatment with other ions, for example it is known that if titanium implants are treated with lanthanum then these ions will preferentially bind to the implant surface preventing calcium from binding. The result is that such implant demonstrate a reduced retention in bone. The exact method by which the bonding of bone occurs remains unclear.

Conversely a series of experiments have been undertaken by the author to modify the  $\text{TiO}_2$  surface with fluoride ions. The resultant titanium fluoride is highly stable and allows a covalent bond to form with the oxygen atoms of the phosphate groups in hydroxyapatite to form fluoridated hydroxyapatite and fluorapatite. Fluoride is also known to improve mineral seeding rates, to stimulate osteoprogenitor cells and alkaline phosphatase activity, and to give rise to increases in trabecular bone density. In studies the effect of fluoride was shown to result in increased retention of implants in bone as measured by torque removal tests. In addition a positive bonding of bone was visualized under SEM as bone could be seen to have fractured, remaining attached to the implant surface. In vitro modelling was therefore employed to further study the influence of fluoride on the interaction between  $\text{TiO}_2$  and bone.

**Materials and Methods** Titanium  $\text{TiO}$ -blasted implants were used with half the sample modified by conditioning with a low concentration solution of hydrofluoric acid. This process was shown not to alter the surface topography when examined under SEM. The modified and unmodified  $\text{TiO}$ blast implants were immersed in a nucleation system designed to cause precipitation of calcium phosphate using buffers of 2mmol/L of  $\text{CaCl}_2$  and 15mmol/L of  $\text{KHPO}_4$  at 37 degrees. Electrodes connected to a computer were used to measure the calcium concentration in the solution over a period of 300 minutes. Implants were subsequently rinsed in distilled water and examined under s.e.m. Any precipitates were analysed by EDS with a Ge-detector.

In a separate experiment radioactive labelled  $^{32}\text{P}$  was used in the phosphate buffer and after rinsing the test and control implants were evaluated for levels of radioactivity.

**Results** Fluoride modification resulted in a notable drop in calcium concentration in the buffer after a 60 minute period, indicating that precipitation had taken place. On examination of the implants there were no visible precipitates on the unmodified control implants but numerous precipitates were seen on the surface of fluoride modified implants. EDS analysis confirmed these precipitates to have high concentrations of calcium, phosphorous and oxygen.

In the radioactivity study, the fluoride modified implants demonstrated over 4 times the levels of radioactivity compared to controls, further strengthening the belief that an increased precipitation of phosphorous containing molecules was taking place.

**Discussion and Conclusion** In these experiments, the formation of a titanium fluoride modified surface on test implants resulted in a significant additional binding of calcium phosphate groups when compared to control  $\text{TiO}$ blast titanium implants. On this basis it can be postulated that the same process will occur in bone resulting in a covalent bond between the implant surface and bone. The released fluoride ions will also catalyse new bone formation and mineralization.

# Surface Configurations of Dental Implants

Ellingsen J.E.

Periodontology 2000  
1998;17:36-46.

Products:  
OsseoSpeed

The development of endosseous implants has been based historically on trial and error using differing materials and more recently for titanium using strict healing protocols, where high success could be shown in high density bone, often where implants achieve bicortical fixation. Today the desire has been to improve our understanding of the bone bonding/binding capabilities of various implant materials as well as to enhance the quality of the bone bed itself by the application of bone inducers. Today more emphasis is placed upon scientifically driven bioengineering and efforts to understand the biocompatibility processes so that implants can be optimized to achieve even stronger bonds with bone.

Today we appreciate the large variety of ions which compete to bond with the implant surface along with proteins, and cellular components such as osteoblasts. The ability to preferentially select osteoblasts and encourage mineralization of bone tissue remains the goal, and such a response will depend on the surface structure and chemistry of the implantable device.

**Surface Macrostructure:** Today the threaded cylindrical implants predominate, such design is based upon long-term prospective clinical results yielding favorable success rates. The use of threads is known to aid primary stabilization. Such stability imparts rigidity which is central to an unimpaired healing process. In addition the application of threads has been shown to affect the stress distribution in bone and today a variety of thread designs are offered to achieve a propitious stress distribution and/or primary stability. Most recently the microthread with a depth of only 0.1 to 0.2mm has been shown to yield the most favorable stress distribution in particular within cortical crestal bone, where bone loss is typically seen.

**Surface Microstructure:** The topography of the surface is an area that has received considerable attention during the last decade. Once again surface topography has been shown to impact upon the interfacial shear strength with bone as well as on the distribution of functional load. A general consensus was developed in the literature which would indicate that a certain micro-roughness was optimal. The actual dimensions of this roughness have been the source of great debate and controversy, It is known that a surface asperity will need a depth of 100 $\mu$ m to incorporate a plug of bone for mechanical interlocking yet numerous studies have demonstrated a significant impact of surface roughness at a much lower level, which may influence cellular adhesion, orientation, and matrix deposition. Such surfaces have included titanium plasma spray, TiO grit blasting, and acid etch treatments or a combination thereof and numerous studies would appear to support the view that a surface roughness value of 1.0 to 1.5 $\mu$ m is optimal.

**Surface Ultrastructure:** Further evidence exists to also suggest there is a biological response to topography at the ultrastructural or nanometer level. Most recently this has been demonstrated by the effects of anodization of titanium, which alters the oxide thickness and porosity of the titanium surface. Implants with this heterogeneous, thick oxide layer have been shown to yield higher interfacial shear strength values at least initially although differences may not be apparent after longer healing periods.

**The Surface Chemistry of Implants:** The last property to be considered is the chemistry of the surface itself. Clearly implants of differing materials interact with bone in different ways. Some like titanium may be bioinert, allowing a close and tight relationship with bone, while others like hydroxyapatite may induce bone bonding. It is also known that the chemical and crystalline structure of hydroxyapatite will also have an impact upon the bone response at a cellular level. In other studies evidence exists to show that non oxidized titanium inhibits the nucleation of Calcium Phosphate when compared to oxidized titanium, and that furthermore the incorporation of fluoride ions on to the surface of TiO<sub>2</sub> results in an increased nucleation and precipitation of CaP. This is thought to be the result of selective release of fluoride for bonding of phosphate and the subsequent incorporation of fluoride into fluoridated hydroxyapatite or fluorapatite. These apatites have reduced solubility and fluoride is known to further stimulate the seeding of apatite onto collagen. In addition the presence of fluoride has been shown to promote alkaline phosphatase activity. The net result of these pathways was previously demonstrated in a study where the peak tensile push-out values for machined titanium conical implants was increased by 3 to 4 fold as a result of treatment with 4% NaF at a pH of 3.5.

**Discussion:** Much attention has been focused on implant macro design and the surface microtopography. However it is clear that bioengineering of the nanostructure and chemical modification of titanium may also help to optimize and maximize the potential interfacial shear strength and progress in these fields may thus help to provide implants with improved clinical performance in the future.

# Pre-treatment of Titanium Implants with Fluoride Improves Their Retention in Bone

Ellingsen J.E.

J Mat Science Mat Medicine  
1995:6:749-753.

Products:  
OsseoSpeed

**Purpose:** The purpose of this study was to investigate the reaction between fluoride ions on a titanium surface and bone to determine if a chemical bond exists.

**Materials and Methods:** Test implants 5mm long and tapered from a diameter of 3mm to 2mm at the apical end were fabricated from commercial pure titanium. A total of 64 implants were placed into the bilateral ulnas of 16 chinchilla rabbits. Two groups of implants were created, a control group which were left as machined and a test group which received one of three types of fluoride acid wash pre-treatment at a pH of 3.0 or 3.5 and a concentration of 0.5% or 4% NaF to create a thin fluoride layer on the titanium surface.

In the first group, one test and one control implant were placed unilaterally into osteotomies that allowed a frictionless insertion under a load of 360g. Four weeks later a second test and control implant were inserted into the contralateral ulna. After a further four weeks of healing the animals were sacrificed and the two groups of implants subject to push out tests, using an Instron tensile testing machine, with a load applied to the apical end of the tapered implants. Peak tensile loads were recorded. The surface of the implants was analyzed using scanning electron microscopy at 85 and 500 times magnification.

The ulnas were then prepared for histological analysis of the implant sites using 15 $\mu$ m sections stained with toluidine blue.

**Results:** The fluoride treated implants yielded higher push out values consistently at after both 4 and 8 weeks of healing, with a 3 to 4 fold increase in resistance. The higher concentration also gave rise to the greatest push out values. While there was some variation in the values for the test implants between 4 and 8 weeks, the control implants demonstrated a consistent lack of resistance regardless of time.

The electron microscopy revealed an almost clean metallic surface for the control implants, compared to the presence of tissues on the test implants which indicated bone had fractured within the tissue itself leaving a layer adherent to the implant surface. This was supported by the histology which indicated the existence of an intimate bone-to-implant contact for test implants even in the cancellous compartment. Such an appearance was lacking for control implants.

**Discussion:** Calcium cations are divalent and are important in the establishment of a bone-to-implant contact when presented with a TiO<sub>2</sub> surface at physiologic pH. In addition the precipitation of Calcium Phosphate has been shown to be enhanced by the presence of TiO<sub>2</sub>. The use of fluoride ions is thought to further optimize the process by allowing selective bonding of Phosphate to the titanium surface by the release of fluoride forming a covalent bond with titanium. In addition fluoride has been shown to stimulate osteoprogenitor cells in vitro and may depress osteoclast activity through the formation of fluorapatite, which is less soluble. Fluoride has also been shown to increase alkaline phosphatase activity which is an indication of bone formation.

All these responses will be dose dependant and in the current study concentration was seen to impact upon push out values. Certainly it can be concluded that the ability of fluoride to prevent the adhesion of protein moieties by the selective binding of phosphate as well as the formation of fluoridated hydroxyapatite and fluorapatite give rise to an increase in the bone-to-implant bond strength, which may be of value in osseointegrated technology.

# Marginal Bone Reaction to Oral Implants: A Prospective Comparative Study of Astra Tech and Brånemark System Implants

Engquist B.  
Åstrand P.  
Dahlgren S.  
Engquist E.  
Feldmann H.  
Gröndahl K.

Clin Oral Impl Res  
2002;13:30–37.

**Products:**  
Fixture TiOblast 3.5 mm  
9–19 mm lengths  
20° UniAbutment 3.5/4.0

**Purpose:** The study compared treatment outcome with respect to implant survival, marginal bone levels and other clinical parameters for the Astra Tech and Brånemark systems implants after three years in function.

**Material and Methods** 66 patients included in the study were randomly assigned to the Astra Tech (AG) or Brånemark (BG) groups, 33 patients in each group. 13 patients had hypertension, 5 had controlled diabetes and 18 were smokers (67% in AG and 33% in BG).

104 maxillary and 80 mandibular implants were installed in the AG. Implants were TiOblast, 3.5 mm diameter and ranged from 9 to 19 mm in length.

107 maxillary and 80 mandibular implants were installed into the BG. Implants were machine prepared, 3.75 mm in diameter and ranged from 10 to 18 mm in length.

Abutment connection was carried out after similar healing periods for both systems, averaging 6.5 months for maxilla and 3.9 months for the mandible. Operation time was recorded for comparison during both first and second stage surgical procedures.

Prosthetic procedures were conventional and followed routine protocol.

The follow-up parameters recorded were:

1) Presence or absence of pain, 2) Implant stability, 3) Plaque score, 4) Bleeding on probing, 5) Mechanical complications, 6) Changes in marginal bone levels.

Marginal bone levels were measured from established reference points for each system at the three-year (3Y) review and compared to those measured at fixture insertion (FI).

**Results** 9 implants failed in the BG, 5 in one patient, yielding a 4.8% failure rate. Only 2 implants failed in the AG, yielding a failure rate of 1.1%, ( $p < 0.05$ ).

One bridge was lost in the BG, yielding a 3% prosthetic failure rate.

Plaque accumulation ranged from 2 to 15%, however there was no bleeding on probing at the three-year follow-up. The lack of attached mucosa ranged from 0 to 25% and was not system specific.

At the 3Y review, marginal bone levels for maxillary implants for the AG measured 1.7 mm below the reference point when compared to the level at FI. For BG implants this figure measured 2.2 mm. Corresponding figures for the lower jaw were 1.2 mm and 1.8 mm for the AG and BG respectively. Changes between the one- and three-year reviews were not significant for either system.

One patient (smoker) from the AG suffered peri-implant mucositis, however this resolved with decontamination and antibiotic therapy.

**Discussion** This study compared the Astra Tech TiOblast fixtures and machine prepared Brånemark fixtures, in particular with respect to marginal bone changes over a three-year follow-up.

While marginal bone changes followed differing patterns in the early phase of treatment, the changes between the one- and three-year follow up were comparable between the systems, with bone levels measuring 1.7 mm and 2.2 mm below the reference points for the AG and BG respectively. These results were not statistically significant.

Failure rates were significantly lower for the AG compared to the BG, however one patient lost 5 implants in the BG, and thus lost the whole prosthesis. The survival rates at the three-year review were 98.9% and 95.2% respectively ( $p < 0.05$ ).

# A Multicenter 12-month Evaluation of Single-tooth Implants Restored 3 Weeks after 1-stage Surgery

Cooper L.  
Felton D.  
Kugelberg C.  
Ellner S.  
Chaffee N.  
Molina A.  
Moriarty J.  
Paquette D.  
Palmqvist U.

Int J Oral & Maxillofac  
Implants  
2001;16:182-192.

Products:  
Fixture ST

**Purpose:** This 3-year prospective study set out to document the survival of Astra Tech Fixture ST placed in the anterior maxilla, and subject to a rapid loading protocol.

**Material and Methods** Patients were recruited when requiring replacement of one or two teeth in the anterior maxilla. All patients presented with bone volume that would allow an implant longer than 11 mm to be placed. Patients were excluded on the grounds of unstable dental disease, parafunction, occlusal instability, smoking or low bone density. A diagnostic work-up with mounted study models and tomographs was completed for each case.

At time of implant surgery a single-tooth implant (Astra Tech, Fixture ST) was placed according to manufacturer's protocol to achieve good primary fixation. A healing abutment was then secured using finger pressure so as to effect a transmucosal healing. After a 3-week period, the healing abutment was removed and a final abutment secured, again with finger pressure, to ensure that the restorative margin was 1 mm below the mucosal margin. A direct temporary crown was fabricated at the chairside using Protemp and was cemented with Temp Bond. A baseline long-cone radiograph was taken, along with an assessment of implant mobility, papilla index, presence or absence of inflammation, presence or absence of plaque, and width of keratinized tissue.

Eight weeks after surgery the temporary crown was removed and a final impression taken for the subsequent fabrication and cementation (glass ionomer) of the definitive ceramic, or ceramo-metal crown. At this time the abutment screw was tightened to 20 Ncm. Data was collected at 6 months and 1, 2 and 3 years post insertion of the temporary crown. In addition radiographic follow-up allowed the assessment of peri-implant radiolucencies, as well as the marginal bone changes with respect to an established reference point on the implant.

**Results** 57 implants were placed in 51 patients, however 4 patients were subsequently found to be smoking and were excluded. For the remaining 53 implants, the majority of surgical sites presented with type 2 or 3 bone quality and class A or B bone volume. 70% of implants were longer than 13 mm and 83% were inserted in the central or lateral incisor positions. Of these implants one was diagnosed as a failure at time of temporary crown fabrication and another at 8 weeks, when the master impression was due, yielding a survival rate of 96.2%. At the 1-year recall there was minimal evidence of peri-implant mucosal inflammation (3.6%), with a net gain in papilla length of 0.61 mm.

Radiographic follow-up revealed a 0.59 mm change in marginal bone levels, which appeared to stabilize after 9 weeks, with 70% recording a bone loss of less than 1 mm.

No complications were recorded with respect to abutment screw loosening. Some prosthetic complications were recorded with respect to crown de-cementation and crown fracture. One case of peri-implant mucositis recovered uneventfully, when treated with antibiotics.

**Discussion** A survival rate of 96.2% is comparable with other single-tooth studies utilizing a standard protocol for unloaded healing. In addition tissue response was favorable, with a healthy maintenance of marginal bone and filling out of interdental papillae, aiding a good esthetic result. Implant design and the conical implant-abutment connection have been cited as important factors in the maintenance of these tissues, and also contribute to a stable connection, highlighted by an absence of abutment screw loosening. In conclusion this study demonstrates that in the presence of good primary stability, single-tooth implants can be subject to a rapid loading protocol, yielding an efficacious and predictable result.

# A Prospective 5-year Study of Fixed Partial Prosthesis Supported by Implants with a Machined and TiO<sub>2</sub>-blasted Surface

Gotfredsen K.  
Karlsson U.

J Prosthodont  
2001;10:2-7.

## Products:

Fixture Machined  
Fixture TiOblast 3.5 & 4.0  
20° UniAbutment 3.5/4.0  
45° UniAbutment 3.5/4.0

**Purpose:** This study set out to record and compare Astra Tech implants and the marginal bone loss at implants with a machined (M) and roughened (TiOblast™, TB) surface when used to support fixed partial prostheses over a 5-year prospective study.

**Materials and Methods** 50 patients were enrolled on to the study and presented with partially edentulous spans of at least one year standing. In the maxilla 45 implants were placed (M = 25 and TB = 20) and 83 implants were inserted into the mandible (M = 39 and TB = 44). Each patient received the two surface types alternately to allow a within patient comparison and there were equal numbers of the two surface types placed (n = 64/surface). Surgery was performed according to manufacturer's recommendations with a submerged healing of 3 to 7 months depending on the jaw. Abutment connection was with the standard UniAbutment. All partial prostheses were screw retained and insertion was always within two months of exposure at which time baseline radiographic and clinical data was recorded. Clinical data included an assessment of all parameters according to the criteria established by Albrektsson et al. Any technical complications with either the components or prostheses were also noted. In addition patients were independently asked to grade function and esthetics as good, moderate or poor.

Intra-oral annual radiographs were taken in the same standardized manner. Marginal bone levels were assessed by an independent radiologist to determine the amount of bone loss on the mesial and distal surfaces of each implant to the nearest 0.1 mm.

Statistical analysis was performed at the end of the 5-year recall to determine the difference between survival rates and marginal bone loss for the two implant surfaces. In addition one implant of each type was selected for each patient to allow a within patient comparison.

**Results** Ten patients with 16 implants were lost to follow-up. Over the five year study period 3 M implants failed such that the cumulative survival rates were 95.1% and 100% for M and TB implants respectively. Mean, marginal bone loss measured 0.21 mm and 0.51 mm for M and TB implants respectively with only 5 implants recording a bone loss of > 2.0 mm. These differences were not statistically significant. At the end of the study period 6% of both types of implant were associated with mucosal inflammation.

With regard to technical complications only 2 abutments fractured within 2 years of function. Five abutments required retightening. A total of 12 bridge screws in 7 patients required retightening and 2 bridges were remade. 100% of patients recorded the function as good and 79% recorded the esthetics as good at the 5-year recall.

**Discussion** The current study demonstrated survival rates for both machined and TiO<sub>2</sub>-blasted Astra Tech implants which fall well within the criteria for success set out by Albrektsson et al. There were 3 failures all of which were implants with the machined surface. There was a slightly higher rate of marginal bone loss and associated soft tissue inflammation recorded for the TB implants, however the differences were not statistically significant and again fall well within established criteria for success. The most common technical problem of bridge screw loosening was restricted to prostheses supported by two implants only.

# Maxillary Implants Loaded at 3 Months after Insertion: Results with Astra Tech Implants after up to 5 Years

Steveling H.  
Roos J.  
Rasmusson L.

Clin Impl Dent Rel Res  
2001:3:120–124.

**Products:**  
Fixture TiOblast 3.5 & 4.0  
Fixture ST 4.5

**Purpose:** The purpose of the study was to evaluate the long-term outcome of Astra Tech implants inserted into the maxilla and loaded after only 3 months of healing.

**Material and Methods** 15 Astra Tech ST (Fixture ST, Ø 4.5 mm) implants and 29 standard Astra Tech TiOblast (Ø 3.5/4.0 mm) implants were inserted into the maxillae of 17 patients to support 13 single tooth restorations and 9 fixed bridges. The observation period is up to 5 years with 16% followed for this period and 50% for 3 years. Implants ranged from 9 mm to 17 mm in length (majority 13 mm) with bone volume recorded in groups A-C with the majority classified as A or B. Bone quality was assessed at time of drilling and recorded as being in categories 1 to 4 (Lekholm & Zarb). Surgery was performed without antibiotic prophylaxis and implants were placed according to manufacturers protocol. Of the 44 implants placed, 29 were posterior to the canine positions.

Implants were exposed and restored just 3 months after placement and baseline radiographs were taken using a paralleling technique, and then annually to assess any changes in marginal bone height on the mesial and distal aspect of each fixture, using a x8 magnification to within 0.1 mm. Any gain in bone height was recorded as a change of +0.0 mm. Any soft tissue complications such as peri-implant mucositis was noted.

**Results** All patients healed uneventfully, both after first and second stage surgery. All implants osseointegrated and no failures occurred up to the 5 year follow-up. All prostheses remained in function throughout the study period and there were no recorded adverse events or complications associated with the prostheses.

When evaluating the radiographs the change in bone height from baseline to each year of follow up was 0.6 mm, 0.6 mm, 0.4 mm, 0.6 mm, 0.9 mm.

Only one implant was recorded as being associated with a soft tissue inflammation with attendant bleeding on probing. However once addressed there were no further recordings of inflammation or bleeding on probing at any implants.

**Discussion** Earlier studies on implant failures in the maxilla and more recent studies demonstrating reduced implant stability in poorer quality maxillary bone would suggest that the early loading of maxillary implants is hazardous. However all the studies indicating an increased risk for maxillary implants have tended to focus on the machine prepared titanium surface, which has been largely superseded.

In the current study implants which have benefitted from a change in both surface topography and geometry have been evaluated over 5 years, having been loaded just 3 months after placement. Both the Astra Tech standard and ST implants have previously been shown to respond well to early loading, although this has principally been in the mandible. In the current study all implants were placed in the maxilla and 66% were placed in posterior locations, in bone assessed as being quality 3. The 100% success rate up to the 5 year follow-up in association with a mean marginal bone loss of only 0.9 mm from baseline, including the first year of function is comparable with results for implants which have benefitted from the more conventional 6 month period for osseointegration.

# Implant-Supported Fixed Prosthesis for the Rehabilitation of Periodontally Compromised Dentitions: A 3-year Prospective Clinical Study

Seung-Won Y.  
Ericsson I.  
Chon-Kwan K.  
Carlsson G.  
Nilner K.

Clin Impl Dent Rel Res  
2001;3:125-134.

Products:  
Fixture TiOblast 3.5 & 4.0

**Purpose:** This prospective study set out to evaluate the short to medium-term outcome of rough surface implants used to support fixed prostheses in totally or partially edentulous patients with a history of periodontal disease.

**Materials and Methods** 43 patients attending a private clinic for periodontal treatment were considered for the study when teeth were extracted and when they could demonstrate an improvement in their oral home care with an attendant reduction in plaque and gingival inflammation scores. Six patients were rendered edentulous. All patients consented to implant therapy in preference to conventional alternatives.

The Astra Tech Implant System was employed, with its grit-blasted rough surface, TiOblast. All sites were evaluated during planning for bone volume and quality. All patients were treatment planned for fixed prostheses. Implants were installed in a two-stage procedure with a healing period of 3 to 8 months. If > 30% of fixture threads remained uncovered after installation then guided bone regeneration procedures were employed.

Edentulous patients were asked to refrain from wearing their dentures for 10 days. Patients were reviewed regularly for their oral hygiene. Acrylic-on-gold was used for full-arch prostheses and porcelain-fused-to-metal for partial prostheses, which were screw retained and inserted within 2 to 3 weeks of the abutment connection, with cross-arched splinting for edentulous jaws. All patients were instructed in oral hygiene, and maintenance.

Baseline parameters were recorded at the time of prosthesis insertion, and annually thereafter to register plaque score (PS), bleeding on probing (BOP), pocket probing depth (PPD) > 4 mm, presence or absence of peri-implant mucositis, pain or discomfort, hard or soft tissue complications, component failure, prosthetic failure (e.g. fracture), implant mobility. In addition changes in the marginal bone levels were recorded using a paralleling technique to allow the accurate assessment of the mesial and distal marginal bone, using a computerized measuring program.

**Results** 125 implants were placed, 72% of which were to support partial prostheses. Approximately 50% of patients were classified as having a bone volume of either category B or C and 80% had a bone quality classified as 3. Only 5 patients required augmentation procedures. All 125 implants were deemed to have osseointegrated at the time of exposure and all have been followed up to the 3-year review.

Throughout the study period a positive PS and BOP was seen to exist for < 10% of all implant sites and no PPD > 4 mm was recorded. There were no soft tissue complications or component failures. Three episodes of porcelain fracture and one de-veneering of acrylic teeth were recorded. With respect to changes in marginal bone levels 81% of implants recorded < 0.5 mm over the 3-year period with a mean of 0.21 mm. More bone resorption was noted around implants in type C4 bone with 37% demonstrating > 0.5 mm of bone loss.

**Discussion** This study reports a 100% implant success rate over a 3-year follow-up, with implants placed into bone of quality 3 or 4. There were no significant hard or soft tissue complications and no component failures. Patients maintained a high level of oral hygiene, which is reflected in the excellent marginal bone response with a mean of 0.21 mm bone loss of the 3-year follow-up. This study supports the findings of other that Astra Tech implants performed well in patients with a history of periodontal disease, without notable increases in implant failure or peri-implant mucositis.

# A 5-year Prospective Study of Astra Single Tooth Implants

Palmer R.  
Palmer P.  
Smith B.

Clin Oral Impl Res  
2000;11:179-182.

Products:  
Fixture ST 4.5/5.0  
Abutment ST

**Purpose:** To evaluate the Astra Tech single tooth implant system over a 5-year follow-up.

**Material and Methods** 15 patients each received one Astra Tech ST implant (Ø 4.5 mm). 11 implants were short, measuring 11 mm and four measured 15 mm in length.

Implants were placed according to recommended surgical protocol with the head of the implant 2 to 3 mm apical to the cemento-enamel junctions of the adjacent teeth. In total 6 central incisors, 8 lateral incisors, and 1 bicuspid were replaced. No additional ridge expansion or grafting procedures were used for any implants.

All implants were left to osseointegrate for 6 months prior to connection of the 0.0 mm ST abutment in 12 cases and the 1.0 mm ST abutment in 3 cases. Implants were temporised either with the ST coping or a temporary crown. Ceramometal definitive crowns were placed as early as possible.

Patients were followed-up every 6 months to determine clinical stability of the crown and tissue health.

Radiographs were taken using a long-cone technique at crown cementation and annually thereafter, and were assessed at x7 magnification. Marginal bone level was measured with reference to a defined point at the top of the implant. Results were subject to statistical analysis.

**Results** One patient was lost to follow-up. For the remaining 14 patients all have attended their review appointments.

No implants have been lost and there have been no soft tissue problems and minimal bleeding on probing. Prosthetically there have been no recorded cases of abutment screw loosening. One crown has decemented and required recementation after 18 months. One further crown suffered porcelain fracture and required replacement.

Mean distance for the marginal bone level measured from the reference point to the most coronal bone to implant contact point was at crown cementation (baseline) 0.47 mm and at the 5-year follow-up 0.39 mm. 33% of implants measured no bone loss and in some cases there was a clear bone gain. The changes in marginal bone levels were not statistically significant.

**Discussion** The Astra Tech single tooth implant system was most effective at replacing missing teeth.

The system was simple to use and there were very few complications. All implants remained in function and screw joints remained stable throughout the study. Excellent soft tissue health was maintained around all implants.

Marginal bone levels were extremely well maintained over the 5-year follow-up and may be attributable to the TiOblast surface and microthreaded design of the coronal portion of the implant.

# A Clinical, Radiographic, and Microbiologic Comparison of Astra Tech and Brånemark Single Tooth Implants

Puchades-Roman L.  
Palmer R.  
Palmer P.  
Howe L.  
Ide M.  
Wilson R.

*Clin Impl Dent Rel Res*  
2000;2:78-84.

## Products:

Fixture ST 4.5  
Abutment ST 4.5/5.0  
Abutment Screw ST

**Purpose:** To compare the clinical, radiographic and microbiologic status of a matched group of teeth and single tooth implants and to determine if the implant-abutment joint design or other features of the Astra Tech and Brånemark implant systems, impact upon the results seen.

**Material and Methods** A retrospective collation of 30 patients treated for single tooth replacement were matched, with 15 patients each having either Brånemark or Astra Tech implants. Those in the Brånemark group received machine prepared implants with flat-to-flat fixture/abutment interface as with the CeraOne™, while patients in the Astra Tech group received Astra Tech ST implants with the conically related Abutment ST. 73% of Astra Tech implants had been in function for 6 years, while 66% of Brånemark implants had been in function for less than 5 years. Distribution of implant positions was comparable with all but one implant in the anterior maxilla.

Clinical measurements included plaque score, sulcus bleeding index, and pocket probing depth with a constant force probe. Long-cone periapical radiographs available from the annual reviews were evaluated for marginal bone levels at x7 magnification, with respect to established reference landmarks at the top of each fixture.

Subgingival microbiota were sampled by the placement of 3 paper points for 10 seconds followed by their immersion in transport medium prior to processing. The first 100 organisms randomly selected were categorized. Counts were carried out blind to avoid bias, and were examined twice. All results were subject to statistical analysis.

**Results** Compared to matched control teeth and between the two implant types there was no statistical difference for plaque scores or for sulcus bleeding, although there was a small difference for sulcus bleeding for the Astra Tech implants when compared to control teeth.

Pocket depth was significantly higher around implants than control teeth for both groups though this was more apparent for Brånemark implants ( $p < 0.001$ ) than for Astra Tech implants, ( $p < 0.05$ ). This was reflected in the significant difference for probing depths around the two implant types, which measured as a mean 1.66 mm for Astra Tech implants and 3.33 mm for Brånemark implants, ( $p < 0.05$ ).

With respect to peri-implant microbiota there was no significant difference between implants. However more spirochetes were found around implants when compared to teeth,  $p < 0.05$ . By contrast there was a statistically significant difference ( $p < 0.001$ ) between marginal bone levels, which measured as a mean 0.6 mm mesially and 0.3 mm distally for Astra implants compared to 1.6 mm mesially and distally for Brånemark implants.

**Discussion** The histomorphological differences of the peri-implant tissues compared to the periodontal tissues will likely explain the significantly deeper pockets around the implants compared to the control teeth. This is not likely to be a reflection on tissue health but would explain higher sulcus bleeding scores, and the significantly higher proportion of spirochetes observed in otherwise healthy peri-implant sites.

When comparing implant types, deeper pocket depths and significantly increased marginal bone loss seen around Brånemark implants has been explained by others as the result of the microgap and microleakage of the butt joint design. The Conical Seal Design™ of the Astra Tech system, removes the irritant gap and eradicates microleakage. In addition, surface macro- and micro-modifications of the implant collar, notably the Microthread™ and TiOblast™ surface are said to yield in an improved cortical bone response.

# A Prospective Split-mouth Comparative Study of Two Screw-shaped Self-tapping Pure Titanium Implant Systems

van Steenberghe D.  
De Mars Greet.  
Quiryneen M.  
Jacobs R.  
Naert I.

Clin Oral Impl Res  
2000;11:202-209.

Products:  
Fixture TiOblast 4.0  
8-19 mm lengths  
20° UniAbutment 3.5/4.0

**Purpose:** The aim of this study was to compare the tissue response to the surfaces of Astra Tech (AT) and Brånemark System (BS) screw-shaped implants when placed in the same patients. This article presents the two-year data.

**Material and Methods** 18 patients were treated with both AT 4.0 mm TiOblast and BS Mark II self-tapping fixtures. Lengths of implants placed varied from 8-19 mm for AT and 10-18 mm for BS. Surgery was performed according to manufacturer's recommendations.

Time taken for surgical procedures at both insertion and exposure was recorded, as was any adverse event. Baseline long cone radiographs were taken at prosthesis delivery and then annually to monitor marginal bone levels. Additionally the presence of plaque, sulcus bleeding, and pocket depth were evaluated. Results were subject to statistical analysis.

Clinically, difficulties during the prosthetic phase were noted.

**Results** 50 AT and 45 BS implants were randomly distributed according to the split mouth design with 28 maxillary and 22 mandibular implants for AT and 23 maxillary and 20 mandibular implants for BS. Bone quantity and quality scores were evenly matched for both groups. 16 AT implants of less than 10 mm in length were used, however the Mark II BS implant does not come in lengths of less than 10 mm. In these circumstances, standard BS implants had to be used instead.

Cumulative survival scored 100% for AT and 97.7% for BS, with the loss of one fixture. There was no statistical difference between plaque scores, sulcus bleeding or probing depths even after two years.

Baseline bone level with regard to the reference point of each implant measured 1.48 mm for AT and 2.27 mm for BS. The difference was statistically significant  $p < 0.001$ . These figures were 1.66 mm and 2.30 mm respectively after two years, and the difference between them still remained significant,  $p < 0.001$ . Changes compared to baseline data was not significant measuring as a mean 0.2 mm for AT and 0.0 mm for BS respectively.

The time for abutment connection was markedly reduced for AT measuring as a mean 15 minutes compared to 20 minutes for BS.

More solder joints were required for AT prostheses achieving a clinically acceptable fit of the framework compared to the BS prostheses.

**Discussion** This is the first split mouth design comparing two implant systems with differing surface roughnesses. The ability of the shortest AT implants to withstand high occlusal forces in molar regions is attributed to the increased bone-to-implant contact and interfacial shear strength achieved through the rougher TiOblast surface. It is also apparent that the marginal bone levels are located more coronally around AT implants, increasing the total bone-to-implant surface area. For those BS selected sites that could not accommodate a Mark II 10 mm fixture, a 7 mm standard implant was selected. It is notable that 4 out of 5 of these shorter Brånemark implants failed. The cumulative success rate for AT implants of 100% is impressive, when compared to other long term data utilizing shorter implants. Abutment connection time for BS was 33% longer than for AT.

# Implant-supported Mandibular Overdentures Retained with Ball or Bar Attachments: A Randomized Prospective 5-year Study

Gotfredsen K.  
Holm B.

Int J Prosthodont  
2000;13:125–130.

**Products:**  
Fixture TiOblast 3.5  
Ball Abutment  
Bar Attachment

**Purpose:** This prospective study set out to determine the health of the peri-implant tissues and maintenance requirements for overdentures supported by either ball or bar attachments.

**Material and Methods** 26 patients were included in the study, 12 of whom smoked. Optimized conventional dentures were fabricated prior to the placement of two 3.5 mm diameter Astra Tech implants in the mandibular canine regions. Implant lengths varied according to available bone height, with a mean of 13.7 mm.

All implants were placed according to protocol with a submerged healing period. The choice of attachment system was randomized and the lower dentures were adjusted to incorporate two clips for the round bar or two ball housings, converting them to overdentures.

Patients attended a hygienist every 3 months and every 6 months clinical parameters were measured at four sites around each implant. These included: Plaque Index (PI), Gingival Index (GI) and Pocket Probing Depth (PPD) for each group. Removal of the attachment system was required so that a film holder could be screwed directly to the abutment heads, in order to obtain reproducible intra-oral radiographs. Marginal bone loss was assessed on the mesial and distal aspects via repeat measurements at x7 magnification. All results were subject to statistical analysis to determine the presence of any differences between the bar and ball groups.

**Results** 11 patients were treated with bar attachments and 15 patients with ball attachments. One implant failed before baseline and was subsequently replaced. No further implants were lost up to the 5-year recall (98%). On average 76% of surfaces scored 0 for PI and 65% scored 0 for GI. There was no significant difference between the two attachment groups with regards to these scores. Nor was there any significant difference between PPD for the two groups which never exceeded 6 mm. Hyperplasia was noted for three patients in the bar group, which required surgery.

Marginal bone distance to reference point measured 0.62 mm at baseline, increasing to 0.72 mm at the 5-year recall. There was no significant difference between the two groups.

A variety of prosthetic complications were noted during the study period both with the dentures themselves (such as fracture, or relining requirements), and also with the clips, which required reactivation or replacement. Loosening of either the attachment or abutment mainly occurred as a result of the radiographic procedure. For the bar group a total of 53 complications were recorded compared to 48 for the ball group. This equates to 1 complication/patient/year or 0.6 complications/patient/year respectively. The difference reached significance in the first year,  $p < 0.05$  with more complications recorded for the bar group.

**Discussion** Over the 5-year period there were no loaded implant failures, with an excellent maintenance of marginal bone and an absence of mucositis, regardless of attachment mechanism. Three patients required surgery to remove hyperplastic tissue from around the bar. These data were a reflection of the strict oral hygiene regime that had been established. Smoking did not appear to influence the outcome.

Prosthetic complications were notable but similar to or better than data from other studies. The majority of complications were directly related to the radiographic procedure. A number of opposing dentures required relining or remaking because of increased awareness of the looseness of these prostheses, subsequent to their conversion to a mandibular overdenture. Nonetheless overall satisfaction was high and the prosthetic survival rate was 100% over the 5-year period.

# Treatment of Edentulism Using Astra Tech Implants and Ball Abutments to Retain Mandibular Overdentures

Cooper L.  
Scurria M.  
Lang L.  
Guckes A.  
Moriarty J.  
Felton D.

Int J Oral & Maxillofac  
Implants  
1999;14:646-653.

Products:  
Fixture Microthread  
3.5 & 4.0  
Ball Abutment

**Purpose:** The aim of the study was to report the interim 2-year results of two parasymphyseal implants with ball abutments for the support of an overdenture and to demonstrate the efficacy and to record the long-term outcome over a 5-year period.

**Materials and Methods** 58 patients with an atrophic edentulous mandible of at least 10 mm in height were enrolled on to the study. All patients had idealized conventional dentures fabricated prior to implant surgery to define the restorative dimensions and aid in correct location for the osteotomy sites. All surgical procedures were according to conventional protocol to allow the placement of experimental implants based upon the standard Astra Tech implant geometry but with a microthread of pitch 0.185 mm compared with the standard thread pitch of 0.6 mm. Two implant diameters were used, Ø 3.5 mm and 4.0 mm.

In order to create a transmucosal healing with one-stage surgery, a healing abutment was located in place of the cover screw and the mucosal sutured around the abutments. Dentures were generously relieved and relined with Coe-Comfort. All implants were left to osseointegrate for 3 months at which time healing abutments were replaced by ball abutments and a reline/pick up impression taken to allow the incorporation of the ball housing into the denture base. Implant survival, soft tissue and denture complications were recorded.

**Results** All patients tolerated the one stage surgical procedure well. During the healing phase 5 implants were diagnosed as failures in 4 patients, one of whom was a smoker. None of the implants failed as a result of infection, but appear to have failed to osseointegrate with associated pain and/or mobility either prior to or at the time of ball abutment connection. This gave rise to a 95.7% success rate.

Each patient required a mean of 0.65 visits after insertion of the overdentures to address any complications. One week after the denture reline 2 ball housings dislodged from the acrylic and required a repeat of the reline and re-incorporation of the housings. In addition there was one episode of a fractured abutment, one loose abutment and a denture fracture. There were also 3 episodes of loose ball housings within the acrylic and 2 requests to improve denture retention.

There were no reported adverse events and no soft tissue complications. All patients were satisfied with their dentures.

**Discussion** Previous reports would indicate that the application of implants to help retain mandibular dentures provides a significant functional and psychological improvement. This study would tend to support this finding.

The use of a one-stage surgical technique is finding popularity and the short term data in the current study indicates that implants can osseointegrate with a high degree of predictability when adopting this protocol. In this study an experimental threaded cylinder implant with a microthread gave rise to a 95.7% success rate. The one-piece ball abutment proved reliable with one episode of loosening and one fracture. The ball housing proved more problematic, with 3 episodes of loosening and 2 episodes of dislodging from the denture base. All patients were satisfactorily restored to full function and with improved confidence in their dentures.

# Astra Tech and Brånemark System Implants: A Prospective 5-year Comparative Study after One Year

Åstrand P.  
Engquist B.  
Dahlgren S.  
Engquist E.  
Feldmann H.  
Gröndahl K.

Clin Impl Dent Rel Res  
1999;1:17–25.

**Products:**  
Fixture TiOblast 3.5 & 4.0  
9–19 mm lengths  
UniAbutment 20°

**Purpose:** The study compared treatment outcome with respect to implant survival, marginal bone levels and other clinical parameters for the Astra Tech and Brånemark systems.

**Material and Methods** 66 patients included in the study were randomly assigned to the Astra Tech (AG) or Brånemark (BG) groups, 33 patients in each group. 13 patients had hypertension, 5 had controlled diabetes and 18 were smokers (67% in AG and 33% in BG).

104 maxillary and 80 mandibular implants were installed in the AG. Implants were TiOblast, 3.5 mm and 4.0 mm diameter and ranged from 9 to 19 mm in length.

107 maxillary and 80 mandibular implants were installed into the BG. Implants were machine prepared, 3.75 mm in diameter and ranged from 10 to 18 mm in length.

Abutment connection was carried out after similar healing periods for both systems, averaging 6.5 months for maxilla and 3.9 months for the mandible. Operation time was recorded for comparison during both first and second stage surgical procedures.

Prosthetic procedures were conventional and followed routine protocol.

The follow-up parameters recorded were:

1) Presence or absence of pain, 2) Implant stability, 3) Plaque score, 4) Bleeding on probing, 5) Mechanical complications, 6) Changes in marginal bone levels.

Marginal bone levels were measured from established reference points for each system at fixture insertion (FI), abutment connection (AC), baseline (BL) and at the one-year review (OY).

**Results** 8 implants failed in the BG, 5 in one patient, yielding a 4.3% failure rate. Only 1 implant failed in the AG, yielding a failure rate of 0.5%, ( $p < 0.05$ ).

One bridge was lost in the BG, yielding a 3% prosthetic failure rate.

Plaque accumulation ranged from 0 to 25% and bleeding on probing from 0 to 5% at the one-year follow-up. There was no difference between the systems.

Marginal bone levels for the AG measured 0.1 mm below the reference point at FI, 0.7 mm at AC, 1.4 mm at BL and 1.6 at OY. Respective figures for the BG were 0.1 mm at FI, 0.3 mm at AC, 1.8 mm at BL and 1.9 mm at OY. The overall changes in marginal bone levels were not statistically different between the systems.

**Discussion** This study compared the Astra Tech TiOblast fixtures and machine prepared Brånemark fixtures. Exposure surgery and abutment connection was simpler in the Astra Tech system, as indicated by a 40% reduction in the time taken to perform this procedure.

Failure rates were significantly lower for the AG compared to the BG, however one patient lost 5 implants in the BG, and thus lost the whole prosthesis. The survival rates at one-year were therefore 99.5% and 95.7% respectively.

Marginal bone changes followed differing patterns with more resorption around the implants in the BG after baseline. This may reflect differing patterns of remodelling around the two systems. At the one year follow-up the mean marginal bone loss was 0.3 mm less for implants in the AG compared with the BG (not significant).

**Astra Tech Note:** The BG implants have a reference point that is placed deeper in the bone, in reality giving rise to a larger difference in the alteration of marginal bone levels.

# Five-year Prospective Follow-up Report of the Astra Tech Dental Implant System in the Treatment of Edentulous Mandibles

Arvidson K.  
Bystedt H.  
Frykholm A.  
von Konow L.  
Lothigius E.

Clin Oral Impl Res  
1998;9:225-234.

Products:  
Fixture TiOblast 3.5 & 4.0  
UniAbutment 20°  
Bridge screw

**Purpose** To report on the long-term survival of both implants and prostheses over a 5-year prospective study period.

**Material and Methods** Data was collated from two independent prospective studies yielding a total of 109 patients treated for mandibular edentulism. Each patient received 4 to 6 Astra Tech implants. All implants were submerged and subsequently exposed 3 months later. All patients received a screw-retained fixed beam fabricated from type III gold and veneered with pink acrylic and Ivoclar artificial acrylic teeth.

Baseline clinical measurements taken at bridge insertion included plaque score, gingival index, sulcus bleeding and pocket probing depth. One intra-oral radiograph of each implant was taken using a long-cone technique, in addition to a panoramic radiograph. Mesial and distal marginal bone levels were measured in tenths of a millimeter using x7 magnification. Follow-up radiographs were taken at year 1, 3 and 5 years. Clinical follow-up was annual.

At the 3- and 5-year reviews mobility of the prostheses was assessed and then the prosthesis removed to assess individual implant mobility. Results were judged according to Albrektsson's criteria for success.

**Results** A total of 618 implants were inserted of which 615 were utilized for reconstruction. 2 patients were excluded yielding 107 prostheses available for follow-up. Over the 5-year period a total of 16 prostheses supported by 90 implants were lost to follow-up.

Of the original 618 implants inserted only 5 failed to osseointegrate and 3 were left as sleepers. Two further implants were removed due to persistent pain. Finally one further fixture failed after 4 years in function. Thus the cumulative success rate at 5 years was 98.7%. 100% of prostheses remained in function. There was no detectable mobility of either prostheses or individual implants at the 3- and 5-year follow-ups, and no recorded episodes of screw or abutment loosening or fracture.

Clinical parameters revealed a good level of oral hygiene associated with healthy peri-implant soft tissues that was consistent throughout the study, with less than 1% of sites demonstrating any bleeding on probing. Mean probing depth measured 1.31 mm at the end of the study.

A total of 517 intra-oral radiographs were available from the 5-year follow-up. The mean change in marginal bone height for these implants when compared to baseline measured 0.26 mm.

**Discussion** Based upon the criteria set by Albrektsson, that an implant should remain immobile, free of pain and infection, and should not demonstrate a peri-implant radiolucency or a vertical bone loss of > 0.2 mm per year from baseline, it is possible to confirm that only 8 implants failed to meet all these conditions necessary for success at the 5-year follow-up.

Thus in the current study a cumulative success for implants of 98.7% was recorded, which compares favorably to the recommended minimum of 85%. In addition a prosthetic success of 100%, the absence of bridge screw or abutment loosening, and a mean marginal bone loss of less than 0.3 mm from baseline to year 5 would seem to support the notion that the system is both biologically and mechanically sound.

# Marginal Bone Levels at Single Tooth Implants with a Conical Fixture Design. The Influence of Surface Macro- and Microstructure

Norton M.

Clin Oral Impl Res  
1998;9:91-99.

Products:  
Fixture ST 4.5

**Purpose:** The purpose of this report was to monitor marginal bone levels at a single tooth implant with a coronal conical collar, with titanium that had been modified at both the macroscopic and microscopic levels, as compared to a machined conical collar.

**Materials and Methods** 33 consecutively placed Astra Tech single tooth implants were monitored for maintenance of marginal bone. The implant is grit blasted to give a surface roughness of the order of 1 to 5  $\mu\text{m}$ , and in addition the conical collar which is 5.4 mm in length and 4.5 mm in diameter is characterized by a so-called Microthread™, with a pitch of 0.185 mm. 76% of all implants had been in function for greater than one year, with all the remaining implants having been in function for greater than 6 months. All measurements were made on long cone periapical radiographs by means of  $\times 8$  magnification, utilizing the Microthreads™ as a gauge. If bone gain was apparent this was recorded as 0.0 mm bone loss so as not to give a false positive mean. Furthermore where bone loss occurred, the soft tissue appearance was noted along with bleeding on probing to assess soft tissue inflammation.

**Results** For the total group of 33 implants, no failures occurred, with 67% being recorded as having no bone loss. Cumulative mean marginal bone loss ranged from 0.33 mm for the total group up to one year of loading, to 0.61 mm for the 4 implants that had been in function for at least four years. Of these four implants, three had no bone loss, but one implant, the worst in the total group, had up to 2.5 mm bone loss. No implants lost bone along the entire length of the conical collar. Where bone loss occurred this generally stabilized within the first year. For these implants no apparent soft tissue inflammation was noted clinically.

**Discussions** There has been considerable research into roughening of titanium implants to enhance the interfacial shear strength of the bone-to-implant interface. Studies have demonstrated that this can result in increased bone-to-implant contact and at least a 3-fold increase in removal torque forces. By contrast other studies have demonstrated that there is an increase in marginal bone loss with roughened surfaces such as titanium plasma spray, which if ongoing, threatens the long term success of the implant due to increased risk of peri-implant disease. The present report, on 33 consecutively placed Astra Tech single tooth implants clearly demonstrates that a roughened surface of the order of 1–5  $\mu\text{m}$ , the so-called Tioblast™ surface, along with the special Microthread™ on the coronal conical collar of the implant, resulted in maintenance of marginal bone over a follow-up period of 1 to 5 years. The mean marginal bone loss was only 0.33 mm and 67% of the implants were recorded as having no bone loss.

These results were in stark contrast to a single tooth implant of a similar geometry, with a machined conical collar which was found to loose up to 3.6 mm of bone in clinical trials. Since this was compared to a similar machined implant without a conical collar, it was assumed that this was the result of the conical collar geometry and not microleakage at the implant/abutment junction. However by modifying the surface structure of the conical collar, this report has shown that it can enhance bone maintenance. Additionally it was noted for those implants where bone loss was recorded, that there were no apparent soft tissue complications, and the bone loss seemed to stabilize rather than progress.

# The Astra Tech Single-tooth Implant System: A Report on 27 Consecutively Placed and Restored Implants

Norton M.

Int J Periodont & Rest Dent  
1997;17:575-583.

Products:  
Fixture ST 4.5  
Abutment ST

**Purpose:** This study presents the results of a 1 to 4-year retrospective study on 27 consecutively treated patients for missing single teeth by means of single tooth implant of the Astra Tech Dental Implant System.

**Material and Methods** 27 patients with one or more missing teeth received a total of 39 Astra Tech ST implants, with their unique TiOblast surface and tapered, microthreaded collars. Surgery was according to a conventional protocol with implants placed 3 mm below the cemento-enamel junction of adjacent teeth. A 3 or 6 month healing period was allowed for osseointegration in the mandible and maxilla respectively. Where there was inadequate bone coverage, guided bone regeneration techniques were used. Abutment connection utilised the 0.0 mm Abutment ST in all cases. A torque driver was used to tighten screws to 25 Ncm. The ST abutment benefits from the internal Conical Seal Design and the external Octagonal Star Design to aid crown antirotation. Ceramometal crowns were cemented with Temp Bond and baseline data was recorded for marginal bone levels at the mesial and distal surfaces of each implant (using the long-cone paralleling technique). In addition any complications of the soft tissues and/or prosthetic superstructures were recorded. Recall visits were arranged 1 week, 1 month and 6 months after crown insertion. Thereafter patients were placed on annual recall.

**Results** All implants osseointegrated, with 27 being placed in all maxillary positions from 14 to 25. In addition 12 implants were placed in mandibular positions 36, 32, 31, 41, 46 and 47. Of the 39 implants inserted 27 had been restored into function and provided data for the follow-up. Complications during follow-up were generally restricted to crown decementation (n = 2). One abutment screw became loose.

With regard to marginal bone loss, only two implants recorded a mean bone loss of more than 1 mm, both of which were related to either abutment screw loosening or adjacent periodontally compromised teeth. Cumulative implant survival measured 100%.

**Discussion** Single-tooth implant replacement has been shown to yield high success rates. The current study reinforces these findings presenting a 100% cumulative success rate. Few complications were apparent and there was no need for patients to attend on more than one visit per year. As such the protocol for six monthly reviews was revised to annual reviews. For those crowns that decemented all were distal to the canines and may have been more subjected to occlusal forces. There were few component problems with only one case of abutment screw loosening and this is supported by other long-term data on the Astra Tech system with its Conical Seal Design.

# A Comparative Prospective Clinical Study of Two Single-tooth Implants: A Preliminary Report of 102 Implants

Kemppainen P.  
Eskola S.  
Ylipaavalniemi P.

J Prosthet Dent  
1997;77:382-387

**Products:**  
Fixture ST  
Abutment ST  
Abutment Screw ST

**Purpose:** The purpose of this study was to evaluate and compare two commercially available implant systems for restoration of single missing teeth.

**Material and Methods** Patients requiring the replacement of a single missing tooth were randomly assigned for treatment with either an Astra Tech ST implant (ATST) or an ITI implant (ITI). Patients were evaluated with regards to medical and dental histories, general health, occlusion, as well as the clinical and radiographic evaluation of the intended implant site.

Implants were placed according to manufacturer's protocol, other than the application of lower drilling speeds, which was considered worthwhile to reduce trauma to the bone.

All implants were left to osseointegrate for 6 months, with the Astra implants benefitting from a submerged healing. ITI implants were left transmucosal. Baseline radiographs were taken and abutment connection completed at this time. Octa or solid abutments were used for ITI and the Abutment ST for the ATST systems.

Three to four weeks later silicone impressions were taken and ceramometal crowns fabricated, which were cement retained for the ATST system and the solid ITI abutment, but crowns were screw retained to the Octa abutments or cemented to screw retained telescopic copings (n = 9).

Baseline measurements were taken one week after crown insertion and then repeated 12 months later. Plaque index (PI), gingival index (GI), and pocket probing depths (PPD) were all scored or measured. Additionally intra-oral radiographs were used to measure marginal bone levels at x 4 magnification in 0.1 mm increments.

**Results** A total of 102 implants were placed in 82 patients. 46 implants were assigned to 37 patients in the ATST group and 56 implants to 45 patients in the ITI group. Implants in the ITI group tended to be shorter with more 10 mm and 12 mm implants compared to 13 mm and 15 mm implants in the ATST group. Abutment ST was used in all ATST cases. In the ITI group 25 implants were restored with Octa abutments and 31 with solid abutments.

One Astra Tech Implant failed to integrate and was removed at exposure surgery, yielding a 97.8% success rate for the ATST group. All other implants were clinically and radiographically osseointegrated and the success rate for the ITI group was 100%.

PI revealed an absence or minimal plaque accumulation for > 90% of all crowns in both groups, and the corresponding GI scored low in greater than 90% of all cases in both groups. There was no statistically significant difference. PPD measured < 3 mm for almost all implants in both groups at the 1-year recall.

Measurements for marginal bone at both the mesial and distal surfaces revealed a mean bone loss of 0.13 mm for the ATST group and 0.11 mm for the ITI group.

For two Octa abutments the titanium occlusal screw loosened (8%) requiring their retightening. Both cases were for replacement of mandibular molars.

**Discussion** The total sample success was 99% for the 102 implants that were placed in a total of 82 patients. Differences in success rates for the two implant types were not statistically significant. All the other implants that were deemed to be osseointegrated continued to be retained in function at the 1-year review. All clinical and radiographical parameters indicated maintenance of both hard and soft tissue health, regardless of the system employed. There was no statistical difference in PPD regardless of whether a one or two-stage surgical technique was employed. Both systems appeared to satisfy the established criteria of success. Both systems emphatically demonstrated the benefit of the cone screw joint with no recorded failures of the abutment screw. However two occlusal screws loosened with the Octa abutment in the ITI system.

# Single-tooth Replacement by Osseointegrated Astra Tech Dental Implants: A 2-year Report

Karlsson U.  
Gottfredsen K.  
Olsson C.

Int J Prosthodont  
1997;10:318–324.

Products:  
Fixture ST 4.5  
Abutment ST

**Purpose:** This study presents the interim 2-year results of a 5-year long-term study on the treatment of missing single teeth by means of single tooth implant of the Astra Tech Dental Implant System.

**Material and Methods** 47 patients with one missing tooth each were enrolled on to the study. Astra Tech ST implants, with their unique TiOblast surface and tapered, microthreaded collars were used in all patients with lengths ranging from 11 mm to 17 mm. Surgery was according to a conventional protocol with a 3 to 7 months healing period for osseointegration. In three cases, lack of bone required the use of a guided bone regeneration technique. Abutment connection utilized the Abutment ST, which benefits from the internal Conical Seal Design and the external Octagonal Star Design to aid crown antirotation, and lengths ranging from 0.0 mm to 4.0 mm were selected. Ceramometal or allceramic crowns were cemented 2–3 weeks after abutment connection and baseline data recorded for marginal bone levels at the mesial and distal surfaces of each implant (using the long-cone paralleling technique). In addition any complications of the soft tissues and/or prosthetic superstructure were recorded.

**Results** All implants osseointegrated, with 79% being in maxillary positions from 15 to 26, and 21% being in mandibular positions 36 to 46. There were only 4 episodes of post surgical complications, with 2 implants self exposing, one case of infection subsequent to exposure and one case of granulation tissue formation. No other surgical problems were noted. Of the 47 crowns 43 were ceramometal and 4 were all-ceramic.

Three patients were lost to follow-up and data is therefore reported on 44 implants, with between 40 and 43 implants available for each recall visit due to the occasional missed recall. Mean marginal bone loss from baseline to year 1 measured 0.20 mm and this increased to 0.31 mm at the end of year 2. Notably 50% of all surfaces recorded no marginal bone loss to year 1, and this increased to 60% of surfaces at the 2-year recall.

Complications during follow-up broadly fell into two categories which were crown decementation (n = 6) and gingival retraction (n = 4). One abutment screw became loose. Cumulative implant survival measured 100%.

**Discussion** In general single-tooth implant replacement has been shown to yield high success. The current study reinforces these findings presenting a 100% cumulative success rate. By virtue of the success of this treatment modality it has also been noted that patients often do not see a need to attend for recall, and this resulted in 8.5% of available implants being lost to follow-up.

When recording marginal bone levels it was of interest that there was an increase in the number of surfaces that did not record bone loss (50% to 60%), even though there was an increase in marginal bone loss overall. Indeed there was also an increase in overall marginal bone gain at some surfaces, and when those cases that suffered bone loss related to crown decementation, or a loose abutment screw are excluded the results indicate that there was no further mean marginal bone loss after year 1.

For those crowns that decemented the majority were in contact in centric and two were in contact in protrusion. All contacts were reduced and the latter two taken out of protrusive guidance. There were few component problems with only one case of abutment screw loosening and this is supported by other long-term data on the Astra Tech system with its Conical Seal Design. Although a small amount of gingival recession occurred, which revealed a metal margin in three cases, no further treatment was indicated.

# A 5-year Prospective Clinical Study of Astra Tech Dental Implants Supporting Fixed Bridges or Overdentures in the Edentulous Mandible

Makkonen T.  
Holmberg S.  
Niemi L.  
Olsson C.  
Tammisalo T.  
Peltola J.

**Clin Oral Impl Res**  
1997;8:469–475.

**Products:**  
Fixture TiOblast 3.5 & 4.0  
UniAbutment 3.5/4.0

**Purpose:** The purpose of the study was to document the results of treating mandibular edentulism with the Astra Tech dental implant over a 5-year period.

**Material and Methods** 33 patients were included in the study, subsequent to rigorous clinical and radiographical evaluation. All patients had been edentulous for at least one year and were wearing removable upper and lower dentures. Residual mandibular alveolar bone height was required to measure > 8 mm. Patients were either assigned to the overdenture group (ODG) or the fixed prosthesis group (FPG), depending on their preference, financial limitations and the number of implants that could be placed. The implants were of the standard design and either 3.5 mm or 4.0 mm in diameter, with varying lengths. All implants were placed according to manufacturer's protocol and benefitted from a period of submerged healing for 3–4 months.

All patients in the ODG received 2–4 implants while those in the FPG received 5–6 implants. All implants were placed in the interforaminal region.

Prosthetic treatment followed abutment connection and employed all standard impression, registration, and laboratory techniques for the fabrication of conventional screw-retained acrylic/gold beam bridges, or clip retained overdentures on screw retained Dolder bars.

Baseline measurements after prosthesis installation included plaque score, gingival score, and the recording of any complications, either of a biological or technical nature. Radiographs were taken using the Scanora system. All clinical and radiographic measurements were repeated at each annual follow-up and changes in marginal bone level for each year, per patient, were recorded and compared using the unpaired Student t-test to see if any differences existed between the groups. Changes in soft tissue health between baseline and year-5 were averaged and then subject to statistical analysis using Fisher's permutation test to determine any significant difference between the ODG and the FPG.

**Results** 20 patients comprised the ODG with a total of 78 implants and 13 patients comprised the FPG totalling 77 implants. No long-term surgical complications arose and all but 2 implants in 2 patients were found to be osseointegrated, yielding a 98.7% success. No further implants failed during the remainder of the study period.

Prosthetic complications revealed one loose screw in year 1, one bar fracture in year 3, a framework fracture, and a denture fracture in year 4 and a clip fracture in year 5. Biological complications noted were implant associated with a peri-implant infection and marginal bone loss > 1 mm in year 5. The maintenance of oral hygiene was high in both groups and 95% of all implants in both groups were free of gingival inflammation. There was no significant difference between the two groups.

The mean marginal bone loss at the end of the study period measured 0.36 mm in the FPG and 0.56 mm in the ODG, this was not statistically significant. The cumulative implant survival rate was 100% for the FPG and 97.4% for the ODG.

**Discussion** There is a need for implant systems to be rigorously evaluated in a prospective clinical manner, and it has been suggested that a minimum 5-year follow-up is appropriate. The current study indicates that the Astra Tech dental implant is an effective unit to support both fixed prostheses and overdentures for restoration of the edentulous mandible. Both implant and prosthesis success was high. Hard and soft tissue response over the 5-year follow-up was excellent. Very few biological and technical complications were reported.

# Implant Therapy Involving Maxillary Sinus Lift in Periodontally Compromised Patients

Ellegaard B.  
Kølsen-Petersen J.  
Baelum V.

Clin Oral Impl Res  
1997;8:305–315.

Products:  
Fixture TiOblast 3.5 & 4.0

**Purpose:** The study set out to compare the clinical outcome of implants placed into periodontally compromised patients, when employing a conventional osteotomy preparation or in conjunction with a sinus lift procedure.

**Material and Methods** Patients with a deficient posterior maxillary dentition were enrolled on to the study and benefitted from placement of either ITI or Astra Tech (AT) TiO<sub>2</sub>-blasted implants. When implant sites were closely related to the maxillary sinus a simultaneous sinus lift procedure was undertaken so long as there was at least 3 mm of alveolar bone to the sinus floor, for primary stabilization. Implant surgery was carried out according to manufacturer's protocol and the sinus lift procedure was via a lateral window approach. The space created by tenting the sinus lining was left to fill with coagulum. A total of 80 implants were placed, 38 of which involved the maxillary sinus. Twentysix AT and 12 ITI implants were placed in association with a sinus procedure and 25 AT and 17 ITI implants were placed in a conventional manner in a total of 24 patients. All implants related to a sinus lift procedure were buried for a protected 5–6 month period of healing. Conventional ITI implants were left to heal transmucosally.

All implants were subsequently exposed and abutments connected to allow fabrication and support of prostheses, at which time baseline data for plaque, bleeding on probing (BOP), and probing depths (PD) was collected. Patients were initially seen every 3 months for oral hygiene. Patients were subject to chlorhexidine and/or mechanical therapy if there was evidence of plaque, BOP or PD > 3 mm. If PD measured > 5 mm with radiographic evidence of bone loss, patients received antimicrobial therapy. At the annual recall four surfaces of each implant were scored for plaque, BOP and PD. In addition measurements were made of the crestal bone to the shoulder of the implant on both the mesial and distal aspects of each implant, to the nearest 0.5 mm.

Statistical analyses were used to determine the first occurrence for both bone loss and PD at different measurements ranging from 1.5–6.0 mm, as well as for implant survival.

**Results** The premolar region was the most common site for treatment. Implants were followed up for a mean of 28.9 months. No standard AT implants failed (0%) but one AT sinus implant failed at 12 months (3.8%), compared to 2 sinus implant failures for the ITI system (16.7%) at 12 and 42 months and 1 standard implant failure at 11 months (5.9%). 70–80% of AT implants and standard ITI implants remained free from bone loss > 1.5 mm at 36 months, however only 29% of ITI sinus implants satisfied this parameter. No AT or ITI implants revealed a PD > 6 mm at 36 months however between 20 and 54% of implants did reveal a PD > 4 mm. Nonetheless, > 65% of implants remained free from BOP.

There were no statistical differences for any of the parameters when comparing conventional to sinus implants for the two systems under study.

**Discussion** In the current study two systems, AT and ITI were tested in the periodontally compromised patient both in a conventional manner and in relation to a sinus lift procedure. Using Kaplan-Meier Estimates the survival rates recorded were AT conventional 100% > AT sinus 95% > ITI conventional 91% > ITI sinus 86%. There were no statistically significant differences for any of the parameters measured, and data was comparable to that published for implants placed into non-periodontally compromised patients. There were no significant differences between implants placed conventionally or in relation to the sinus, although ITI sinus implants did show a trend for higher failure, greater bone loss and deeper peri-implant pockets.

# Implant Therapy in Periodontally Compromised Patients

Ellegaard B.  
Baelum V.  
Karring T.

Clin Oral Impl Res  
1997;8:180–188.

Products:  
Fixture TiOblast 3.5 & 4.0

**Purpose:** The aim of the investigation was to assess the survival and prognosis of dental implants placed into periodontally compromised patients.

**Material and Methods** 68 patients with a history of periodontal disease and associated tooth loss were enrolled on to the study. Patients were systemically healthy and had responded positively to periodontal therapy pre-operatively. Patients had a mean age of 60 years. Smokers accounted for 64%, and women for 75% of the patient pool. Bone loss around natural teeth ranged from 36 to 50%.

ITI and Astra Tech (AT) implants were used and were placed according to standard manufacturer's protocol benefitting from a transmucosal and submerged healing respectively. For AT implants exposure for abutment connection took place three months after implant insertion. All patients were instructed in post operative care and maintenance with twice daily rinsing with chlorhexidine (0.2%).

A total of 31 AT implants were placed in 19 patients and 93 ITI implants in 56 patients. After 3 months for osseointegration, abutments were connected and 3 months later baseline data for plaque, bleeding on probing (BOP), and probing depths (PD) was collated. All implants were subsequently restored. Patients were recalled every 3 month and the parameters re-evaluated. Patients were subject to additional chlorhexidine and/or mechanical therapy if there was evidence of plaque, BOP or PD > 3 mm. If PD measured > 5 mm with radiographic evidence of bone loss, patients received antimicrobial therapy. At the annual recall four surfaces of each implant were scored for plaque, BOP and PD. In addition measurements were made of the width of keratinized tissue in mm, as was the measurement of crestal bone to the shoulder of the implant on both the mesial and distal aspects, to the nearest 0.5 mm.

Statistical analyses were used to determine the first occurrence for both bone loss and PD at different measurements ranging from 1.5–6.0 mm as well as for implant survival.

**Results** The premolar region was the most common site for treatment. Implants were followed up for a mean of 31.7 months. No AT implants failed (0%), compared to 2 early failures and 1 late failure for the ITI system (3.2%). When considering survival by jaw type, data revealed 97.3% for maxilla vs 92.3% for mandible. 100% of AT implants remained free of PD > 6 mm at 36 months compared to 92.4% for ITI implants, while 44.2% and 63.1% remained free of a PD > 4 mm after a similar period. Nonetheless, 70% of implants remained free from BOP at 36 months and 86% of AT and 76% of ITI implants remained free from bone loss > 1.5 mm. Differences in plaque, BOP, and PD > 4 mm were higher for implants surrounded by non-keratinized tissue.

**Discussion** The survival of implants placed in to periodontally compromised patients has been questioned, yet the current study clearly indicates a high survival rate up to 5 years in function, with 100% of Astra implants in function at 3 years and 97.3% of ITI implants at 5 years. Loss of marginal bone was insignificant as was PD > 6 mm. These results are comparable to those in patients without periodontal disease and indicate that AT and ITI implants in periodontally compromised patients fulfil recognized criteria for success. The presence of non-keratinized tissue was more typically associated with PD > 4 mm and BOP.

# Histologic Evaluation of the Bone Integration of TiO<sub>2</sub> Blasted and Turned Titanium Microimplants in Humans

Ivanoff C-J.  
Hallgren C.  
Widmark G.  
Sennerby L.  
Wennerberg A.

Clin Oral Impl Res  
2001;12:128-134.

Products:  
TiOblast surface

**Purpose:** This study set out to compare the percentage bone-to-implant contact and percentage bone area for machined prepared titanium (MP) and a commercially available TiO<sub>2</sub>-blasted surface (TB) using microimplants placed into humans.

**Material and Methods** 54 microimplants 2 x 5 mm in dimension were manufactured from c.p. titanium. 27 implants were machine prepared to act as controls (MP). The remaining 27 implants (TB) were TiO<sub>2</sub>-blasted with particles of an average size of 25 μm. A confocal laser profilometer (Topscan 3D) was used to characterize the surface topographies by measuring surface parameters of height deviation ( $S_a$ ), surface enlargement ( $S_{dr}$ ) and wavelength ( $S_{\alpha}$ ).

27 patients planned for conventional implant surgery were also consented for the placement of one TB and one MP experimental implant placed distal to the most distal conventional implant inserted. All osteotomies were performed under antibiotic cover and copious irrigation using a small 1.5 mm twist drill. The experimental implants were screwed in manually. Flaps were repositioned and all patients instructed in post-operative care.

After a period of healing, all experimental implants were retrieved using a 3.0 mm trephine with their surrounding bone intact, at the time of abutment connection. Specimens were immediately fixed in 4% buffered saline. Specimens were then embedded and prepared for ground sections and stained with 1% toluidine blue for evaluation under a light microscope. Percentage bone-to-implant contact (%BIC) was measured using the Microvid system. In addition measurements were made of the percentage bone area within threads (%BA). All results were subject to statistical analysis.

**Results** For overall surface roughness parameters  $S_a$  and  $S_{dr}$  there was no statistical difference. However  $S_{\alpha}$  was significantly longer for TB implants. When looking to each thread area the flanks were rougher for TB implants whereas for valleys and tops, the surface was rougher for MP controls.

Implants were placed in both jaws with 36 maxillary and 18 mandibular sites. The mean healing period was 6.3 months in the maxilla and 3.9 months in the mandible. One patient died and these implants were excluded. From the remaining 52 implants three of the MP implants failed to integrate, one exfoliating early. 5 TB and 6 MP implants were exposed early and had marginal bone loss. 4 TB implants had bone overgrowth. All these implants were included in the analysis.

%BIC measured 37% for TB implants and 9% for MP implants,  $p < 0.0001$  for the total data set. The figures for maxilla ( $p = 0.0009$ ) and mandible ( $p = 0.0077$ ) were comparable. Histological all implants were related to some degree of bone contact, however the pattern of bone contact was different with bone approaching the surface and following the thread contour for TB implants. Bone was mostly lamellar in structure with some woven bone and areas of loose connective marrow tissue. % BA measured as a mean 34% for TB implants and 22% for MP implants ( $p = 0.007$ ). There was no significant difference for implants in the maxilla ( $p = 0.1337$ ) but significance was reached in the mandible ( $p = 0.0208$ ).

**Discussion** The current study indicates minor differences in the roughness parameters when considering the overall thread profile, but a notable difference in the character of the topography. There was a significant improvement for %BIC and %BA for TiO<sub>2</sub>-blasted implants. This may indicate a preference for their anisotropic topography or emphasize the importance for an increase in roughness of the flank of the threads. In any case it is clear that early failures, presumably as a result of pressure from the overlying partial dentures was restricted to the machine prepared implants, which seemed less able to withstand this early functional load, perhaps as a result of the reduced %BIC and %BA. Jaw location did not appear to influence the outcome.

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

Rasmusson L.  
Kahnberg K-E.  
Tan A.

Clin Impl Dent Rel Res  
2001;1:2-8.

Products:  
Fixture ST 4.5  
Fixture Microthread 4.0

**Purpose:** The current study set out to investigate whether an alteration to implant surface texture by means of grit-blasting and /or the addition of retention elements as a microthread would influence the healing of marginal bone defects and the associated implant stability.

**Materials and Methods** Three implant types were employed in the study, these were Brånemark System 3.75 x 8.5 mm (BS) which were machine prepared, and Astra Tech ST 4.5 x 9 mm (ATST) and Astra Tech Microthread 4.0 x 9 mm (ATM), which both present with a titanium grit-blasted surface and so-called microthreads in the coronal third of the implant. The ATST implants also present with a tapered coronal collar.

One of each implant was immediately inserted into the socket of either P2 or P3 premolars, which were extracted bilaterally in each one of six greyhound dogs, under anesthesia. Crestobuccal bone defects measuring 3 x 3 mm were created adjacent to the implants on one side only (test side), with the contralateral alveolus being left intact to act as control. A transducer was attached to all implants in order to measure their baseline resonance frequency (ISQ value) to assess their interfacial stiffness, before flaps were repositioned and implants benefitted from submerged healing for 4 months.

After the healing period all animals were sacrificed and at that time a second ISQ value recorded for each implant, which was removed *en bloc* and fixed in formalin. Specimens were embedded, sectioned and ground to 10 µm prior to staining with toluidine blue 1% and Pyronin-G. Histomorphometric evaluation was carried out on both sides of each specimen to measure the percentage bone-to-implant contact (BIC), the percentage bone area in all threads (BA), and the distance from each implant's reference point to the most coronal bone contact.

**Results** Healing was uneventful and all implants showed some degree of bone regeneration at the defect sites. When considering the ISQ values there was a typical increase in stiffness for all implants as a result of osseointegration in both test and control groups, which tended to be more significant for ATST and ATM. In addition the change in ISQ at 4 months compared to baseline for test implants compared to control implants reached statistical significance for both Astra Tech implant types ( $p < 0.05$ ). Histomorphometry revealed a statistically significant increase in mean BIC for Astra Tech implants compared to the Brånemark implant with 4-month values measuring 51% (ATM) > 47.4% (ATST) > 23.6% (BS) for test and control implants combined. Mean BA measured 38.9% (ATST) > 36.7% (ATM) > 32.5% (BS) for test implants and 42.1% > 41.3% > 34.8% for control implants respectively. The mean distance from each implant's reference point to the most coronal bone contact was significantly longer for the Brånemark implants compared to the Astra Tech implants ( $p < 0.05$ ) measuring 2.70 mm (BS) > 2.20 mm (ATM) > 2.18 mm (ATST).

**Discussion** The finding in this study that implants with a roughened surface result in an increased BIC is supported in the literature from human, animal and *in vitro* studies. It is also interesting to note that the distance to the most coronal bone at defect sites was notably shorter for these same roughened implants. This may also be related to the microthreads. Increase in ISQ values was mostly attributable to osseointegration, however some notable relative increase in ISQ was seen for roughened implants. Whether new bone filling in the defects provides any additional stability can not be verified. Data would suggest this to be unlikely, either due to lack of integration or possibly due to its immature structure.

# Soft Tissue Response to Clinically Contaminated and thereafter Cleaned Titanium Surfaces. An Experimental Study in the Rat

Ericsson I.  
Lekholm U.  
Sennerby L.  
Holmén A.

Clin Oral Impl Res  
2000;11:370-373.

Products:  
UniAbutment Machined  
UniAbutment TiOblast  
UniAbutment Polished

**Purpose:** The aim of the current investigation was to evaluate soft tissue response to titanium abutments left as machined or prepared by polishing or grit-blasting, after being chemically and/or mechanically cleaned.

**Materials and Methods** Eight machined abutments and 9 polished and 9 TiO<sub>2</sub>-blasted abutments were connected to implants in patients who had previously been treated for full arch fixed prostheses. Abutments were placed randomly amongst the 4 patients and were left in situ for one year. At the end of this conditioning period, all test abutments were removed and replaced with the patient's original abutments. The test abutments were split into 3 groups with 3 implants of each type in each group (except group 1, which only had 2 machined abutments). Abutments in group 1 were immediately autoclaved, while abutments in group 2 were cleaned with a cation active cleaning detergent (Biosurface AB) prior to autoclaving. Abutments in group 3 were also cleaned with the same detergent but were subsequently sterilized by glow discharge for 30 seconds.

These 26 test implants were then randomly inserted into skin pouches created on the abdomens of 8 Sprague-Dawley rats, one abutment in each pouch. In addition 3 new, sterilized control abutments of each surface type were also inserted into individual pouches, resulting in a total of 44 abutments, with 6 pouches each in 7 rats and 2 in one rat. Pouches were then left to heal with the abutments in situ for 6 weeks, at which time the rats were sacrificed and the abutments retrieved with surrounding soft tissues, from which they were separated, prior to preparation for histologic analysis. Sections were 1 μm in thickness and stained with 0.5% Azur II, and 0.5% methylene blue in 1% disodium tetraborate. Morphometric analysis was performed using Microvid.

For each specimen a general morphologic description was given and measurements of the capsule thickness and number of macrophages and fibroblasts were made from specified areas on 3 sections of each specimen. Mean values were calculated for each abutment and group means calculated from these data.

**Results** One TiO<sub>2</sub>-blasted abutment was lost during healing. When comparing test and control abutments of each surface types, no differences were noted and the data could be pooled. Mean capsule thickness measured 134 μm for the TiOblast surface, 131 μm for the machined surface and 132 μm for the polished surface. The number of macrophages counted within the specified area measured 20.8 for TiOblast, 15.1 for machined and 19.6 for polished surfaces. There were no significant differences between any of the results. Morphologically the tissue appeared very similar with a dense fibrous capsule, with poor vascularity at the interface and the occasional multinuclear giant cell. The fibroblast was the predominant cell type.

**Discussion** Within the confines of this study it was not possible to determine any differences between the different surface types nor between the mode of cleaning/sterilization, when considering soft tissue response. In addition no information can be extrapolated from these results with regard to bone tissue response to the differing surfaces.

# Augmentation of Exposed Implant Threads with Autogenous Bone Chips: Prospective Clinical Study

Widmark G.  
Ivanoff C-J.

Clin Impl Dent Rel Res  
2000;2:178-183.

Products:  
BoneTrap

**Purpose:** The current study was undertaken to evaluate the success of augmenting exposed implant threads with autogenous bone chips collected in an osseous trap.

**Material and Methods** 21 patients treated with implants were consecutively assigned to the study when a fenestration or dehiscence defect resulted in the exposure of four or more threads, requiring grafting. Only one implant was used per patient.

Implants were placed according to a standard surgical protocol and the type of defect and number of exposed threads recorded. Bone chips were collected using the Astra Tech BoneTrap™ with a Medena M0350 suction tip (Astra Tech AB). A separate suction device was used to remove saliva. The resultant compacted bone pellet was mixed with patient's blood and the mass packed tightly against the exposed implant surface to effect complete coverage of the exposed threads. After a 6-month submerged healing period all implants were exposed, and re-entry was facilitated to visualize the grafted area and measure the number of threads remaining exposed.

**Results** 12 patients presented with dehiscence defects and 9 with fenestrations. The number of exposed threads ranged from 4 to 14 with a mean of 8.4 threads. This equated to a mean exposure of 7 threads for dehiscence defects and 9.5 threads for fenestration defects. On re-entry the total number of threads exposed for the 21 implants ranged from 0 to 8, with a mean of 1.6. By group the mean number of exposed threads measured 1.3 and 1.7 for dehiscence and fenestration defects respectively. The gain of bone coverage was calculated as 81.5%.

**Discussion** There is some questions of doubt expressed in the literature as to the significance of covering exposed threads, and what method should be utilized, such as the application of barrier membranes etc. However the results of the present study confirm that autogenous bone chips, which can be conveniently collected during the preparation of the osteotomy site using a bone trap, can be placed under the periosteum and predictably result in an 80% increase in coverage of exposed threads. All augmented tissues were hard to probe and bone-like in appearance. This contrasts the softer tissue that has been found under membranes used for guided bone regeneration, which have also been associated with a higher risk of infection. The gain in coverage measured approximately 80% although some loss of graft volume was noted.

# Peri-implant Tissues at Submerged and Non-submerged Titanium Implants

Abrahamsson I.  
Berglundh T.  
Moon I-S.  
Lindhe J.

J Clin Periodontol  
1999;26:600-607.

Products:  
Fixture TiOblast 3.5  
45° UniAbutment 3.5/4.0

**Purpose:** To study the hard and soft tissue integration around Astra Tech components when used in a conventional one-stage and two-stage transmucosal surgical technique.

**Material and Methods** This animal study used the partially edentulated mandibles of 6 beagle dogs. Three months post-extraction, 3 Astra Tech TiOblast implants 8 x 3.5 mm were inserted unilaterally, with the most coronal bevel of the implants at the crestal cortical margin. Cover screws were placed and implants submerged for 3 months prior to a second surgical procedure to expose and secure Uni-abutments of 1.5 mm and 3.0 mm in length. At the same time a further 3 implants were surgically inserted in the contra-lateral side, with the coronal bevel of the implants once again level with the crestal cortical bone. However for these implants, abutments were placed immediately and soft tissues sutured around them for transmucosal healing. All dogs were routinely followed-up with daily hygiene.

Radiographs were taken using a modified Eggen technique to allow the accurate measurement of mesial and distal bone levels at time of fixture placement, 3 months post insertion and 6 months post insertion. Measurements were made mesially and distally using an imaging system under light microscope.

Clinical examinations were carried out to record plaque scores and a modified gingival index. Animals were sacrificed 9 months after the first implantation procedure and implants were harvested *en bloc* prepared and embedded for ground sections or for the fracture technique to allow histometric analysis of the dimensions and type of hard and soft peri-implant tissues, with particular attention to the *zone of connective tissue integration*. In addition a digital assessment of bone-to-implant contact in both the coronal unthreaded and threaded portions of the implant were undertaken. Results were subject to statistical analysis.

**Results** Clinically all implants included in the analysis demonstrated successful osseointegration and very low levels of plaque and excellent soft tissue health. Radiographs revealed that over the 9 months follow-up marginal bone loss measured as a mean 0.42 mm for implants subjected to the two-stage technique and 0.3 mm for those treated transmucosally. Histology revealed identical tissue types to be found in relation to the various implant components. Histometric measurements revealed a very close approximation for the two groups with the junctional epithelium measuring as a mean 1.9 mm, the *connective tissue compartment measuring* 1.17 mm and the distance from the abutment/fixture junction to the marginal bone level measuring 0.8 mm as a mean. With regards the morphometric measurements for the *connective tissue zone* again there was a very close approximation for all fractions including collagen, vessels, fibroblasts and residual tissues. Bone-to-implant contact for the coronal unthreaded portion measured 75.0% for the one-stage implants and 72.6% for the two-stage implants and 61.4% and 66.7% respectively for the threaded portions.

There was no statistical difference for any parameters measured.

**Discussion** The notion that an implant can be left exposed at the time of surgical insertion, without impacting on the tissue integration has been questioned and studied with various implants. This study compared the two surgical techniques for the Astra Tech TiOblast fixture and Uni abutment. Results clearly indicated that the tissue types, their dimensions and morphometry were identical regardless of procedure and that the percentage of bone-to-implant contact and marginal bone height is also unaffected.

# Formation of Mineralizing Osteoblast Cultures on Machined, Titanium Oxide Grit-blasted, and Plasma-sprayed Titanium Surfaces

Cooper L.  
Masuda T.  
Whitson S.W.  
Yliheikkilä P.  
Felton D.

Int J Oral Maxillofac  
Implants  
1999;14:37–47.

Products:  
TiOblast surface

**Purpose:** This study set out to determine at the histological level, the influence of surface topography and surface roughness on the cellular activity, matrix formation and mineralization of the bovine mandibular osteoblast (BMO) model. TiO<sub>2</sub> grit-blasted (TGB), and titanium plasma (TPS) surfaces were to be compared to machined titanium which would act as the control.

**Materials and Methods** 3 Titanium discs, 12.5 mm in diameter were finished to a 600-grit roughness, which is comparable to machined titanium. One disc was then prepared with a TPS coating (TPS, Interpore) and another by grit-blasting with TiO<sub>2</sub> (TiOblast™, Astra Tech). All discs were rinsed in 70% ethanol and dried under UV light. The discs were then scanned using atomic force microscopy to ascertain surface roughness parameters such as median height (mH), peak to valley measurements (PVM), and average surface roughness (aSR).

Each disc was cultured with 50,000 fetal BMO cells. Cultures were fed by media on day 3 and a mineralization media provided for multilayered cells at day 5. This was changed daily for 21 days and culture samples were collected at day 14 and at the end of the culture period.

Cultures were prepared, fixed and embedded for sectioning to 5 μm. Sections were stained with H&E, PAS Alcian blue, and von Kossa's 5% aq. AgNO<sub>3</sub>. Immunocytochemical analysis was carried out to determine the presence of bone sialoprotein (BSP) and osteocalcin (Oc). Sections were also prepared and viewed under SEM for morphologic and elemental analysis.

**Results** The 3 discs displayed unique visual topographies. SEM and surface roughness parameters confirmed the TPS and TGB discs to be notably rougher with an mH of 0.36 μm for the machined control compared with 1.5 μm for TGB and 1.89 μm for TPS. The PVM for the control disc was 0.73 μm, compared with 2.73 μm for TGB, and 3.78 μm for TPS. The average roughness, aSR, was 838 Å, 3809 Å, and 5048 Å for control, TGB and TPS surfaces respectively.

Mineralization was noted at 14 days for all surfaces but visually less so for TPS. It was noted in this and other studies that cultures often contracted on the TPS surface, such that the cultures were lost to the study. This is seen as a direct response to surface morphology, which impacts upon the biochemical difference in cell-mediated adhesion. Mineralization was also evident for machined > TGB but not on the TPS surface. These findings are probably a reflection of the fact that TPS-adherent cells are altered in their progression from osteoblastic to osteolytic cells. Under light microscopy, all cultures demonstrated multilayering and PAS staining of cells was evident for cultures on the control and TGB surfaces.

In the immunocytochemical analysis, BSP was only found in the upper layers of the culture for machined and TGB surfaces, but was found only within cells adjacent to the substrate for the TPS surface. Oc expression was concomitant with the visual evidence of mineralization, and was thus absent in the TPS culture. Elemental analysis revealed calcium phosphate within the mineralized layers of both machined and TGB surface cultures, but was almost absent for the TPS coating. The SEM view showed little material or adherent cells left attached to the machined surface. By contrast the TGB surface had many adherent cells and some tenacious remnant material, which was also evident in larger quantities on the TPS surface, although less adherent cells were present on this surface.

**Discussion** This study demonstrates that surface topography has an influence on the adhesion and multilayering of cells, and the process of mineralization. The formation of differing amounts of mineral were confirmed by light microscope, by elemental analysis and the expression of Oc. There was notably less mineral for the TPS surface compared to machined and TGB surfaces. In association with the differing distribution of BSP and the contraction of cells on the TPS surface, this indicates that surface topography might influence cell adhesion and modulate osteoblast differentiation.

# Anchorage of TiO<sub>2</sub>-blasted, HA-coated, and Machined Implants: An Experimental Study with Rabbits

Gotfredsen K.  
Wennerberg A.  
Johansson C.  
Skovgaard L.  
Hjørtning-Hansen E.

J Biomed Mater Res  
1995;29:1223–1231.

**Products:**  
Fixture Machined  
Fixture TiOblast 3.5  
Fixture Hydroxyapatite

**Purpose:** To evaluate bone anchorage of endosseous implants by means of mechanical and histologic assessment, when comparing a machined titanium surface (M), to a TiO<sub>2</sub>-blasted surface (TB) also with an hydroxyapatite coating (HA).

**Materials and Methods** 24 female white rabbits, were treated for the insertion of transcortical implants into the metaphysis of the tibia, bilaterally. The three surfaces preparations, M, HA and TB were used on two implant configurations, cylinder and screw (10 x 3.5 mm) and each implant type benefitted from both 3 weeks and 12 weeks of healing. Six rabbits were allocated to 4 groups: Screws at 3 weeks and 12 weeks and cylinders at 3 weeks and 12 weeks. Each rabbit received 1 implant of each surface type, bilaterally (n=6). All implants were provided with a hex top to allow their insertion and removal to measure peak removal torque. One operator performed all implant insertion and retrievals according to a specific protocol.

After the healing periods the three implants in the right tibia of each animal were removed using a reverse torque and a Tonichi torque gauge to measure the peak values. The left tibia was removed with implants en bloc, sawn into individual implant specimens and ground down to 20 μm sections. Histomorphometry was used to evaluate percentage bone-to-implant contact (BIC) for the entire implant length and in the cortical zones on both mesial and distal aspects.

Implant surfaces were characterized by viewing them under scanning electron microscope (SEM) and a quantitative evaluation of surface roughness (R<sub>a</sub>) was undertaken using the optical laser profilometry technique (TopScan 3D).

**Results** The SEM analysis revealed the HA coating to be characterized by the most irregular surface, compared to the small pits and machining grooves seen with the TB and M implants. The Ra values measured 1.89 for HA > 0.61 for TB > 0.31 for M.

When comparing mean peak removal torque values, the HA implants required a significantly higher removal torque of 107 Ncm, when compared to 58 Ncm for TB implants and 34 Ncm for M implants (p < 0.0001, for both screw and cylinder configurations). The difference in removal torque values between TB and M implants was also statistically significant, p = 0.004 for screw implants and p < 0.0001 for cylinder implants. Cylinder implants also demonstrated a statistically higher torque requirement when compared to screw type implants for TB and M, p = 0.002.

For BIC (screws / cylinders) at 3 weeks HA = 25.8% / 18.5%, TB = 20.7% / 14.7% and M = 9.7% and 7.6%. At 12 weeks the corresponding values measured 24.1% / 28.2% for HA, 22.5% / 26.1% for TB and 12.5% / 22.1% for M. There was a statistical increase in removal torque when comparing cylinder implants at 3 and 12 weeks, p = 0.002.

**Discussion** This study corroborates the findings of other studies, that rougher surfaces yield a higher interfacial shear strength. There was a strong correlation between the total BIC and that of the cortical zones, which implies a significant contributory factor of the bicortical fixation. Histology clearly demonstrated an osteoconductive property to the TB implants which explains the higher BIC when compared to M implants and the more rapid osseointegration of the TB implants. While a trend could be seen between BIC and removal torque data, no correlation could be demonstrated. This suggests that the overriding factor was mechanical interlocking as a function of surface texture. Histology also revealed inconsistency in the HA coating and that HA may be subject to biological degradation.

# Histomorphometric and Removal Torque Analysis for TiO<sub>2</sub>-blasted Titanium Implants. An Experimental Study on Dogs

Gofredsen K.  
Nimb L.  
Hjörting-Hansen E.  
Jensen J.S.  
Holmén A.

Clin Oral Impl Res  
1992;3:77-84.

Products:  
Fixture TiOblast 3.5  
10 mm length

**Purpose:** To evaluate the strength of osseointegration of TiO<sub>2</sub>-blasted screw and cylinder implants compared to machine prepared controls, when placed immediately into extraction sockets.

**Material and Methods** Test implants were blasted with TiO<sub>2</sub> particles. Surface topography was analyzed under scanning electron microscope (SEM).

1 implant of each type was randomly inserted into the immediate premolar extraction sockets of 6 beagle dogs, bilaterally. In order to evaluate bone repair and osseointegration all dogs were placed on a course of tetracycline throughout the study. Xylenol Orange and Calcein Green were injected at prescribed times, within the study period.

Long-cone periapical radiographs were taken at 2 weeks post-op and at 12 weeks at the time of sacrifice. 2 dogs with a total of 8 implants were made available for histologic analysis. Specimens were harvested en bloc and prepared for ground sections. These were evaluated under light microscope to allow a quantitative measure of the bone-to-implant contact.

Removal torque was measured for 16 implants from 4 dogs using a torque gauge, with a range of 0 to 150 Ncm. Only after removal was the implant type and surface type revealed.

**Results** The SEM indicated that the TiO<sub>2</sub>-blasted implants had a rougher surface than the machine prepared surface.

Radiographs revealed that vertical defects around the implants decreased over 12 weeks from a mean of 1.7 mm to 0.4 mm and horizontal defects decreased from 0.4 mm to 0.1 mm. Histometric analysis revealed a mean percentage bone-to-implant contact of 69% for both surfaces with histology revealing an intimate relationship with all 24 implants and bone fill by periosteal apposition. There was no significant differences for defect fill or bone-to-implant contact.

By contrast, the torque required to remove the implants indicated statistically higher values for all implants with the TiO<sub>2</sub>-blasted surface,  $p < 0.001$ , compared to the machine prepared surface. Median values of 105 Ncm and 35 Ncm respectively. For two TiO<sub>2</sub>-blasted screw implants, the torque limit of 150 Ncm was inadequate to remove the implants.

**Discussion** The application of a grit blasting technique using commercially pure titanium powders allowed surface modifications to a machine prepared titanium surface, altering the surface roughness.

This study compared implants of identical macroscopic design but with the TiO<sub>2</sub>-blasted versus the machine "as-is" surfaces. Increased surface roughness was confirmed by SEM.

Histologic and radiographic examination revealed that with small extraction defects it was possible to achieve osseointegration and good defect fill around both types of implant design and both surfaces.

While the fraction percentage of bone-to-implant contact was not significantly different, the absolute value was higher for the TiO<sub>2</sub>-blasted implants, as these provide a larger surface area of contact. Indeed the same is true when comparing the screw shape to the cylinder.

These increases may explain the higher torque removal values for screws versus cylinders and particularly for TiO<sub>2</sub>-blasted surface versus machined, which was 3-fold and highly statistically significant,  $p < 0.001$ .

# Implant-Abutment Interface: Biomechanical Study of Flat Top Versus Conical

Hansson S.

Clin Impl Dent Rel Res  
2000;2:33-41.

Products:  
Fixture Microthread 3.5

**Purpose:** The aim of this study was to determine the impact of having a conical versus a flat-top fixture-abutment connection on the induced stress patterns within the bone surrounding an implant with a microthreaded portion, via finite element analysis.

**Material and Methods** The finite element method is a very powerful mathematical tool used to calculate the stresses in a structure.

An axisymmetric finite element model of the mandible was used, with previously established parameters for elastic constants. The bone and titanium were assumed to be isotropic, having the same elastic properties in all directions. The implant was modeled to represent a 3.5 mm diameter implant with either an 11-degree internal connection or a flat-to-flat connection. Axial stiffness decreased at the apical end to simulate the macrothreads of an implant reducing the overall wall thickness compared to the microthreaded region.

Axial loads of 1000 N were applied to both systems, with either an even load distribution over the surface or concentrated on selective nodes.

Principal stresses in the bone and the interfacial shear stress were calculated on the assumption that there was no fusion between implant and bone, such that the interface could not resist tensile stress. Interlocking between implant and bone was modeled by connecting interfacial implant and bone nodes in a vertical direction resisting shear.

**Results** Peak interfacial shear stresses measured between 44 and 100 MPa for the flat-to-flat connection becoming progressively worse when the load applied was modeled only on a lateral node contact.

For the conical connection the stresses ranged from 26 to 32 MPa, when applying the same load. In addition the stress distribution patterns were markedly different with load being concentrated at the most coronal margin for the flat-to-flat connection but being more evenly distributed and at a deeper level, on the implant surface in the bone, for the conical connection.

A similar pattern was noted for the principle stresses which ranged from -32.4 to -277.7 MPa and from -8.5 to -103.3 MPa for the two connections respectively. These stresses were compressive in nature.

**Discussion** While the principal stresses recorded were higher than the interfacial shear stress recorded for both connections, the forces were compressive in nature, which is well tolerated by cortical bone. In this respect the shear stress is considered to be of greater significance.

Furthermore while clinical function of implant supported prostheses will lead to a variety of vectorial loads and moments, it is likely that only the axial loads will result in interfacial shear stresses, and these can be most destructive if the shear strength of the interface is exceeded, leading to slip and fracture of the interfacial tissues.

In the current finite element analysis it was apparent that the induced stresses were reduced by the application of the axial load along the internal conical surface of the implant. This also resulted in a more even and deeper distribution of the stress taking it away from the more delicate marginal region. *This would indicate that an implant with a conical interface can theoretically resist a bigger axial load before triggering bone resorption.* In general terms the results also indicate that a favorable stress distribution can be accomplished by a more central and deeper application of the axial load.

# Surface Roughness Parameters as Predictors of Anchorage Strength in Bone: A Critical Analysis

Hansson S.

J Biomechanics

2000;33:1297-1303.

Products:

TiOblast surface

**Purpose:** This theoretical, mathematical study was established to define the value of currently used surface roughness parameters as predictors of interfacial shear strength.

**Method and Results** The surface roughness parameters  $R_{a'}$ ,  $R_{q'}$ ,  $R_{t'}$ ,  $R_{sk'}$ ,  $R_{ku}$  are commonly quoted in studies on implant surface roughness and their values attributed to the retention potential of an implant, with respect to the bone-to-implant interfacial shear strength. An idealized surface was modelled with pits being of equal size and shape, and where the pit width,  $w$ , the pit depth,  $d$ , and the distance between pits,  $s$ , could be varied. The value of the  $R_{a'}$ ,  $R_{q'}$ ,  $R_{t'}$ ,  $R_{sk'}$ ,  $R_{ku}$  parameters were calculated in a simplified 2-dimensional model.

In addition the same idealized surface was modelled to allow a calculation of the interfacial shear strength using the conceptual mathematical model published by Hansson & Norton (J Biomechanics 1999) where both the  $f_{pe}$  and the  $f_{pd}$  could be calculated and the *retention potential* of the surface determined when the dimensions  $w$ ,  $d$ , and  $s$  were assumed to be either constant or variable as multiples of the interfacial tissue distance  $L$ , and the strength of the interface at the surface of the implant was assumed to be only 10% that of the strength of mature bone of full mechanical strength.

When increasing the pit width,  $w$ , it is apparent that more bone will be incorporated to resist shear, and accordingly the model of Hansson & Norton calculates an increase in interfacial shear strength. Only the parameter  $R_{sk}$  was seen to give a positive correlation. However for parameters  $R_{a'}$ ,  $R_{q'}$  the correlation is positive when  $w < 2L$ , while for  $R_{ku}$  the correlation is negative when  $w < 2L$ . The correlation for these parameters is reversed when  $w > 2L$ . The parameter  $R_{t'}$  is unaffected by changes in  $w$ . In the circumstances where  $w$  and  $s$  both change and remain equal, the parameters  $R_{a'}$ ,  $R_{q'}$ ,  $R_{t'}$ ,  $R_{sk'}$ ,  $R_{ku}$  do not vary.

In circumstances where pit dimension is unchanged but spacing  $s$  is varied, the conceptual theory clearly identifies an increasing *retention potential* for a decreasing spacing of  $s$ , as this correlates to an increase in  $f_{pd}$ . The parameter  $R_{sk}$  is the only parameter to give a positive correlation regardless of the spacing. However for parameters  $R_{a'}$ ,  $R_{q'}$  the correlation is negative when  $s < 10L$ , while for  $R_{ku}$  the correlation is positive when  $s < 10L$ . The correlation for these parameters is reversed when  $s > 10L$ . The parameter  $R_{t'}$  is unaffected by changes in  $s$ .

For increase in  $d$ , once again the model indicates an increase in interfacial shear strength. However only the parameters  $R_{a'}$ ,  $R_{q'}$ ,  $R_{t'}$  offer a positive correlation, with the other parameters being unaffected by changes in pit depth.

By contrast to the above if all dimensions are changed equally, in other words there is a change of scale, it is apparent that the parameters  $R_{a'}$ ,  $R_{q'}$ ,  $R_{t'}$  will afford a close positive correlation and act as a relative predictor of interfacial shear strength. However in practical terms when comparing surfaces of differing roughness and topography, the differences are more intricate and not limited to a change of scale. More likely they include a change of pit shape, dimension and density. Furthermore the interfacial distance  $L$ , is assumed to remain unchanged but may well diminish with functional loading. In these circumstances the parameters typically quoted for surface roughness will have a very limited power as predictors of interfacial shear strength.

# The Relation Between Surface Roughness and Interfacial Shear Strength for Bone-anchored Implants. A Mathematical Model

Hansson S.  
Norton M.

J Biomechanics  
1999;32:829–836.

Products:  
TiOblast surface

**Purpose:** This study set out to develop a mathematical model for estimation of the interfacial shear strength for a surface roughened implant integrated with bone, when the surface topography is known. In addition, the optimal surface topography for good interfacial shear strength was determined.

**Theoretical Model** The bone-to-implant interface has been clearly defined at the ultra-structural level as one composed of two zones which separate the implant from mature bone. The inner zone represents a layer of amorphous ground substance devoid of mineral and collagen and therefore assumed to contribute a very limited mechanical strength to the interface. The second zone is known to possess some collagen with increasing organization with increasing distance from the implant. This zone may contribute very small amounts of mechanical strength to the interface, until such time at a distance  $L$  from the surface of the implant there is mature bone of full mechanical strength.

With regard to surface roughness it is assumed that such a surface is comprised of pits of differing shapes and dimensions, into which plugs of mature bone may protrude, thereby interlocking and stabilizing the implant. Due to the viscoelastic nature of bone these plugs can be assumed to all fracture at the same time when the ultimate shear force is reached. The magnitude of the interfacial shear strength will depend solely on the distance  $L$ , such that at the surface of the implant the shear strength is low and at the distance  $L$  strength increases to the maximum for mature bone. Within the interfacial tissues the strength can be assumed to increase according to a cosine function.

When considering the effectivity of a pit to retain the plug of bone, it is assumed that a direct contact would represent the ideal where the distance  $L$  is zero. The ratio of the real (where  $L$  is equal to approximately 100–500 nm) to the ideal interfacial relationship is termed as the pit effectivity factor  $f_{pe}$ . In addition the dimensions of the pits will impact upon the retention of the bone plug, where it can be shown mathematically that very small pits contribute little strength due to their inability to accommodate sizeable plugs of mature bone. The retention of bone within the pit will also be influenced by its shape, whereby pits with a rounded surface angle, are less retentive. When comparing pits of differing shape, the half spherical pits can be shown mathematically to have the highest retention potential.

Finally the number of pits on the surface of an implant (which will contribute to the surface roughness) will determine the number of interlocking bone plugs and hence the interfacial shear strength. The pit density,  $f_{pd}$  is simply defined mathematically as the total surface area of all the pit openings (fracture planes) divided by the total surface area of the implant. The shape of the pits will influence the manner in which they can be packed together, with square pits allowing an optimal pit density compared to the more idealized half spherical pit.

The interfacial shear strength of bone can therefore be shown to relate in a proportional manner to both the  $f_{pe}$  and the  $f_{pd}$ .

When considering the ideal implant surface it is clear that the pit density should be maximised. When considering pit shape the half spherical or square pit were seen to yield the most favorable  $f_{pe}$ . For pit dimension, it is apparent within the micrometer range that an increasing pit size gives rise to an increase in resistance to shear, for interlocking plugs of mature bone. The zenith above which increases in pit size do not yield increases in strength will vary according to the shape of the pit. For idealized pits this appears to be equal to approximately  $10L$ . On this basis the pit dimensions should be of the order of 1–5 microns.

# The Implant Neck: Smooth or Provided with Retention Elements. A Biomechanical Approach

Hansson S.

Clin Oral Impl Res  
1999;10:394–405.

Products:  
Microthread

**Purpose:** This study set out to establish the influence on peak bone stress at the bone-to-implant interface by providing retention elements along the entire length of the implant neck, and to also evaluate the impact of bi-cortical fixation and implant axial stiffness, which have also been shown to help in reducing peak bone stresses.

**Materials and Methods** Calculations were made using finite element analysis. In order to obtain sufficient accuracy, initial data was calculated from a 3-dimensional (3-d) model of a 72 mm long uniform section of a mandible, built up with 8 node cubic elements, in order to evaluate its elastic behavior. Data from this model was then transferred into a simpler axisymmetric model built up with 4 node square elements. This axisymmetric model was then adjusted to ensure that relative displacement of upper and lower cortices under a 200 N centrally located load was similar to that obtained in the 3-d model. Certain assumptions were incorporated into the modeling of the bone to allow for its viscoelastic behavior and to avoid the formation of high peak stress artifacts which were seen to occur at singular points. It was also assumed that for a smooth implant surface only compressive stresses would be resisted, compared to compressive and shear stresses for a surface provided with retention elements.

Into this axisymmetric model a 3.5 mm diameter titanium implant was inserted, built up with 4 node elements and with appropriate information on the modulus of elasticity and Poisson's ratio for titanium. The width of the central bore was altered so that the wall thickness varied between 0.3–0.8 mm which in turn would affect axial stiffness of the implant and its surface was either modeled to be smooth or rough by the incorporation of retention elements, all the way to the top of the implant. Additionally, variations in thickness of the cortical bone were modeled and the implant length was varied to allow for uni- and bi-cortical fixation.

A 1000 N vertical load was applied evenly to all upper implant nodes and the influence of surface character, wall thickness and the presence of uni- or bi-cortical fixation was calculated with regards to the peak interfacial bone stress.

**Results** When considering the influence of surface characteristic for implants with bicortical fixation, and a wall thickness of 0.6 mm, peak interfacial shear stress reduced from 80.6 MPa to 29.6 MPa when the neck was characterized with retention elements. Indeed in all calculations there was always an approximate 60 to 80% decrease in peak stress when the implant neck was characterized with retention elements. An increase of wall thickness from 0.3 to 0.8 mm decreased peak stresses by only 10 to 20%. The influence of uni- or bi-cortical fixation was similar.

**Discussion** The majority of implants have a smooth cervical portion around which significant bone loss has been reported, particularly for those with a long conical shaped neck. However Palmer et al., have reported remarkable maintenance of marginal bone around similarly shaped implants provided with retention elements. It has been postulated that with a smooth neck the bone does not partake in distributing axial load and suffers from atrophy according to Wolff's law. By contrast the interlock afforded by retention elements allows for the axial load to be dissipated via interfacial shear which has been shown to be a critical stressor. It can be concluded that the provision of retention elements, an increase in axial stiffness of the implant and bi-cortical fixation will all enhance the performance of an implant to resist higher axial loads.

# ***In vitro* Evaluation of the Strength of the Conical Implant-to-Abutment Joint in Two Commercially Available Implant Systems**

Norton M.

J Prosthet Dent  
2000;83:567–571.

**Products:**  
Fixture ST 4.5  
Abutment ST 4.5/5.0

**Purpose:** The aim of this study was to evaluate the 8-degree internal conical joint used by the ITI implant and compare it to the similar 11-degree conical joint of the Astra Tech implant when the respective implants were subjected to a three-point bending test.

**Materials and Methods** Six test implants and abutments of each type were assembled according to the manufacturers instructions.

The ITI solid abutment was secured using a force of 35 Ncm and the Astra Tech UniAbutment with 25 Ncm. In turn they were each secured in the holding device such that they were gripped at a level which was equivalent to that of the normal marginal bone position expected for an integrated implant.

Each test implant was then loaded at a point 4 mm from the implant-abutment interface with a constant velocity of 1 mm/min. The high load tests provided data relating load to displacement from which curves were drawn allowing relative comparisons. The first point of plastic deformation and the point of ultimate failure were recorded.

The resulting data was compared using Fisher's permutation test to determine the significance of the differences between the two independent groups at the 5% confidence level.

**Results** The mean plastic bending moment for the Astra Tech abutment was  $4176 \pm 103$  Nmm compared to  $2526 \pm 111$  Nmm for the ITI abutments.

The mean maximum bending moment for the Astra Tech abutment was  $5507 \pm 74$  Nmm compared to  $3269 \pm 134$  Nmm for the ITI abutments.

The plastic bending moment was defined as the point at which 0.3 mm of permanent deformation was recorded for each implant. The final results were obtained from 6 Astra Tech and 5 ITI implants (due to 1 technical failure). The mean bending moment of 5507 Nmm for the Astra Tech implant corresponded to a load of 220 N, compared to 3269 Nmm for the ITI implant where the applied load was 131 N.

Differences in the mode of failure were that for the Astra Tech implant the critical zone was in the centre of the cylindrical section of the Uni-Abutment, whilst for the ITI implant it was found at the base of the conical section just above the screw-threads.

The loads at which first plastic deformation and ultimate failure took place were remarkably consistent as demonstrated by the low standard deviations. This would affirm the consistency of the applied manufacturing tolerances for both of the implant systems tested.

**Discussion** The conical implant/abutment interface has been shown by a number of studies to be mechanically superior to the flat hex-top designs when subjected to similar three-point bending tests. This is partly attributed to the more precise fit that can be achieved with conical designs achieving fit accuracies of 1 to 2  $\mu\text{m}$  compared to hex-top designs where it is rarely better than 5 to 10  $\mu\text{m}$ .

The mode of failure was entirely consistent for both implant types showing that the subtle differences in degree of taper and design of the screw portion have a significant impact on performance. The design of the Astra Tech cone joint appears superior to that of the ITI cone, in that it can resist statistically higher bending moments.

# An *in vitro* Evaluation of the Strength of an Internal Conical Interface Compared to a Butt Joint Interface in Implant Design

Norton M.

Clin Oral Impl Res  
1997;8:290–298.

**Products:**

Fixture TiOblast 3.5  
20° UniAbutment 3.5/4.0  
Semi Burnout Cylinder 20  
Bridge Screw

**Purpose:** The aim of the study was to compare the strength of the fixture/abutment and abutment/bridge cylinder interfaces for implants utilizing a butt joint and a conical joint design.

**Materials and Methods** The Astra Tech implant and Brånemark implant were used to represent the conical joint and butt joint designs respectively, with units being assembled according to manufacturer's recommendations.

Each implant was screwed into a metal beam at one end, with the abutment or bridge-cylinder being clamped to another beam at the opposite end. In order to assess the strength of the implant/abutment and abutment/bridge cylinder interfaces, the 3-point bending test was utilized, with the application of a known force at right angles to the interface, by means of a screw driven loading device. For each system and each interface, 6 units were tested.

Recordings were made for both the point of first plastic bending, recorded as a 0.3 mm deformation and also maximum bending to failure. The displacements were recorded on a Linear Variable Differential Trans-former (LVDT). Load and displacement were analysed using an appropriate software program.

**Results** For the implant/abutment interface, the mean moments required to register the point of first plastic deformation was 1315 Nmm and 645 Nmm for the conical joint and butt joint respectively, with a mean moment force of 2030 Nmm and 1262 Nmm to cause failure of each joint. The difference between the moments was highly statistically significant being  $P = 0.00010$  and  $P < 0.0010$  respectively. Furthermore the coefficient of variance was low confirming the strict homogeneity of both material and design, in both systems, which would suggest that the results would be reproducible in larger sample.

In the Astra Tech system failure did not result in either elongation or abutment fracture, however it is likely that imperceptible vertical hair-line fractures did occur at the neck of the implant. For the Brånemark system there was a notable elongation of the abutment screw with loosening of the joint.

When testing the two systems at the abutment/bridge cylinder interface, the mean moments required to register the first point of plastic deformation were 994 Nmm and 725 Nmm for the conical and butt joints respectively, with a moment force of 1866 Nmm and 1305 Nmm required to cause failure of each joint, which for the Astra Tech system was a fracture of the bridge screw, but for the Brånemark system, the abutment screw was once again seen to be the focus of deformation. Again the differences were statistically significant with  $P < 0.010$  and  $P = 0.00010$  respectively.

**Discussion** Biomechanical failure has become the focus of concern with a constant source of data drawing attention to the problems of screw loosening and screw fracture.

Whilst numerous efforts have been made to address this problem, in particular with the introduction of the torque driver, there has been little data published confirming the efficacy of the butt joint or other designs to resist bending moments.

This study has demonstrated that the conical joint is significantly superior to the butt joint in resisting bending moments when tested in the extreme, such as in the 3-point bending apparatus described, and that furthermore the abutment screw is the weakest point in the butt joint design and not the bridge screw, when using the Estheticone system.

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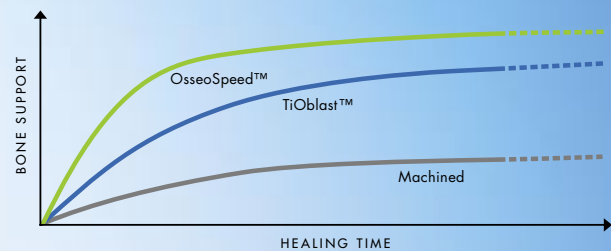
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