Evaluation of Combinations of Titanium, Zirconia, and Alumina Implants with 2 Bone Fillers in the Dog

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The quality of the tissue-implant interface was evaluated using light and scanning electron microscopy with morphometric analysis. Nine dogs were implanted with 3 types of dental implants (titanium, zirconia, or alumina). A total of 24 dental implants was placed in mandibular bone previously filled with coral carbonate calcium (corail) or hydroxyapatite. The study results in breaking the concept of osseointegration into 2 phases: "osseocoaptation," which concerns only the interface (physical contact between the implants and the bone without interpenetration process), and "osseocoalescence," which relies on an interpenetration of the bioactive material, which almost entirely disappears, being substituted by newly formed bone. There was no significant statistical difference between the 3 types of implants. Both fillings showed good ossecoalescence properties. However, hydroxyapatite led to fibrous encystment, preventing osseocoaptation of implants, in contrast with calcium carbonate filling. (Int J Oral Maxillofac Implants 1999;14:271–277)

Key words: bone filler materials, implants, osseocoalescence, osseocoaptation

Over the past few years, many types of dental implants and bone fillers have been introduced.[1] Among them, titanium implants are used more often than alumina and zirconia implants. Bone fillers are commonly used to prepare the implant site. Bone substitutes[2] and autologous bone chips[3] are used to increase or restore the available bone volume in association with implants in the field of oral and maxillofacial implantology.[4–6]

The harvesting of autologous bone from the parietal bone or the chin symphysis is sometimes difficult. Using allogenic bone[7] and xenogenic bone raises ethical problems and the risk[8,9] of virus transmission (HIV, hepatitis, BSE, etc). Nonviable materials such as ceramics[10] and animal material such as coral or mother-of-pearl extract (Pinctada Maxima, Aria Dental, Nice, France) have been suggested as bone fillers. The family of ceramic materials include bioinert nonresorbable metal oxides, such as alumina (Al_2O_3) or zirconia (ZrO_2), which are also used as dental implants. Bioactive ceramic materials, made mostly from calcium salts, include[11]: *(1)* hydroxyapatite (HA), which has few resorptive qualities according to porosity degree; *(2)* calcium phosphates (tricalcium phosphate [TCP]), which are very resorbable in the presentation form (compact or powdered); and *(3)* mixtures of HA and TCP, which are more resorbable if the proportion of TCP increases.

In addition to this range of artificial products is another category of materials: calcium salts of animal origin, such as coral and mother-of-pearl.

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They are mainly composed of aragonite calcium carbonates, which are highly resorbable. Clinically, most implants and bone fillers can provide satisfactory results when used separately, but when combined, results may be different and need further investigation.[12] The interface between implant and bone depends on the nature of the implant and the quality of bone.[13] Thus the aim of this work was to evaluate the "osseocoaptation" quality of 3 different kinds of implants placed in sockets previously filled with coral, and to compare the results with those obtained using HA as a bone filler. Osseocoaptation is a concept that relates to the interface between an implant and bone, which does not demonstrate an interpenetration process.

Materials and Methods

Nine beagle dogs (15 to 26 months old) were obtained for the investigation. All dogs' vaccinations were adequate, and their physical and biologic examinations were normal. All dogs were acclimated (in a controlled-environment isolation facility) before surgery for a minimum of 14 days.

The bone fillers used were: hydroxyapatite (HA) (Alveoform granulation 50/400 µm, Zimmer sa, Vitry Sur, Seine, France) and animal originating calcium carbonate, Coral (Coral 450, Biocoral, Inoteb Noyal-Pontivy, France), in powdered form. The dental implants involved in the investigation were: commercially pure grade 1 titanium (Weber Métaux, Paris, France); alumina ceramic Cerasand implant (Sandhaus, Incermed, Lausanne, Switzerland); and zirconia ceramic Sigma implant (Sandhaus, Incermed). The implant design was identical for all materials, so as to exclude parameters of dimension and geometry. Titanium implants were machined from a wire drawn from commercially pure grade 1 titanium. After sonication cleaning and degreasing, the implants were dry heat–sterilized.

Surgery. The dogs were premedicated intravenously with atropine sulfate (0.025 mg/kg) and anesthesia was induced with 5% thiopental sodium (10 mg/kg). They were intubated and connected to a ventilator. Anesthesia was maintained with fluothane (1% to 1.5%) and oxygen. Lactate Ringer solution (10 mL/kg/h) was administered intravenously during the surgical anesthesia.

Nine adult dogs were given implants. All dogs were anesthetized and positioned in lateral recumbency. Extraction of the mandibular premolars was performed using the least invasive surgical technique. Bone fillers were placed in the sockets (18 with coral, 6 for each dental implant type) and (6 with HA for 6 alumina implants) and the mucosa was sutured. Twenty-four weeks later, implants were placed in the right and the left mandibles using the same procedure for each dog. A mesiodistal incision was made along the buccal side of the alveolar crest through the mucoperiosteum and attached gingiva. A periosteal elevator was used to lift the periosteum, exposing the alveolar bone. Throughout the study, a slow-speed, high-torque drill with an external irrigation system was used to prepare the implant sites. A taper tip was used to assist placement of the implants into the prepared sites. The gingiva was sutured over the submerged implants. After surgery, appropriate antibiotics and analgesics were administered. The animals were allowed unrestricted cage activity and placed on a soft diet during the healing process. Ten months after implantation, the 9 animals were sacrificed. The heads were perfused with saline solution added to 200 mL of 10% neutral formalin through the common carotid arteries. Blocks containing the implants were quickly removed after the fixation perfusion.

Histologic Procedures. Block sections of implants and their surrounding bone were divided longitudinally into 2 parts. One part was studied by light microscopy. After fixation in formalin and decalcification in a mixture of picric acid and nitrous acid, the implants were carefully removed to minimize tissue damage. The specimens were then processed for routine histologic preparation and embedded in paraffin. Sections 5 to 7 µm thick were cut longitudinally and stained with hematoxylin-eosin. The other, undecalcified part, was analyzed by scanning electron microscopy (SEM). The 5-mm-thick calcified sections were fixed in 3.5% glutaraldehyde solution, rinsed in phosphate-buffered saline, and post-fixed for 4 hours in 1% osmium tetroxide in water. After post-fixation, the specimens were rinsed in the buffer and dehydrated in an ascending series of alcohol. All the SEM specimens were critical point–dried, mounted on metal stubs, coated with a 100-Å-thick layer of gold palladium, and examined in a Hitachi S 430 scanning electron microscope (Hitachi, Tokyo, Japan).

Histomorphometric Analysis. The images obtained by SEM allowed precise examination of the bone-implant interface. Three zones on the interface were examined: the cervical, the central, and the apical zones. The cervical zone corresponds to the upper part of the implant in the mandibular cortex. The central zone corresponds to either cortical mandible or the spongious area of the mandible.

The apical zone is the distal part of the implant, which is sometimes surrounded by the inferior alveolar nerve. For calculation of the percentage of direct bone-implant contact, the analog images that were obtained by scanning electron microscope were transformed into numerical images. For data processing an image analyzer computer system (Cambridge Instruments Q 520, Leica sa, Rueil Malmaison, France) was used. A calculated value was used for the global histomorphometry. The value is the mean of the 3 previous values.

Statistical Analysis. Analysis of variance and *t* tests were performed (Excel 7, Microsoft, Redmond, WA).

First Experimental Procedure: Combination of Implants with Powdered Filler Material of Viable Origin ($CaCO_3$). For this part of the study, 5 dogs (14 to 16 kg) were used to evaluate the endosseous titanium, alumina, and zirconia implants placed into the mandible filled with coral (n = 18). After extraction of the 4 premolars on each side, the sockets were filled with coral. The mucosa was tattooed with China ink above the filler sites to ensure implantation in the same sites. The healing process was uneventful. Six months later, 3 to 4 nonsubmerged mandibular implants (with at least 1 each of titanium, alumina, and zirconia) were placed in each animal. On the right side of 2 dogs, no implants were placed in sockets previously filled with coral.

Results

Examination of specimens obtained at 10 months, using methods of macrophotography, radiography, light microscopy, and scanning electron microscopy, showed some differences between implants, especially in the histomorphometric study.

Macroscopic Examination. Measurements of the transverse width of the mandible in its median part were made using a caliper-square on the side with "filled" sites. These were compared to the side whose alveoli were left "empty." Despite inaccuracy, the clinical measurements tended to show that "filled" sites were 1 to 1.5 mm wider, thus suggesting that the volume of available bone was preserved to a certain extent. Macroscopic examination assessed the ability to osseointegrate implants in the coral sockets and evaluated the presence of bone with or without fibrous tissue around the implants.

Osseocoaptation (M.OC) was graded between 0 (no osseocoaptation at all) and 3 (excellent osseocoaptation). The final score was the total of an implant's grades for one specific type (Table 1).

Table 1 Total Bone Integration Scores for 6 Titanium, 6 Alumina, and 6 Zirconia Implants

	Titanium	Alumina	Zirconia
R.OC	13	14	12
M.OC	14	16	17

R.OC= radio-osseocondensation; M.OC = macro-osseocoaptation.

Table 2 Percentage of Bone-Implant Osseocoaptation for Implants Placed in Sockets Filled with Coral

	Cervical	Central	Apical	Global
Titanium	88.5 ± 11.4	44.2 ± 22.7	29.4 ± 20.5	54 ± 12.9
Alumina	88.8 ± 9.3	72 ± 19.3	43.1 ± 27.6	68 ± 13.9
Zirconia	84.4 ± 19.8	64.8 ± 21.3	44.8 ± 17.5	64.6 ± 12.7

Values represent mean ± standard deviation.

Table 3 Comparison of Percentages of Bone-Implant Osseocoaptation in Implants Placed in Sockets Filled with Coral

	Cervical	Central	Apical	Global
Titanium/alumina	0.96	0.05	0.35	0.10
Titanium/zirconia	0.67	0.14	0.19	0.18
Alumina/zirconia	0.63	0.55	0.91	0.67

All coral-filled implants presented good to excellent osseocondensation (Fig 1); zirconia and alumina implants showed better osseocondensation than titanium implants, with good correlation between radiographic scores and global histomorphometry.

Radiographic Examination. Radiographs were used to evaluate bone density around the implant, hence assessing osseocondensation (R.OC). Grading ranged from 0 (no osseocondensation at all) to 3 (excellent osseocondensation). On radiographs, the 3 types of implants presented very close osseocondensation scores (Table 1). No correlation between histomorphometry and osseocondensation was observed.

Microscopic Examination (Light and Scanning Electron Microscopy). Global histomorphometry (average of direct bone-to-implant contact) was calculated to be 68% ± 13.9% for alumina implants, 64.6% ± 12.7% for zirconia implants, and 54% ± 12.9% for titanium implants (Table 2). There was no statistically significant difference between the 3 implant types. On the other hand, studying specific implant zones (cervical, central, or apical) revealed interesting differences (Table 3).

All 3 implant types presented a better percentage of direct bone contact in the cervical zone than in the central or apical zones. Despite alumina's greater percentage of direct bone contact (88.8% ± 9.3% versus titanium's 88.5% ± 11.4% or zirconia's 84.4% ± 19.8%) (Table 2), no statistically significant difference between these 3 implant types was observed. Bone contact values were the lowest in the apical zone.

In the central zone, bone contact was greater for alumina (72% ± 19.3%) and zirconia (64.8% ± 21.3%) than for titanium (44.2% ± 22.7%) (Table 2). There was a statistically significant difference between alumina implants and titanium implants and a difference (not statistically significant) between zirconia and titanium (Table 3). Ceramic implants seem to present greater bone contact than titanium in the central zone. In the

Fig 1 Macrophotograph of calcified section of zirconia implant placed in coral-filled socket. Peri-implant bone contact is very good for all 3 implant types, particularly in the cervical and central zones next to the cortical bone.

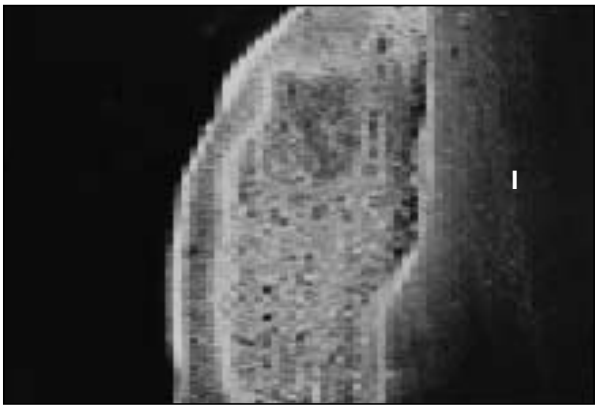

Fig 2 Scanning electron micrograph of cervical zone (titanium implant placed in coral-filled socket). Good quality bone contact goes along with continuous and noninflammatory epithelial contact (magnification ×40). I = implant.

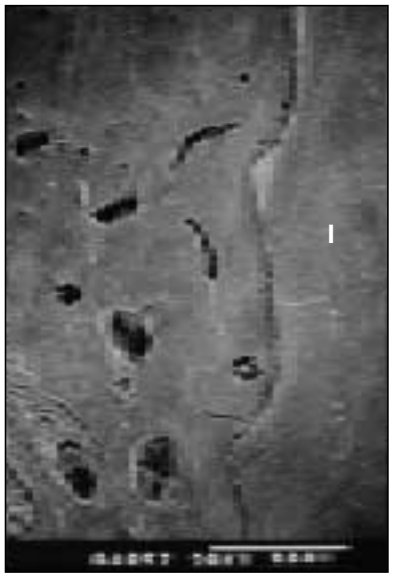

Fig 3 Scanning electron micrograph of central zone (zirconia implant placed in coral-filled socket). Excellent osseocoaptation with typical cortical osteogenesis (magnification ×40). I = implant.

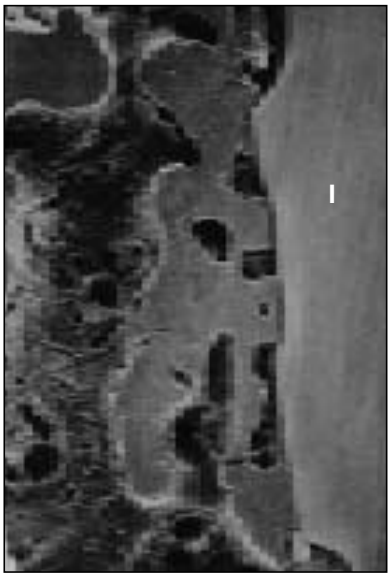

Fig 4 Scanning electron micrograph of central zone (zirconia implant placed in coral-filled socket). Good osseocoaptation with spongious osteogenesis (magnification ×40). I = implant.

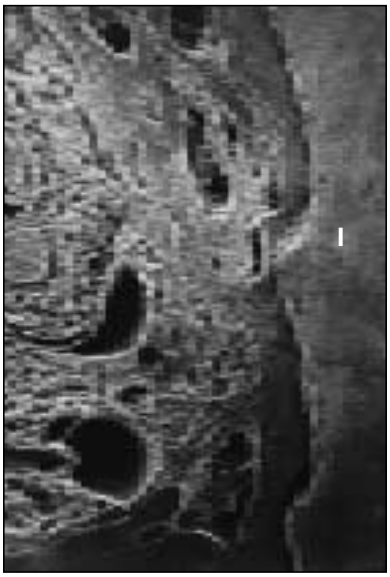

Fig 5 Scanning electron micrograph of the apical zone showing low and heterogeneous values because of a more "airy" cancellous bone, and because of the shape of the mandibular canal (zirconia implant placed in coral-filled socket). All of these photographs show the total disappearance of coral (magnification ×40). I = implant.

apical zone, the bone contact values were the lowest, with a large standard deviation (zirconia, 44.8% ± 17.5%; alumina, 43.1% ± 27.6%; and titanium, 29.4% ± 20.5%) (Table 2).

Discussion

Histologic examination revealed no remaining coral powder. After 3 and 6 months, some socket biopsies without implants showed no trace of coral in mandibular bone. Sometimes, small granules of filler were seen in the internal face of the mucosal flap. Coral was fully remodeled and integrated in the implant-associated newly formed bone, with no disruptive sign of the ossification process.

Peri-implant bone contact measured by histomorphometry was very good for all 3 implant types, particularly in the cervical zone next to the cortical bone. Good quality bone contact was associated with good quality, continuous, and noninflammatory epithelial contact (Fig 2).

In the central zone, bone contact was slightly lower but very close to the average value. Most of the interface was cancellous bone–implant and thus presented a lower density. Proximity between implants and the mandibular cortical bone can account for the high bone-contact percentage values for the 3 implant types. The standard deviation was higher in the central zone because of these structure variations (Figs 3 and 4). In the central zone, the osseocoaptation of zirconia implants was significantly better than around titanium implants (titanium/alumina: $P = .05$). Alumina implants had a tendency to better osseocoaptation than titanium implants (titanium/zirconia: $P = .14$) (Table 3). In the apical region, low and heterogeneous values were found because of poorer quality cancellous bone, and because of the shape of the mandibular canal (Fig 5).

Global histomorphometric values (average of the 3 zones) were quite homogeneous, with a low standard deviation. Titanium presented the lowest bone contact as well as the lowest macroscopic osseocoaptation. No significant statistical difference between the 3 implant types was noted despite an apparent difference between titanium and ceramics (titanium/alumina: $P = .10$; titanium/zirconia: $P = .18$).

Histomorphometric values of the central zone and global histomorphometric values had good correlation with macroscopically evaluated osseocoaptation, but not with radiographic examination. Radiographic analysis provided a visual evaluation of the mandibular profile of bone density and did not take bone-implant contact into account. Radiography is a good means for evaluating osseocondensation or eventually osseosclerosis, but not osseocoaptation. It can only assess the lack of osseocoaptation when peri-implant lysis has occurred.

Materials and Methods: Second Experimental Procedure

The second experimental procedure involved a combination of implants and material of nonviable origin (HA) in pulverized form (50/400 μm). Four dogs were used to study ceramic biomaterials of nonviable origin in combination with alumina implants. At the same time on the same dogs, another study was carried out in the free sockets. After extraction of the 4 premolars on each side, sockets were filled with HA powder and the mucosa was tattooed with China ink at the filler sites. The healing process occurred normally. Six months later, 6 alumina implants were placed at the HA site, and 6 alumina implants were placed in combination with HA in fresh sockets in the mandible. Observations were made after 10 months using the procedures described as before.

Results

This work demonstrates that filling fresh extraction sockets with HA prevents drilling for implantation and therefore, no implant could be placed. For the 6 other implants simultaneously placed with HA, after 10 months 1 failed and 5 were surrounded by a fibrous capsule, which impeded osseocoaptation.

On macroscopic examination, the osseocoaptation of HA associated with alumina implants was low. Radiographs showed osseocondensation graded from intermediate to good. The histomorphometric values of the osseocoaptation of the implant with HA were low. The global value is 22.5% with HA versus 68% with coral (Table 4).

Discussion

In comparing the 2 experiments, the following could be noted. In the first part, coral granules were fully resorbed, and therefore each implant presented excellent "osseocoaptation" leading to osseointegration. In the second part, HA granules were not resorbed and implant integration was altered (see Table 4). A constant peri-implant fibrous network could be seen in the central and apical zones (Figs 6 and 7).

Whatever the region, there was a significant difference in osseointegration at the bone-implant interface between the peri-implant filling with coral and the peri-implant filling with HA (cervical zone $P < .00004$, central zone $P < .001$, apical zone $P = .02$, and global $P < .0001$). Since the osteogenesis surrounded each granule because of the osteoconduction process it was evident that HA showed good "coalescence" (Fig 8). But when HA was used with implants, it prevented the osseointegration of those implants. Consequently, the clinical application of such an implantation procedure is not feasible.

Table 4 Percentage of Bone-Alumina Implant Osseocoaptation in Sockets Filled with Coral or HA

	Cervical	Central	Apical	Global
Alumina + Coral	88.8 ± 9.3	72 ± 19.3	43.1 ± 27.6	68 ± 13.9
Alumina + HA	38.2 ± 13.1	23.8 ± 12.2	5.4 ± 8.5	22.5 ± 8.9

Fig 6 *(Left)* Histologic section of alumina implant (I) with HA combination showing the presence of a fibrous casing surrounding the implant (hematoxylin-eosin, magnification ×120).

Fig 7 *(Right)* Histologic section of HA granule near alumina implant showing the presence of a fibrous casing surrounding the granule (magnification ×130).

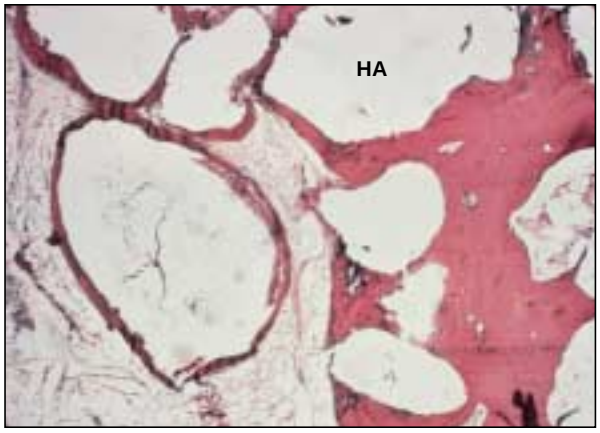

Fig 8 Histologic section showing excellent osteocoalescence and remodeling of the bone with Haversian systems around isolated HA granules (hematoxylin-eosin, magnification ×120).

Conclusion

From this experimental study carried out on 9 dogs and 23 implants, it can be concluded that coral (calcium carbonate), because of its dissolution-resorption capacity, totally disappears. New bone in no way inhibits osseocoaptation of the implants, whether they are made of titanium, alumina, or zirconia.

The mean percentage of implant-bone contact was better for ceramic implants than for titanium implants. In their central zone, alumina implants presented more statistically significant osseocoaptation than titanium implants. At the cervical zone, osseocoaptation was particularly good for all implants. At the apical zone, osseocoaptation was poor and dependent on the mandibular anatomy (because of the mandibular canal). Filling the mandibular sockets with powdered HA material led to osseocoalescence of HA granules but also to fibrous encystment of the implants.

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