Osseointegration of Zirconia Implants with Different Surface Characteristics: An Evaluation in Rabbits

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Purpose: *Zirconia ceramics are a viable alternative to titanium for use as dental implants. However, the smooth surface of zirconia means that longer healing periods are needed to accomplish osseointegration compared to roughened titanium surfaces. Surface modifications can be used to increase the roughness of zirconia. The aim of this study was to assess histologically and compare the degree of early bone apposition around zirconia dental implants with sandblasted, sintered, or laser-modified surfaces to that seen around surface-modified titanium implants. Removal torque was also measured and compared.* ***Materials and Methods:*** *Ninety-six implants—24 each of four types (sintered zirconia, laser-modified zirconia, sandblasted zirconia, and acid-etched titanium)—were placed in 48 New Zealand White female rabbits. One implant was inserted in each distal femur. Half of the specimens were harvested at 6 or 12 weeks and processed for light microscopic analysis; the area of bone-to-implant contact was measured morphometrically. The other half were evaluated for removal torque at 6 and 12 weeks.* ***Results:*** *No statistically significant differences existed in bone apposition between the different surfaces at either time point. Differences in removal torque were significantly different between titanium and sandblasted zirconia and between sintered zirconia and sandblasted zirconia, with the first mentioned demonstrating a higher torque value at 6 weeks. At 12 weeks, the only significant difference in removal torque was between titanium and sandblasted zirconia, with titanium demonstrating the higher value.* ***Conclusion:*** *Comparable rates of bone apposition in the zirconia and titanium implant surfaces at 6 and 12 weeks of healing were observed. Removal torque values were similar for all implants with a roughened surface.* Int J Oral Maxillofac Implants 2012;27:352–358

Key words: *dental implants, osseointegration, surface modification, zirconia*

Many different materials have been suggested for dental implants. Of these, titanium has become the most popular. Long-term success with this material has been well documented.[1–5] However, osseointegration, defined as a direct apposition of bone to the implant surface, is possible with implants made of different materials.[6–15] It has been demonstrated that modification of the implant surface, for example, with a hydroxyapatite coating, sandblasting, and/or acid etching, can increase biocompatibility and reduce the healing time needed before the implant can be loaded.[16] Although titanium has become the material of choice, it has certain disadvantages, such as its unnatural grayish color, which may lead to undesirable esthetic outcomes in cases of recessed or thin gingival tissue and the possible accumulation of titanium particles in local lymph nodes.[17,18]

The successful use of ceramic materials has been documented previously.[9,19–21] Zirconia, a material used for orthopedic implants, may be a viable alternative to titanium; its potential for osseointegration and successful clinical use has been demonstrated.[22–27] Beneficial properties of the material include its ability to transmit light and its ivory color, both of which render it an ideal material for use in the esthetic zone,[28–30] and a high degree of biocompatibility. It has been demonstrated that the inflammatory response and bone resorption induced by ceramic particles are much less pronounced than those induced by titanium particles.[30,31] In addition, zirconia is radiopaque, chemically inert, and extremely hard.

However, zirconia poses a challenge if surface modifications are desired. Methods that have been described previously to accomplish this are the sintering

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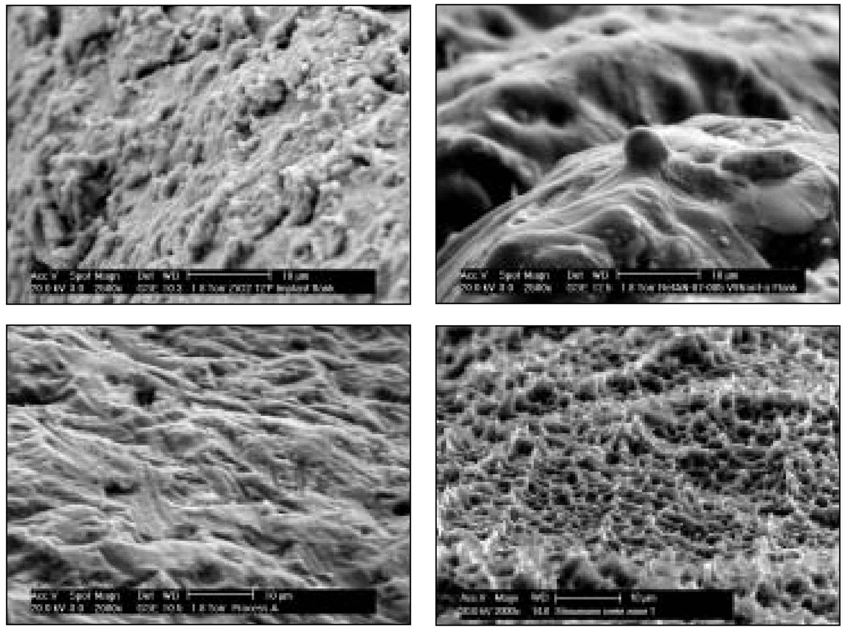

Fig 1 Electron microscopic images of implant surfaces. *(a)* Sintered zirconia (original magnification ×2,500); *(b)* laser-modified zirconia (original magnification ×2,500); *(c)* sandblasted zirconia (original magnification ×2,000); *(d)* titanium (original magnification ×2,000).

of particles to the smooth surface, the use of nanotechnology, and sandblasting.[32–34] A newer approach is the use of lasers to "engrave" a three-dimensional pattern onto the surface; according to preliminary data, this method does not result in mechanical modifications of the material. To date, only limited, retrospective data are available regarding the healing events around these surfaces.[35–38]

The purpose of the present study is to give a descriptive histologic assessment of the degree of early bone apposition around zirconia dental implants with different surface characteristics placed into the rabbit femur at 6 and 12 weeks after insertion, compared to modified-surface titanium implants.

MATERIAL AND METHODS

Experimental Design

Four different implant surfaces were tested in this study: *(1)* zirconia with a sintered surface, *(2)* zirconia with a laser-modified surface, *(3)* zirconia with a sandblasted surface (control 1), and *(4)* titanium with an acid-etched surface (control 2) (Fig 1).

Forty-eight female New Zealand White rabbits weighing between 2.0 and 2.5 kg each were used. One implant was placed in each distal rear femur of each rabbit, with a total of two per rabbit (Fig 2). Half of the implants were harvested for histologic examination at 6 and 12 weeks after implant placement, and the other half were used for removal torque testing.

Animal care and surgical procedures were performed as described previously.[27] In brief, the animals were acclimated to the environment of the animal care facility for at least 1 week before surgery to ensure their health and stability. During this time, they were housed in standard cages for rabbits and fed rabbit chow ad libitum. The rabbits' legs were load bearing throughout the whole study period. Sedation and induction of anesthesia were performed with ketamine (35 mg/kg) and xylazine (2 mg/kg), administered intramuscularly, along with isoflurane/oxygen (intubated) maintenance (1.5% to 2.5%) until completion of the surgical procedure. Intraoperative and postoperative recovery temperatures were maintained with towels and warming elements (eg, heating blankets, water bottles). The study protocol was approved by the Institutional Animal Care and Use Committee of Loma Linda University, Loma Linda, California.

Surgical Procedures

Cylindric screw-type test implants with a diameter of 3.25 mm, an intraosseous length of 6 mm, and a hexagonal coronal portion to allow for implant placement and retrieval were fabricated (Z-Systems AG). A total of 72 zirconia implants (24 each of sintered, laser-modified, and sandblasted zirconia) and 24 titanium implants with a roughened surface were placed in the distal femur using sterile surgical technique. All surgeries were performed by one of three surgeons (OH, NA, SA). The animals' legs were shaved, washed, and decontaminated with iodine. After surgical draping,

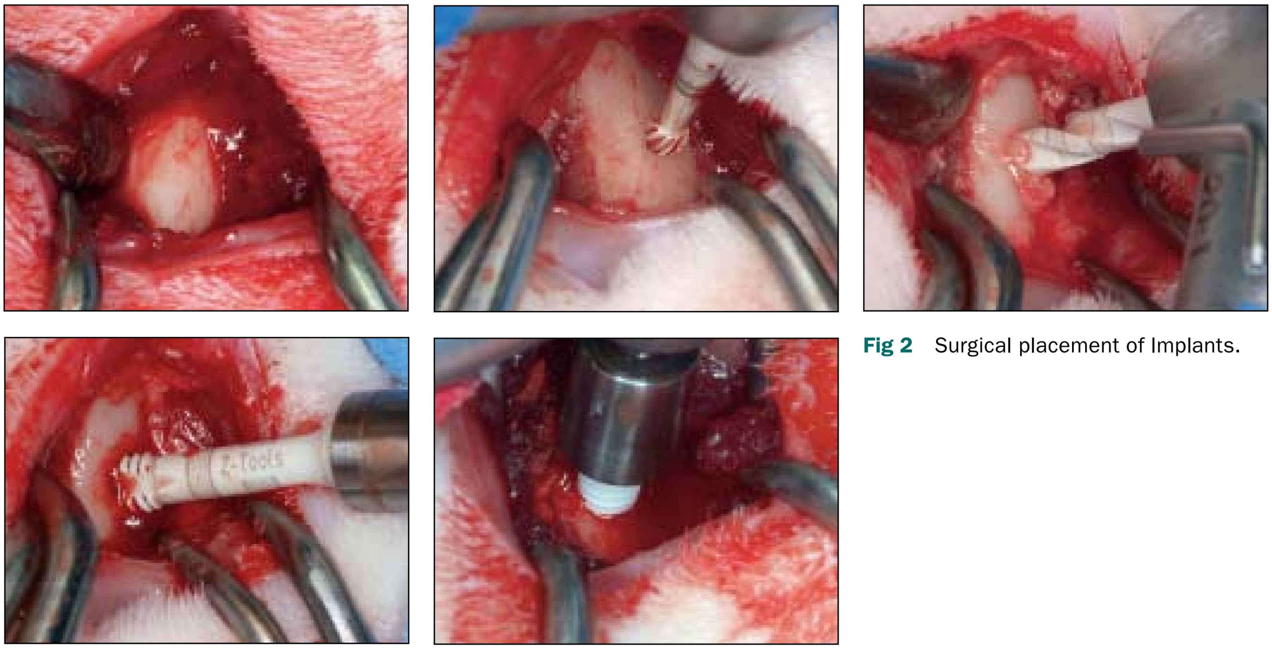

Fig 2 Surgical placement of Implants.

skin incision, blunt dissection of the muscles, and elevation of the periosteum were performed. The implant bed was prepared using a pilot drill (1.2 mm), followed by a step drill (2.75 mm) and tapping, and the implants were inserted to a depth of 6.5 mm with a torque of 30 Ncm. The surgical sites were closed in layers, with the muscle, fascia, and internal dermal layers sutured with 4-0 Vicryl (Vicryl Plus, Ethicon) and the outer dermis sutured to primary closure with 3-0 chromic gut (Ethicon). The animals were rehydrated by injecting Lactated Ringer solution intravenously, corresponding to approximately 2% of body weight. The animals were monitored during recovery for any possible complications and given water and rabbit chow ad libitum during the healing period.

At 6 and 12 weeks after implant placement, the animals were euthanized and the implants were surgically exposed by sharp dissection to the bone. Half of the implants were then removed en bloc with the surrounding bone and stored in 10% formalin. The other half were torque tested to determine the maximum removal torque (GBI and STH50, Mark10).

Histologic Preparation

Specimens were dehydrated in a graded series of increasing ethanol concentrations (40% for 24 hours, followed by 70%), embedded in methyl methacrylate without being decalcified according to standard procedures, and sectioned in the frontal plane through the middle of the cylinders. Sections of 200 µm in thickness were obtained, ground, and polished to a uniform thickness of 60 to 80 µm. The specimens were surface-stained with toluidine blue.

Histomorphometric evaluation was performed directly with a light microscope using standard morphometric techniques. Measurements were carried out directly with a light microscope at a magnification of ×7.5. Bone apposition defined as all areas of direct bone-to-implant contact (BIC) in the chosen area were measured, and their sum was divided by the total implant perimeter in the area. The results were expressed as % BIC. BIC was determined in the area of cortical bone to avoid any falsifications resulting from differences in the relation of cortical to cancellous bone or preparation of the slides.

RESULTS

Surgical procedures and healing were uneventful, with the exception of two animals (#24, #35) that had to be euthanized following fracture of the femur and one site in three animals (#6, #11, #36) that could not be evaluated because of bone overgrowth of unknown etiology. The specimens from these animals for these sites were not collected and the procedures for these time points were repeated. All implants were clinically stable without any signs of inflammation. Histologic bone apposition was observed around all implants at both time points irrespective of the implant surface (Fig 3).

Different % BIC values were noted at the two different time points, as well as for the different surfaces. At 6 weeks, BIC was 32.996% (standard deviation [SD] 14.192%) for the sintered zirconia, 39.965% (SD 13.194%) for the laser-modified zirconia, and 39.614%

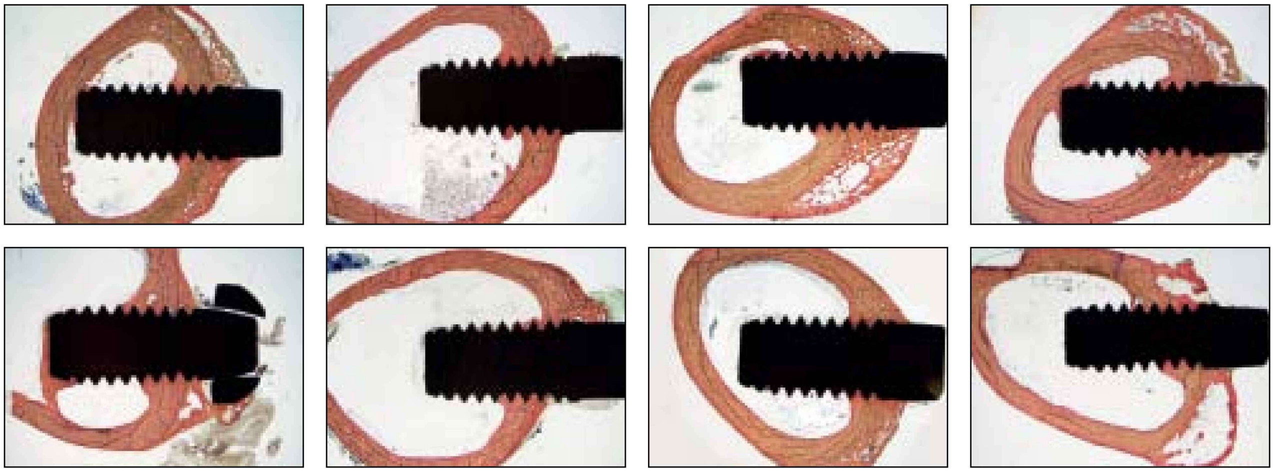

Fig 3 Histologic sections through the different implants showing bone apposition. *Top row*: 6 weeks; *bottom row*: 12 weeks. *Left to right, both rows*: sintered zirconia, laser-modified zirconia; titanium; sandblasted zirconia.

Table 1 Bone Apposition at 6 and 12 Weeks

Time/surface	N	Mean	SD	SE
6 wk				
Laser	23	39.9652	13.19392	2.75112
Ref_T	22	34.1545	10.34089	2.20469
Ref_Z	22	39.6136	15.02973	3.20435
Sintered	24	32.9958	14.19208	2.89695
Total	91	36.6374	13.48049	1.41314
12 wk				
Laser	23	43.8652	14.54409	3.03265
Ref_T	22	34.8182	12.20861	2.60288
Ref_Z	22	41.3500	15.81593	3.37197
Sintered	24	33.7458	14.52925	2.96577
Total	91	38.4011	14.74697	1.54590

SD = standard deviation; SE = standard error; Laser = laser-modified zirconia; Ref_T = acid-etched titanium; Ref_Z = sandblasted zirconia; Sintered = sintered zirconia.

Table 2 Between-Group Comparison (Sidak Multiple Comparisons) of Bone Apposition at 6 and 12 Weeks

Time/comparison	Mean difference	SE	*P*
12 wk			
Laser × Ref_T	9.04704	4.27662	.204
Laser × Ref_Z	2.51522	4.27662	.993
Laser × Sintered	10.11938	4.18456	.101
Ref_T × Ref_Z	–6.53182	4.32388	.580
Ref_T × Sintered	1.07235	4.23284	> .999
Ref_Z × Sintered	7.60417	4.23284	.377
6 wk			
Laser × Ref_T	5.81067	3.97428	.616
Laser × Ref_Z	0.35158	3.97428	> .999
Laser × Sintered	6.96938	3.88873	.380
Ref_T × Ref_Z	–5.45909	4.01820	.691
Ref_T × Sintered	1.15871	3.93360	> .999
Ref_Z × Sintered	6.61780	3.93360	.455

SE = standard error; Laser = laser-modified zirconia; Ref_T = acid-etched titanium; Ref_Z = sandblasted zirconia; Sintered = sintered zirconia.

(SD 15.029%) for the sandblasted zirconia (Fig 4). BIC for the titanium implants was 34.155% (SD 15.816%) at this time point (Table 1). At 12 weeks, the implants showed BIC of 33.746% (SD 14.529%) for the sintered zirconia, 43.87% (SD 14.544%) for the laser-modified zirconia, 41.350% (SD 15.816%) for the sandblasted zirconia, and 34.818% (SD 12.209%) for the titanium (Table 1, Fig 5). No statistically significant differences in % BIC existed between the different surfaces at either time point (Table 2).

Removal torque values varied between 35.409 Ncm (SD 9.063) for the sintered zirconia, 26.309 Ncm (SD 11.415) for the laser-modified zirconia,19.590 Ncm (SD 12.128) for the sandblasted zirconia, and 39.818 Ncm (SD 14.093) for the titanium at 6 weeks (Fig 6). The corresponding numbers at the 12-week time point were 40.591 Ncm (SD 17.081) for the sintered zirconia, 39.708 Ncm (SD 9.819) for the laser-modified zirconia, 28.727 Ncm (SD 18.766) for the sandblasted zirconia, and 51.909 Ncm (SD 16.149) for the titanium (Fig 7).

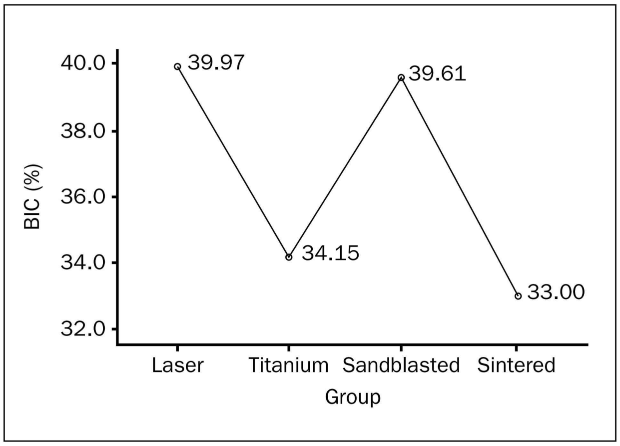

Fig 4 Mean bone apposition at 6 weeks.

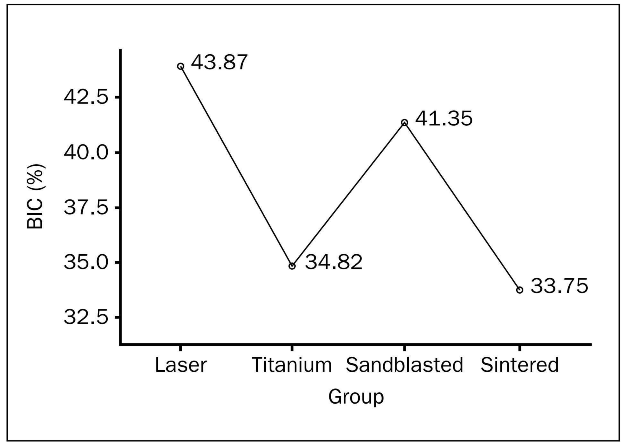

Fig 5 Mean bone apposition at 12 weeks.

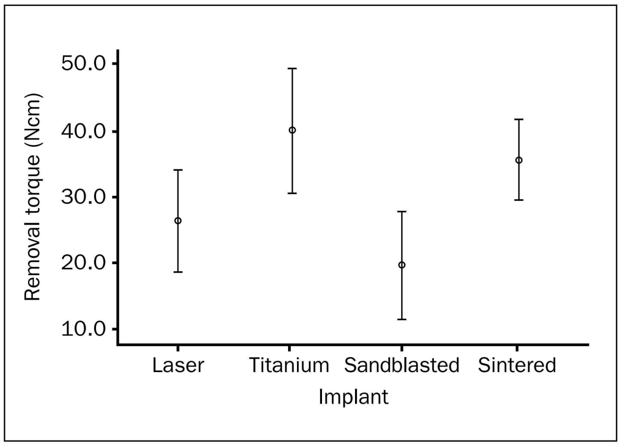

Fig 6 Removal torque at 6 weeks (means and 95% confidence intervals).

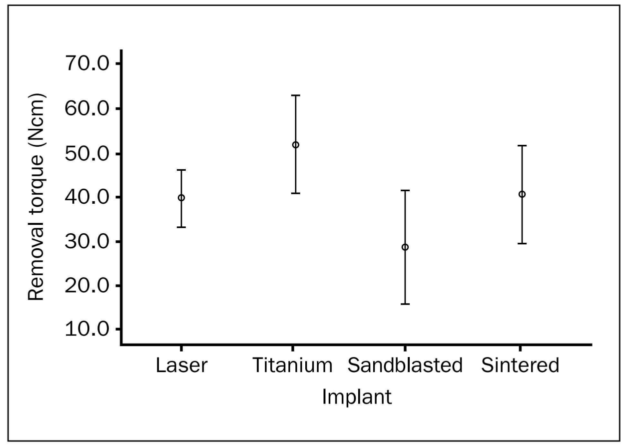

Fig 7 Removal torque at 12 weeks (means and 95% confidence intervals).

At 6 weeks, the differences in removal torque values were statistically significantly different between the titanium group and sandblasted zirconia and between sintered zirconia and sandblasted zirconia, with the first mentioned demonstrating the higher value (Table 3). At 12 weeks, the only significant difference in removal torque value existed between titanium and sandblasted zirconia, with titanium demonstrating higher removal torque (Table 4).

DISCUSSION

One of the critical components in achieving implant stability is sufficient osseointegration. While direct bone apposition can occur on different types of surfaces, it has been demonstrated that a certain degree of surface roughness is beneficial in accelerating bone apposition to the implant surface.[39,40] With shortened treatment time being one of the trends in implant dentistry, the comparatively smooth surface of zirconia implants appears to be a disadvantage.[41] Thus, attempts have been made to alter the surface characteristics of zirconia.[41] However, the comparatively high hardness of the material renders this difficult. Different approaches to roughen the surface have been described, and an acceleration of bone apposition has been demonstrated.[32–34,42] A relatively new approach is the use of lasers to engrave a pattern on the zirconia surface, a method that, according to preliminary data, does not result in modifications of the mechanical properties of the material (unpublished data; direct conversation with manufacturer, September 10, 2010; data received from strength test results as part of patent application).

The aim of this study was to evaluate healing around sintered and laser-modified zirconia surfaces and compare this to the healing around standard, commercially available sandblasted zirconia surfaces as well as to that around a roughened titanium surface. To evaluate these, both histomorphometric analyses and removal torque tests were performed.

Table 3 Between-Group Comparisons of Removal Torque Values at 6 Weeks

Comparison	Mean difference	SE	*P*	95% CI Lower	95% CI Upper
Laser × Ref_T	–13.50909	5.03694	.082	–28.2082	1.1900
Laser × Ref_Z	6.7818	5.03694	.623	–7.9809	21.4173
Laser × Sintered	–9.10000	5.03694	.365	–23.7991	5.5991
Ref_T × Ref_Z	20.22727*	5.03694	.003	5.5282	34.9264
Ref_T × Sintered	4.40909	5.03694	.857	–10.2900	19.1082
Ref_Z × Sintered	–15.81818*	5.03694	.030	–30.5173	–1.1191

SE = standard error; 95% CI = 95% confidence interval; Laser = laser-modified zirconia; Ref_T = acid-etched titanium; Ref_Z = sandblasted zirconia; Sintered = sintered zirconia. * = significant difference.

Table 4 Between-Group Comparisons of Removal Torque Values at 12 Weeks

Comparison	Mean difference	SE	*P*	95% CI Lower	95% CI Upper
Laser × Ref_T	–12.20076	6.56846	.340	–31.3297	6.9282
Laser × Ref_Z	10.98106	6.56846	.434	–8.1479	30.1100
Laser × Sintered	–0.88333	6.56846	.999	–19.5918	17.8251
Ref_T × Ref_Z	23.18182*	6.56846	.014	3.6415	42.7222
Ref_T × Sintered	11.31742	6.56846	.407	–7.8115	30.4464
Ref_Z × Sintered	–11.86439	6.56846	.365	–30.9933	7.2645

SE = standard error; 95% CI = 95% confidence interval; Laser = laser-modified zirconia; Ref_T = acid-etched titanium; Ref_Z = sandblasted zirconia; Sintered = sintered zirconia. * = significant difference.

Whereas a trend of higher bone apposition around the laser-modified zirconia surface was observed at both time points in comparison to the other groups, this difference was not statistically significant. Removal torque values were significantly higher for the titanium and the sintered zirconia implants compared to the sandblasted zirconia implants at 6 weeks. At 12 weeks, the only difference that remained was between the acid-etched titanium and the sandblasted zirconia. The absence of more pronounced differences could be a result of the comparatively small numbers of implants in each group. In addition, bone healing in rabbits is approximately two times faster than in humans.[42–44] Time intervals of 6 and 12 weeks were chosen to approximate healing times of 12 and 24 weeks in the human mandible.[42–44] This time span may be sufficiently long to allow for bone healing, regardless of the type of surface used.[45]

The results demonstrate similar outcomes for sintered and laser-modified zirconia surfaces, as compared to the outcomes for a roughened titanium surface, eliminating the longer healing period previously necessary to guarantee sufficient stability around zirconia implants. The clinical significance of these findings needs to be further evaluated in future studies. Although the differences were not statistically significant, the laser-roughened zirconia surface may be superior to the sintered zirconia and titanium surfaces.

CONCLUSION

No differences in bone apposition could be observed between the different groups after healing periods of 6 and 12 weeks in a rabbit model. Removal torque values were similar for titanium and for sintered and laser-modified zirconia implants, exceeding those of sandblasted zirconia implants.

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