Which Surface Properties Enhance Bone Response to Implants? Comparison of Oxidized Magnesium, TiUnite, and Osseotite Implant Surfaces

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Purpose: This study compared the speed and strength of osseointegration and osteoconductivity between an oxidized experimental magnesium (Mg) implant, an oxidized commercially available TiUnite implant, and a dual acid-etched surface Osseotite implant. The aim was to investigate which surface properties enhance bone response to implants, and thereby to test a biochemical bonding theory. ***Materials and Methods:*** A total of 60 screw implants (20 of each design) were inserted through 1 cortex into the tibiae of 10 rabbits. Surface chemistry, oxide thickness, morphology, crystal structure, and surface roughness were evaluated. After healing times of 3 and 6 weeks, all bone implants were unscrewed with removal torque (RTQ) devices, and the bone specimens were subjected to histomorphometry. ***Results:*** RTQ values for Mg, TiUnite, and Osseotite implants were 27.1, 21.3, and 15.4 Ncm, with new bone formation values of 29%, 18%, and 15%, respectively, at 3 weeks. At 6 weeks the RTQ values were 37.5, 36.4, and 21.5 Ncm, with new bone formation values of 39%, 31%, and 26%, respectively. ***Discussion:*** Mg implants demonstrated significantly greater RTQ values (P = .008 and P = .0001) and more new bone formation (P = .031 and P = .030) than Osseotite at 3 and 6 weeks, respectively. Mg implants also showed higher RTQ values at 3 weeks and new bone formation at 6 weeks than TiUnite, but neither were significant (P > .05). TiUnite showed significantly higher RTQ values than Osseotite at 6 weeks (P = .001), but was not significant at 3 weeks (P >.05). Osseointegration rate (ΔRTQ/Δweeks) was significantly faster for Mg (P = .011) and TiUnite (P = .001) implants between 3 and 6 weeks of healing time, but was not significant for Osseotite. ***Conclusions:*** The results indicate that surface chemistry facilitated more rapid and stronger osseointegration of the Mg implants despite their minimal roughness compared to the moderately roughened TiUnite. This suggests potential advantages of Mg implants for reducing high implant failure rates in the early postimplantation stage and in compromised bone, making it possible to shorten bone healing time from surgery to functional loading, and enhancing the possibility of immediate/early loading. *Int J Prosthodont 2006;19:319–329.*

Implant surface innovations have resulted in improved clinical success. Machined/turned surfaces no longer represent the best solution for osseointegrated implants. Novel implant surfaces may facilitate immediate/early loading as a viable treatment option. Currently, the trend of clinical implant surface modifications is shifting toward changes in surface chemistry, exemplified by electrochemically oxidized TiUnite implants (Nobel Biocare),[1] fluoride-treated Osseospeed implants (Astra Tech),[2] and sodium chloride–treated hydrophilic Sand-blasted, large-grit, acid-etched (SLA) implants (Straumann).[3] There are few studies with experimental data on clinically available surface-modified implants that make direct comparisons between SLA and Osseotite implants,[4] Osseotite and TiUnite implants,[5,6] or SLA and TiUnite implants.[7] To the best of the authors' knowledge, the precise relationship between surface properties and bone response for surface-modified clinical implants remains unknown.

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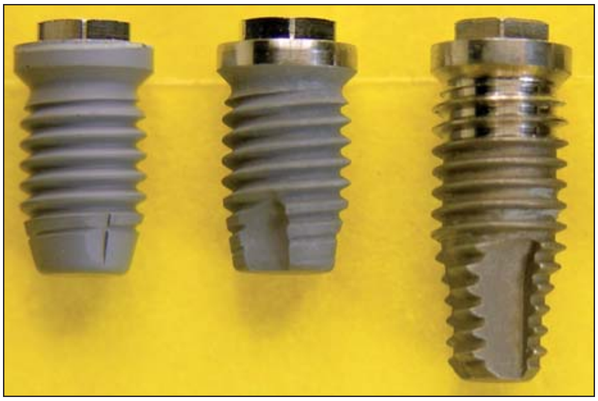


Fig 1 The 3 implant types: Mg (*left*), TiUnite (*middle*), and Osseotite (*right*).

In vivo effects of surface chemistry have been investigated by Sul et al.[8–14] Sulfur (S)-incorporated,[8] phosphorus (P)-incorporated,[8] or calcium-incorporated[9,10] oxidized implants showed significantly improved bone responses compared to machined/turned implants. Surfaces with incorporated calcium ions showed significantly enhanced integration strength of bone implants compared to S-incorporated or P-incorporated implants.[11] Sul et al recently investigated magnesium (Mg)-incorporated oxidized implants and reported significant enhancement of the bone response (removal torque [RTQ] and resonance frequency tests) compared to machined/turned[12] and oxidized implants.[13] The optimal surface properties of Mg-incorporated implants for bone enhancement have been suggested.[14] However, clear explanations for the osseointegration mechanism of oxidized implants do not exist at present. A biochemical bonding theory was proposed.[12,13,15,16] The present study investigated the rate and strength of new bone formation, osseointegration, and osseoconductivity of 2 different oxidized implant surfaces and 1 dual acid-etched surface in a rabbit model. On the basis of previous findings, it was hypothesized that the potentially bioactive surface would encourage faster and stronger integration of implants in bone, even at healing periods earlier than 6 weeks. The aim of this study was: *(1)* to compare bone response to topographically changed and surface chemistry–modified clinical implants, *(2)* to investigate which surface properties of implants enhance bone response, and *(3)* to thereby assess the validity of the biochemical bonding theory proposed previously. Comprehensive descriptions of the surface properties of the implants in the present study will be reported in a companion paper.

Materials and Methods

Implant Design and Preparation

Three groups of screw-shaped titanium implants were used: 1 custom-made experimental Mg implant (3.75 $\times$ 7 mm) and 2 commercially available clinical implants, the TiUnite implant (3.75 $\times$ 7 mm, Nobel Biocare) and the Osseotite implant (3.75 $\times$ 8 mm, Implant Innovation) (Fig 1). The latter 2 clinical implants were purchased from their respective manufacturers; however, the Mg implant was custom made at our laboratories. Mg implants are prepared using a microarc oxidation (MAO) process in galvanostatic mode, with the anodic forming voltage increased at a rate of dV/dt, controlled at ≥ 0.5 V/second with combined electrochemical parameters.[13,16,17] Two platinum plates with surface areas of 16 cm^2 each were used as counter electrodes at each side of the titanium anode. Currents and voltages were continuously recorded at intervals of 1 second by an IBM computer interfaced with a DC power supply. The ripple variability was controlled to less than 0.1%. The Mg and TiUnite screws are electrochemically oxidized implants. The designs of the 3 implant types seem to be rather similar, but differ somewhat with respect to the radius in the valley and peak of the threads (Fig 2). All implants had a thread pitch of 0.60 mm and a thread angle of 60 degrees. The Mg implant had an outer diameter of 3.75 $\pm$ 0.01 mm, an inner diameter of 3.11 $\pm$ 0.01 mm, a radius in the thread valley of 0.05 mm, and a full radius at the thread peak. The main difference in the macroscopic features between implant geometry was in the cutting edges at the apical portion. There were 3 cutting edges for Mg and TiUnite implants and 4 cutting edges for Osseotite implants. The magnitude (size and depth) of cutting edges was ranked as such: Mg < TiUnite < Osseotite.

Implant Surface Properties

Surface chemistry, morphology, oxide thickness, pore characteristics, crystal structure, and roughness were evaluated. Surface chemistry was analysed by x-ray photoelectron spectroscopy (XPS) (ESCALAB 250, VG Scientific) (Fig 3). Surface morphology was characterized by scanning electron microscopy (SEM) (JSM-6700F, JEOL) (Figs 2d to 2f). Oxide thickness and pore configurations of the oxidized implants were measured with focal emission mode (FE-SEM) on cross-sections prepared using the metallurgical method of nickel plating. One implant from each group was randomly selected and measured 5 times on the thread peak, thread valley, and thread flank each, for a total 15 measurements for each selected implant. The crystal structure of the Mg implant was determined using

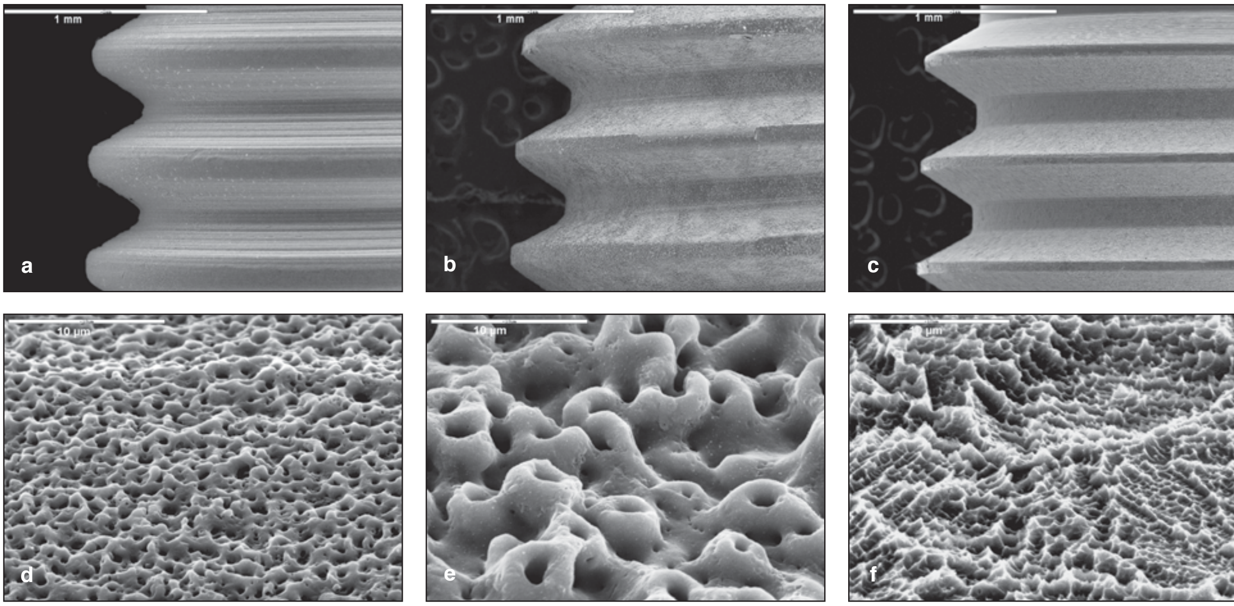


Fig 2 SEM pictures showing (**a to c**) thread geometry (original magnification 65×) and (**d to f**) surface morphology (original magnification 5,000×): Mg (**a and d**), TiUnite (**b and e**), and Osseotite (**c and f**) implants.

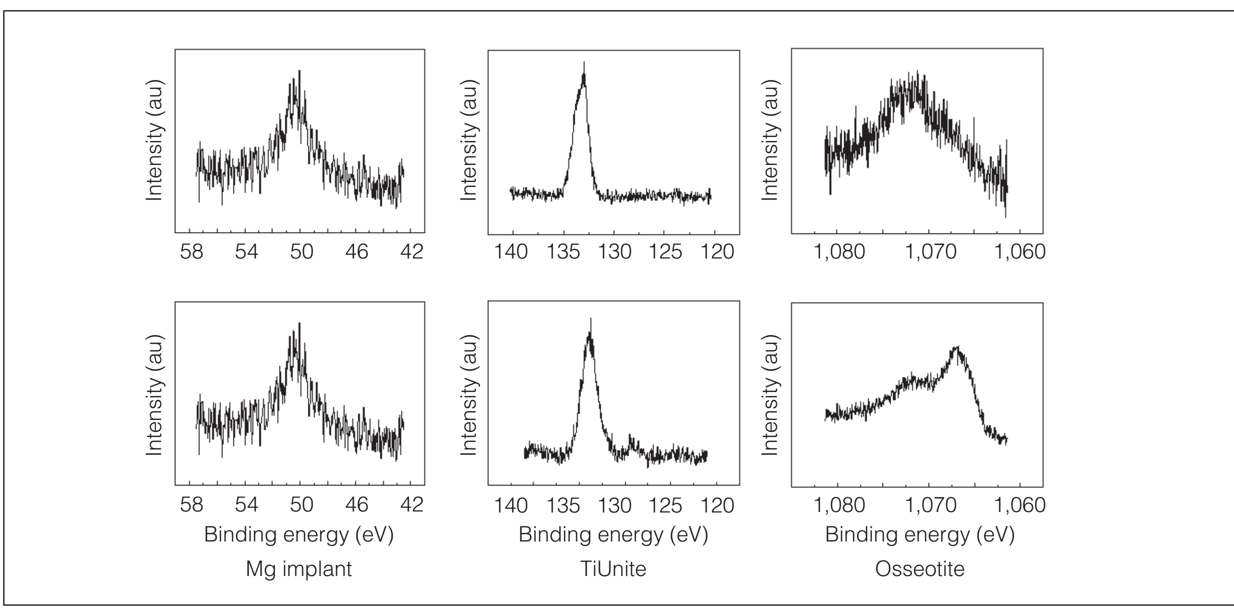
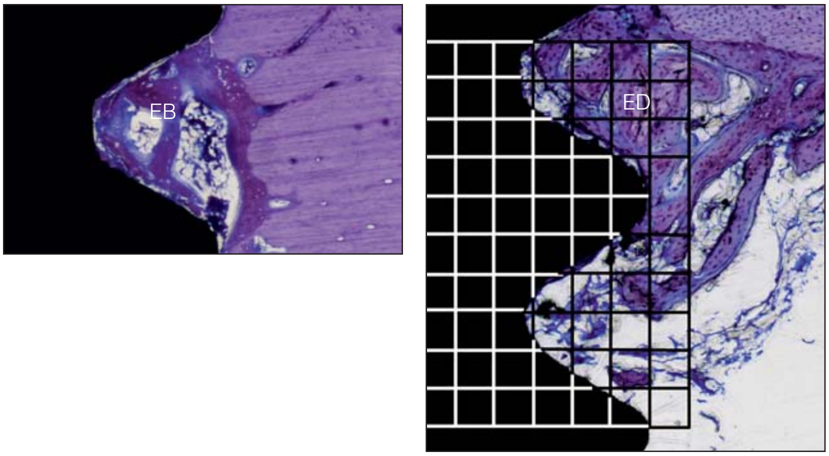


Fig 3 XPS high resolution spectra, detected on the as-received (*top*) and Ar-sputter cleaned (*bottom*) surfaces of the 3 implants, shows the representative elements incorporated in titanium oxides matrix during the surface treatments: (*left*) Mg (Mg 2p) in Mg implant surfaces, (*middle*) P (P 2p) in TiUnite implant surfaces, and (*right*) Na (Na 1s) in Osseotite implant surfaces.

low-angle x-ray diffraction with a thin film collimator (X`Pert PRO-MRD, Philips) on a plate-type sample prepared with the same electrochemical parameters as the test screw-shaped implants. Surface roughness was measured using optical interferometry (MicroXam, Phase-Shift). Three implants from each group were measured on 3 thread peaks, 3 thread valleys, and 3 thread flanks each, for a total 27 measurements for each group. The measuring area was 260 µm × 200 µm for each group. A gaussian filter was used to separate roughness from errors of form and waviness. The filter type was set to 50 µm × 50 µm.



Figs 4a and 4b Survey image of new bone formation on the cut and ground section after RTQ testing. The amount of newly formed bone in the vicinity of the implant surface was measured at 2 interfacial zones: *(1)* inside the threads surrounded by the old cortical bone (EB, *left*), excluding periosteal bone formation surrounding the proximal part of the implant; and *(2)* the subcortical area, ie, endosteal downgrowth (ED, *right*). A demarcation line/cement line was observed between the old and the newly formed bone.

Animals and Surgical Technique

A total of 10 mature New Zealand white male rabbits were used in this study, which was approved by the local animal ethics committee at the Karolinska Institute, Sweden. The mean weight was 3.8 kg (± 0.36) before surgery and 3.6 kg (± 0.37) at sacrifice. Prior to surgery the animals were anesthetized with intramuscular injections of fentanyl and fluanison (Hypnorm Vet, Janssen) at 0.5 mL per kg body weight and intraperitoneal injections of diazepam (Valium, Roche) at 2.5 mg per animal. The skin and fascial layers were opened and closed separately. The periosteal layer was gently pulled away from the surgical area and was not resutured. Three implants (1 from each group) were randomly placed in 1 tibia, and after 3 weeks, another 3 implants (1 from each group) were placed in the other tibia. In the case of the Osseotite implant, only acid-etched threads were engaged in bone. To eliminate the effects of implant length on the RTQ values, all implants were engaged to the same length in bone. Therefore, the engaged length of the Osseotite implant was the reference length for implant insertion. Final twist drills were 3.35 mm in diameter. During all surgical drilling, low rotary drill speeds and saline cooling were used. The animals were kept in separate cages and immediately after surgery were allowed full weight bearing. The animals were sacrificed by intravenous injections of pentobarbital (Apoteksbolaget) after a predetermined follow-up period.

Evaluation of the Bone Response and Rate of Osseointegration

Bone response was evaluated using RTQ measurements, which report peak values in Ncm. The RTQ instrument is an electronic device incorporating a strain gauged transducer that measures the total torsional resistance to implant removal, which can be assumed to represent the interfacial shear strength between bone tissue and the implant over the full bone-implant interface.[15,19] The static torque is applied to the implant at a linearly increasing rate of 9.5 Ncm/second (Wannerskog C-A, personal communication, 2005). The device ensures an exact measurement, in contrast to hand-controlled devices, by eliminating operator errors, and has been shown to have high reproducibility and low operator sensitivity.[15,19] Furthermore, the present study utilized a newly developed axial-alignment table to ensure that the rotational axis is kept aligned between the transducer and the implant. This alignment table was designed to correct a 3-dimensional adjustment at the micrometer scale.

Osseointegration rate is defined by the proportion of RTQ values to a change in healing times. It can be equated as follows:

$$\text{osseointegration rate} = \Delta\text{RTQ}/\Delta\text{healing time}$$

where ΔRTQ indicates the change in RTQ values and Δhealing time represents an interval of the healing time of implants in bone.

After RTQ testing, the same samples were prepared for undecalcified cut and ground sections and sectioned into 2 parts using the Exakt system (Exakt).[19,20] To evaluate osteoconductivity of the implant surfaces, newly formed bone around the implants on both sides was quantified in 2 interfacial zones: *(1)* inside the threads against the old cortical bone (endosteal bone formation [EB]), and *(2)* below the old cortex (endosteal downgrowth [ED]) (Fig 4). Newly formed bone was also quantified in the middle and distal implants of the 3 implants placed in each tibia, since demarcation was difficult between old cortex and newly formed bone surrounding the proximal implant. The amount of newly formed bone below the old cortex was calculated using a grid with 10 squares (100 × 100 μm) on the 6 × 20 magnification of cut and ground sections. The subcortical area measured was 1,000 × 100 μm away from the old cortical bone (Fig 4).

Table 1 Summary of Surface Characteristics of the Implants

Oxide characteristics	Mg	TiUnite	Osseotite
Chemical composition*	Mainly TiO_2, Mg ≤ 9.3 at%, $P \leq 3$ at%. Contaminant: C ≤ 15 at%. Traces: S.	Mainly TiO_2, $P \leq 10.9$ at%. Contaminant: C ≤ 24 at%, Na ≤ 4 at%, N ≤ 1.5 at%. Traces: S.	Mainly TiO_2. Contaminant: C ≤ 34 at%, Na ≤ 18 at%, N ≤ 4.8 at%. Traces: S.
Morphology	Duplex oxide structure. Outer porous film with micropores and inner barrier film without micropores	Duplex oxide structure. Outer porous film with micropores and inner barrier film without micropores	Grain boundary orientation (×1,000) Micropits texture at high magnification (×10,000)
Pore/pit size	≤ 2 µm	≤ 4 µm	≤ 2 µm
Oxide thickness	Homogenous	Heterogeneous	
Barrier film	3.4 µm (± 0.1) at all threads	5.7 µm at the first thread 5.9 µm at the third thread 9.3 µm at the fifth thread	0.0003–0.014 µm†
Porous film	1.3–2 µm	0.9–5.0 µm	
Crystal Structure	Anatase + rutile	Anatase + rutile‡	Amorphous‡
Roughness			
Sdr (%)	0.69 (± 0.24)	1.35 (± 0.16)	0.72 (± 0.42)
Sds (µm-2)	26.4 (± 11.5)	0.12 (± 0.04)	125.3 (± 37.3)
Sa (µm)	0.06 (± 0.01)	28.6 (± 16.0)	0.12 (± 0.05)

*Chemical elements were measured at relative atomic concentration (at%) after Ar sputtering (corresponding to 2-nm-thick oxide).
†No determination possible. In general, however, native oxide thickness is known to be in the range of 3 to 14 nm.[18]
‡Crystal structure was not measurable on the screw-type implants TiUnite and Osseotite (data as supplied by the manufacturers and according to Hall and Lausmaa[1]). A thin oxide layer in the range of 3 to 14 nm is known to be amorphous.[16]
C = carbon.

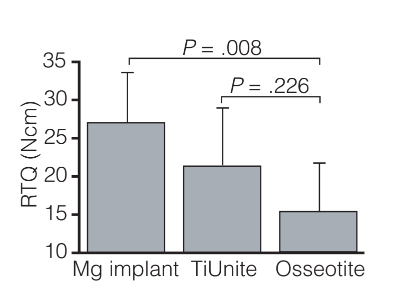


Fig 5 Mean peak RTQ values of the 3 implants after 3 weeks of healing time. Compared to Osseotite, Mg showed a highly significant mean RTQ value (P = .008), whereas TiUnite showed no significant difference (P = .226).

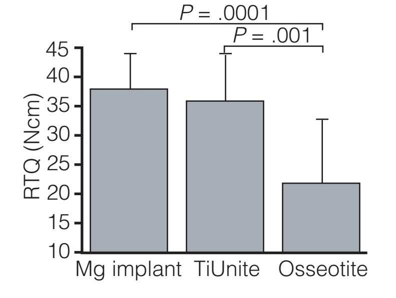


Fig 6 Mean peak RTQ values of the 3 implants after 6 weeks of healing time. Mg and TiUnite surfaces demonstrated significantly higher mean RTQ values than Osseotite surfaces (P = .0001 and P = .001, respectively).

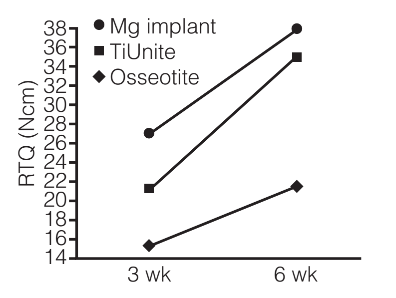


Fig 7 The rate of osseointegration (ΔRTQ/Δweeks) between 3 and 6 weeks showed significant differences in Mg (P = .011) and TiUnite (P = .001) implants, but no significant differences (P = .23) in Osseotite implants.

Statistical Analysis

Multiple comparisons of the RTQ values, newly formed bone, and roughness values were performed using 2-way analysis of variance (ANOVA) and the Tukey test. Osseointegration rate (ΔRTQ/Δweeks) of implants between a follow-up period of 3 and 6 weeks was compared using Wilcoxon signed rank test. The statistics program SPSS 11.5 (SPSS) was used. Data were presented as the mean ± SD. Differences were considered highly statistically significant at $P \leq .01$, statistically significant at $P \leq .05$, and not significant at $P \geq .05$.

Results

Surface Properties

Chemical composition, morphology, pore/pit characteristics, oxide thickness, crystal structure, and roughness of the implant groups used in this study are summarized in Table 1.

RTQ Measurements

At 3 weeks follow-up, Mg implants demonstrated a highly significant increase in RTQ value over Osseotite (27.1 vs 15.4 Ncm, n = 10, P = .008) and showed about a 20% greater RTQ value than TiUnite (27.1 vs 21.3 Ncm, n = 10, P = .236). There were no significant differences between the TiUnite and Osseotite implants (21.3 vs 15.4 Ncm, n = 10, P = .226) (Fig 5).

At 6 weeks follow-up, Mg implants demonstrated a significantly higher mean RTQ value than Osseotite (37.5 vs 21.5 Ncm, n = 10, P = .0001) and a greater value than TiUnite (37.5 vs 36.4 Ncm, n = 10, P = .938). TiUnite implants showed a significantly higher mean RTQ value than Osseotite (36.4 vs 21.5 Ncm, n = 10, P = .001) (Fig 6).

Osseointegration rate (ΔRTQ/Δweeks) between 3 and 6 weeks showed significant difference for Mg (3.5 Ncm/week, P = .011) and TiUnite (5.0 Ncm/week, P = .001) implants, but no significant difference for Osseotite implants (2.0 Ncm/week, P = .23) (Fig 7). Furthermore, the Mg implant at 3 weeks showed higher mean RTQ value than Osseotite at 6 weeks (27.1 vs 21.5 Ncm).

New Bone Formation

Newly formed bone in zones EB and ED at 3 and 6 weeks healing time is shown in Figs 8a to 8c. For simplicity, mean values of newly formed bone in zones EB and ED are shown together in Fig 9.

At 3 weeks follow-up, Mg implants demonstrated significantly more new bone than Osseotite (29% vs 15%, n = 6, P = .031) and showed a 61% increase compared to TiUnite (29% vs 18 %, n = 6, P = .174). There were no significant differences between TiUnite and Osseotite (18% vs 15.5%, n = 6, P = .699) (Fig 10).

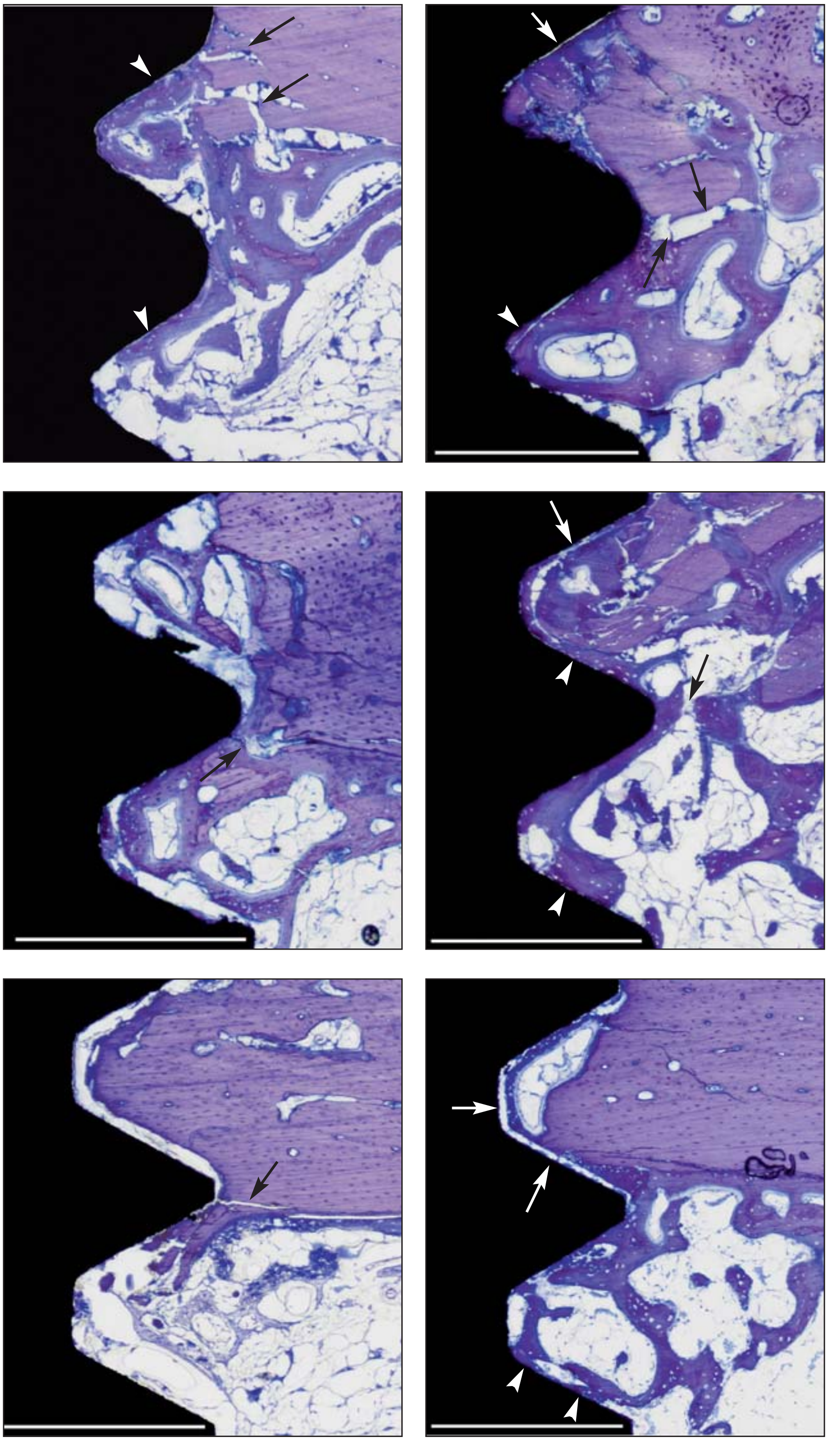
At 6 weeks follow-up, Mg implants demonstrated significantly more new bone than Osseotite (39% vs 26%, n = 6, P = .030) and showed a 26% increase compared to TiUnite (39% vs 31%, n = 6, P = .268). There were no significant differences between TiUnite and Osseotite (31% vs 26%, n = 6, P = .520). Mg implants at 3 weeks showed a higher mean value of new bone formation than Osseotite at 6 weeks (29% vs 26%) (Fig 11).

New bone formation between 3 and 6 weeks significantly increased for all implant groups ($P < .05$), but no differences were observed among the groups (Fig 12).

Discussion

This study compared RTQ values and bone responses of an experimental Mg implant and commercially available TiUnite and Osseotite implants. Our results showed that the strongest bone response was seen with the Mg implant and the weakest bone response with the Osseotite implant. The implants investigated differed from one another with respect to surface properties and implant design/geometry. The latter differences seem small (see Figs 1 and 2) and would not be expected to favor Mg implants. For instance, the notch of Osseotite implants is quite deep, and the TiUnite notch is less deep, whereas the notch of Mg implants is very shallow. A deep notch allows more bone ingrowth and should result in stronger RTQ, since this bone will have to be fractured at testing. Furthermore, the greater radius of the thread tip of Mg implants should anything but favor superior RTQ. Therefore, it is the authors' strong conviction that design differences, at least when evaluations are based on RTQ comparisons, would positively influence the investigated implants in the following order: Mg < TiUnite < Osseotite. Surface roughness evaluations revealed similar Sa values for Mg and Osseotite implants, which were minimally rough (Sa 0.69 and 0.72 µm, respectively) compared to moderately rough TiUnite implants (Sa 1.35 µm). The Sdr values of Mg and Osseotite implants were similar (26.4% and 28.6%, respectively) compared to 125.3% for TiUnite implants. Based on these values, it is clear that TiUnite implants were strongly favored with respect to their moderately roughened surface; and yet, they did not achieve the greatest bone integration. The surgical technique left all implants only partly screwed into the bone, so that the relatively smooth upper portions of the clinical implants, particularly Osseotite, would not adversely influence the outcome. Therefore, it seems probable that the strong bone response to the Mg implant is dependent on its chemical/physical surface characteristics rather than topographic or design characteristics.

Surface chemistry, oxide thickness, and crystal structure of the Mg implant are of particular interest. Previous experimental data indicate that surface chemistry–modified, crystallized thick oxides with porous surfaces achieve significantly greater bone-to-implant contact, resonance frequency, and RTQ values than conventional titanium dioxide (TiO_2) surface chemistry with amorphous thin (native) oxide and a nonporous surface.[8-14,21-26] It remains unknown whether the qualitative differences (micropore vs micropit appearance) of surface morphology between the oxidized implant and acid-etched implant surfaces will influence bone response. It is noteworthy that Mg implants at 3 weeks obtained higher mean RTQ values and larger amounts of new bone formation than Osseotite implants at 6 weeks. The results of TiUnite at 6 weeks are in good agreement with the reports of Gottlow et al,[5] who demonstrated significantly higher bone-to-implant contact, resonance frequency, and RTQ values of TiUnite compared to Osseotite in rabbits. When comparing Mg and TiUnite implants, Mg showed greater RTQ values and larger amounts of new bone formation than TiUnite



Figs 8a to 8c The cut and ground sections after RTQ testing of (*top*) Mg implant surfaces, (*middle*) TiUnite implant surfaces, and (*bottom*) Osseotite implant surfaces at 3 (*left*) and 6 (*right*) weeks of healing time. Newly formed bone tissue inside the threads surrounded by the old cortical bone (EB) and in the subcortical area (ED), can be distinguished by the demarcation line/cement lines. Fracture from RTQ testing occurs at the bone/implant interface (*white arrows*), but also in bone (*black arrows*) far away from implant surfaces as detected using a light microscope (LM). The bone/implant interfaces are still intact (*arrow heads*). Opposed to LM observations in the present study, previous SEM fracture analysis by Sul et al demonstrated that interfacial failure occurred at *(1)* the titanium (oxide) surface of immature bone, *(2)* inside the immature bone per se, and *(3)* between the immature bone and the surrounding mature bone, and thereby dependent on bonding strength.[13,26]

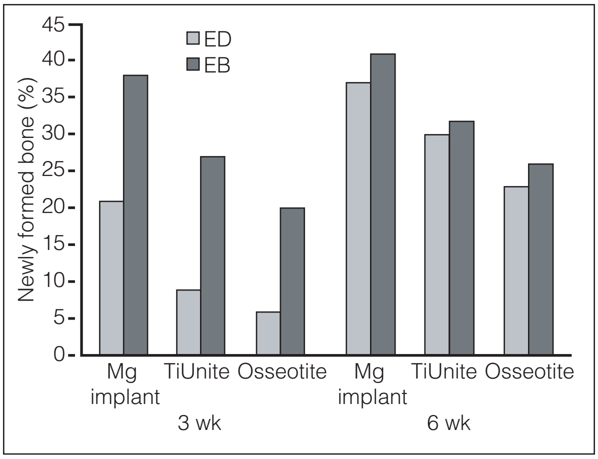


Fig 9 New bone formation for the 3 implants at 3 and 6 weeks of healing time. New bone formation in threads surrounded by the old cortical bone (EB) is greater than in the subcortical area (ED) at 3 and 6 weeks of healing time. However, new bone forms more rapidly in the subcortical area than in threads surrounded with the old cortical bone.

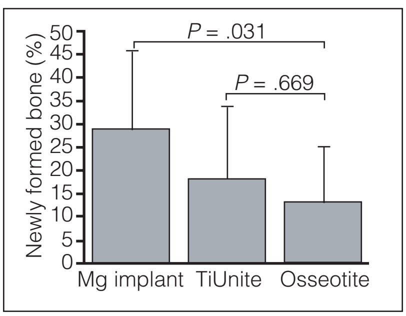


Fig 10 Mean amount of new bone formation of the 3 implants after 3 weeks of healing time. Compared to Osseotite, Mg showed a significantly different mean value (P = .031), whereas TiUnite shows no significant difference (P = .699).

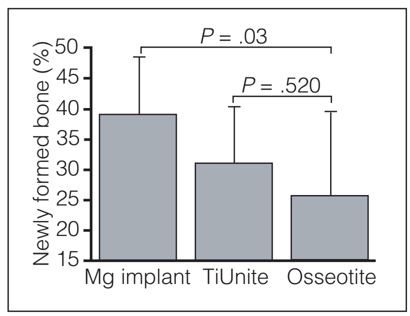


Fig 11 Mean amount of new bone formation of the 3 implants after 6 weeks of healing time. Compared to Osseotite, Mg showed a significantly different mean value (P = .03), whereas TiUnite shows no significant difference (P = .520).

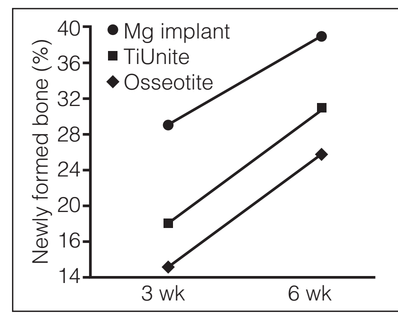


Fig 12 Rate of new bone formation between 3 and 6 weeks showed significant differences for all implant surfaces (P < .05).

at follow-up periods of 3 and 6 weeks, but the differences were not significant. For both Mg and TiUnite implants, the crystal structure of titanium oxide was anatase + rutile and the mean pore size was ≤ 2 μm. The oxide thickness values of Mg implants are within the range of those of TiUnite. The oxide thickness of TiUnite differs from thread to thread and widely varies in the range of 0.9 (barrier film at the fifth thread) to 9.3 μm (porous film + barrier film at the fifth thread). Mg implants, on the other hand, showed relatively homogeneous oxide thicknesses of 1.3 (barrier film) to 3.4 μm (porous film + barrier film) at all threads. Sul et al[14,24–26] have reported that RTQ, bone-to-implant contact, and resonance frequency values significantly increased as the oxide thickness increased from 0.4 to 3.4 μm; however, RTQ values decreased when oxide thickness was further increased to 5.8 μm. In addition, optimal oxide thickness was strongly dependent on the surface chemistry of oxidized implants and may, in fact, be dominated by it.[14]

Surface chemistry shows clear differences between some 9 at% Mg- and 3 at% P-incorporated titanate in the Mg implant and some 11 at% P-incorporated titanate in the TiUnite. Differences of surface chemistry between Mg and TiUnite implants were determined by field-assisted migration of ions from the different electrolyte systems during the MAO process.[16,17] In the case of Osseotite, unexpectedly high sodium (Na) and nitrogen (N) content were detected, up to 18 at% and 4.8 at% after argon (Ar) sputter cleaning (corresponding to 2-nm oxide thickness), indicating that they may not be surface contaminants. The source of the high Na and N remains uncertain, but is probably not from the etching chemicals used for Osseotite (hydrogen chloride and sulfuric acid).

Therefore, it is highly likely that the strong bone response to the Mg implant is associated with surface chemistry, ie, Mg-titanate chemistry.

A number of indications supporting this theory have recently been provided by experimental findings of Sul et al, who found that Mg surface chemistry, despite significantly lower roughness, demonstrated significantly higher RTQ values than the TiO_2 surface chemistry of oxidized implants[13] and significantly faster and stronger osseointegration than machined/turned implants at the same follow-up periods.[27] In addition, of all surface properties (surface chemistry, oxide thickness, surface porosity, crystal structure, and surface roughness), surface chemistry (relative atomic concentration of Mg ions) was the parameter with the strongest correlation to bone response.[14]

Overall, these results support the hypothesis that bioactive surface chemistry favors fast and strong integration of implants in bone at healing periods earlier than 6 weeks. The osseointegration mechanism of the Mg implant may be explained by bioactive surface chemistry–mediated biochemical bonding, as previously proposed by Sul et al.[15] Mechanical interlocking seems unlikely to result in the strong bone integration observed for Mg implants at a healing time of 3 weeks, since at 6 weeks bone was only beginning to grow into the pores of the Mg implant.[12] Furthermore, Sul et al[12,13] recently provided positive evidence for biochemical bonding of oxidized bioactive implants, such as ionic movements/exchanges and ion concentration gradient at the interface between bone and the Mg implant surface.

The fast and strong integration of Mg implants at healing times of 3 and 6 weeks may show promising clinical implications. First, Mg implants may reduce high failure rates of clinical implants in the early period of bone healing (eg, 70% total implant failure during the first year of loading[28]) and in compromised bone. Second, Mg implants may shorten the bone healing time from surgery to functional loading. Finally, they may enhance the possibility of immediate or early loading.

Conclusions

The osseointegration rate (ΔRTQ/Δweeks) between 3 and 6 weeks of healing time was significantly different for oxidized Mg and TiUnite implants, but not significantly different for dual acid-etched Osseotite surfaces. TiUnite surfaces showed significantly higher RTQ values than Osseotite surfaces at 6 weeks. Mg implant surfaces at both 3 and 6 weeks of healing time significantly enhanced RTQ and new bone formation compared to Osseotite, and also demonstrated stronger osseointegration and superior osteoconductivity (new bone formation) compared to TiUnite. The results showed clear indications that of all surface properties investigated, surface chemistry was the most determinant parameter and facilitated faster and stronger osseointegration of Mg implants, despite a lower roughness than TiUnite. However, it is not currently possible to rule out potential synergy effects of the other surface properties on improvements of bone response to oxidized implants.

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Commentary on the Role of Basic and Translational Research

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Advancing clinical therapies rely on systematic and rigorous scientific investigation prior to widespread use in the patient care setting. The research presented here by Sul et al offers both of these qualities in a well-designed and clearly written article. The challenge for the clinician, however, is to fit this basic research into the larger context, and to appreciate both its sophistication as science and its limitations as preliminary experimental evidence of an alternative strategy to manage edentulism.

At present, the literature on implants is dominated by 2 principal forms of science: *(1)* basic research at the cellular/molecular or the in vivo (animal) level, which offers relatively good control of many variables that may affect an important outcome; and *(2)* clinical research that reports on the success or survival of implants or their associated restorations, as well as improvements in the quality of life of patients. Often, the success/survival data generated for new systems and therapies are from relatively short-term studies, as revised therapies negate an investigator's interest in conducting long-term research with studies already initiated. The result of this environment is an intellectual and ethical chasm in which therapies that dare to challenge proven standards are not rigorously investigated with a sufficient number of patients (human subjects) over a meaningful period of time in a suitably controlled clinical research setting *before* marketing to the wider practitioner and patient audience. Today's thinking practitioner is immersed in a quandary where traditional osseointegration-based therapy is under constant modification, and translational research is not conducted to a degree sufficient to quell the healthy skepticism that one is trained to develop during graduate study. The influence of industry-conducted and industry-supported research on oral implant research, basic and clinical, is enormous, in part due to the limited resources assigned to this type of research by government and other non-industry parties, and in part due to implant manufacturers striving to improve their product to enhance both patient care and corporate success.

Sul et al state that "surface chemistry facilitated more rapid and stronger osseointegration of the Mg implants