Some Biomechanical and Histologic Characteristics of Early-Loaded Locking Pin and Expandable Implants: A Pilot Histologic Canine Study

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ABSTRACT

Background: A two-stage approach with a 3- to 6-month healing period is recommended for the "conventional" osseointegration technique with oral implants. This may induce inconvenience and discomfort for patients, and immediate early loading protocols are preferable.

Purpose: To compare a new type of implant with two locking pins, designed to allow immediate loading, with an expandable implant design with regard to bone tissue response and implant stability.

Materials and Methods: The molars and premolars of two beagle dogs were extracted in the mandible, and two types of implants (an apically expandable implant and a locking pin implant) were immediately placed in the sockets. The dogs received at least four implants (two of each type) in each side of the mandible. Implants were loaded with gold-palladium bridges 15 days later. The loaded implants were left for 3 months, and the dogs were sacrificed. Resonance frequency analysis (RFA) was performed at placement and sacrifice. Ground sections for histomorphometry were produced for each implant.

Results: Implant stability as measured by RFA was similar for the two types of implants before healing. At termination of the study, stability was higher for the locking pin implants. Bone histomorphometry showed that both types of implant were anchored by the same amount of bone and that bone-titanium interfaces did not differ.

Conclusion: The locking pin implant showed better secondary stability than did the expandable implant, probably because of a better transmission of strains to bone.

KEY WORDS: animal study, bone histomorphometry, dental implant, immediate loading, titanium implant

Maintenance of a high level of stability is a requisite for a successful long-term function of oral implants. Brånemark established a unique two-stage submerged procedure for the treatment of edentulous patients, as follows: once inserted into the prepared bone site, the fixtures are left undisturbed for 6 months in the maxilla and for 3 months in the mandible; in a second stage, the abutments are connected to the fixtures at the end of this healing period.[1,2] Although the Brånemark protocol is often referred to as a "conventional osseointegration technique," it often presents inconvenience and discomfort for the patients, who have to live without teeth or wear a denture during the healing period.

In the past, immediate loading of dental implants was rarely successful, probably because of excess micromotions. Brunski found that micromotions of more than 100 μm must be avoided; otherwise a fibrous layer interposes between bone and titanium, leading to implant failure.[3] Multiple implants and rigid

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cross-arch restoration have been proven to be effective in minimizing the harmful effects of micromotions.[4,5] However, when single-tooth treatments are used and partially edentulous patients are to be treated with immediate-loading protocols, the risk for implant failure is probably increased although some studies have reported encouraging outcomes.[6,7] Thus, a very significant improvement in implantology would be new types of fixtures that allow for immediate functional loading with minimal or no micromotion.

The use of an apically expandable implant system was proposed by Lazarof.[8,9] This system is based on a US patent of Ashuckian, who designed an implant with two legs that were spread apart by the rotation of a threaded internal screw.[10] The four pods of the Sargon® implant (Sargon® Enterprises, Inc., Encino, CA, USA) are similarly expanded when a nut is driven occlusally along an expansion screw. Nowzari and colleagues reported that such a system was clinically asymptomatic soon after insertion and during functional loading.[11] However, the thin pods of this implant made it fragile although it demonstrates an increased resistance against frictional forces when expanded maximally. The aim of the present study was to compare two newly designed implants by using resonance frequency analysis (RFA) in a canine model.

MATERIALS AND METHODS

Animals

Two female beagle dogs weighing 11 to 12 kg were used in this study. The animals were left to acclimate for 3 weeks before surgery and were given dry dog food ad libitum. After surgery the animals were fed a soft diet for 15 days; they resumed their normal diet during the 3 months of the study.

Implants

Two types of implants were used in this study. Both configurations were designed to reduce micromovements generated through occlusal loading. An expendable cylindrical implant with four pods with an internal expansion nut (Euroteknika, Paris, France) was used (Figure 1). This implant is expanded through an internal screw located at the bottom of the inner pit of the implant. The screw is activated with a thin screwdriver until strong bony resistance appears. Another implant used was a new type of implant with a bicortical locking

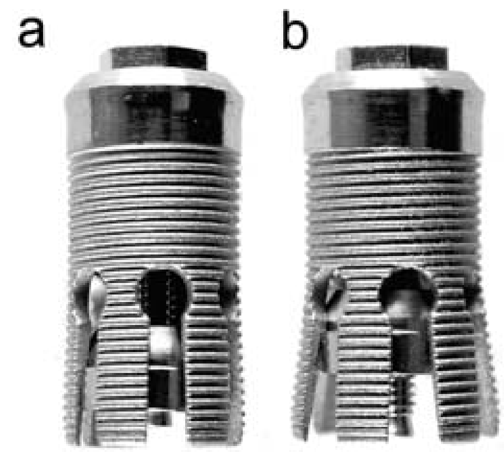

Figure 1 Expendable implant with four pods unexpanded (a) and expanded (b).

system with two titanium pins, also manufactured by Euroteknika (Figure 2). This implant mount is engaged with the drilling jig, and its cannon drills to penetrate the external cortices, the implant's aperture, and the internal cortices. The pins are then impacted through with a mallet to lock it inside the bone.

The finite element analyses of these implants have been presented elsewhere.[12] The implants were made of commercially pure (CP) titanium grade 2, and their dimensions were selected after tooth extraction, to fit the anatomic conditions. Implant diameters of

Figure 2 Locking pin implant, with the two pins inserted in the implant holes.

3.75 mm, 4.75 mm, and 6.00 mm and lengths of 10.0 mm and 11.5 mm were used.

Surgical Treatment

The same protocol was used for the two surgical periods. Before surgery the dogs were premedicated with glycopyrrolate SC (Robinul®, Vétoquinol, France) and anesthetized with an intravenous mixture of diazepam 20 mg (Valium®, Produits Roche, Neuilly sur Seine, France) and ketamine 110 mg (Imalgene 1000®, Mérial, Lyon, France). The dogs were intubated and maintained on nitrous oxide (N_2O), oxygen (O_2), and halothane 2%. In the first surgical step, casts of the upper and lower jaws were obtained, then the posterior two bicuspids and one molar were extracted from both sides. After standard drilling with a low-rotational-speed procedure under profuse saline irrigation, the implants were placed in these freshly prepared sockets. One dog received two expandable implants and two locking pin implants on the left side and three expandable implants and two locking pin implants on the right side. The other dog received two expandable implants and two locking pin implants in each mandible. Sockets were allowed to heal for 15 days, a period necessary for preparing the gold-palladium crowns. In the second surgical step, before placement of the crowns, resonance frequency measurements were performed. The implants were screwed in with a final torque of 30 N/cm and were carefully equilibrated to comply with a good centric occlusion with no excursive interference.

Near the end of the study, double calceine labeling was done to determine the mineral apposition rate, and a "2 days on, 10 days off, and 2 days on" schedule was used (calceine dose: 30 mg/kg intramuscularly). The animals were sacrificed by a massive intravenous dose of sodium pentobarbital (Dolethal®, Laboratoire Vetoquinol, Paris, France), and the bridges were removed before a new resonance frequency determination. The jaws were then fixed en bloc in 70% ethanol containing 10% formalin.

Resonance Frequency Analysis

RFA was performed with the use of an Osstell™ system (MediTeam Dental AB, Sävedalen, Sweden) on all implants (Figure 3). The measurements were expressed as implant stability quotients (ISQs) with values ranging from 0 to 100. The higher the ISQ value, the more stable is the implant.

Figure 3 Resonance frequency analysis being performed on an implant inserted in a beagle dog; the Osstell system instrument is affixed to the implant.

Histologic Technique

The mandible halves were radiographed on a numeric system (Faxitron® Edimex, Angers, France) in order to determine the exact position of the implants and the angles of the locking pins (Figure 4). Blocks containing a single implant and the surrounding bone were prepared with a precision banding saw. They were embedded in polymethylmethacrylate, sectioned on a low-speed Accutom™ saw (Struers A/S, Copenhagen, Denmark) equipped with diamond blades. Serial sections (500 μm thick) of the implant and surrounding bone were made parallel to the implant axis or parallel to the locking pins. Slices were affixed with an adhesive layer onto plastic translucent slides with photopolymerizable glue (Exakt Adhesive system). The slides were ground to a thickness of 50 μm with a rotating grinding plate (EXAKT Apparatebau GmbH & Co.,

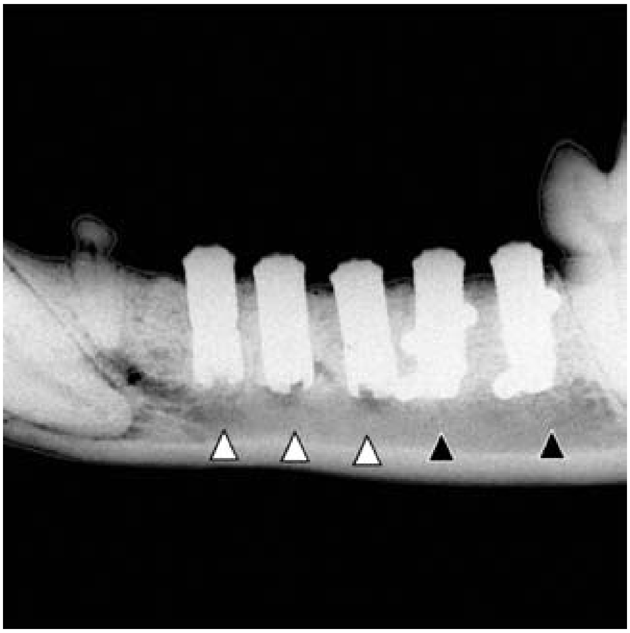

Figure 4 Radiograph of the left hemimandible of one dog; note the expandable implants (▷) and the locking pin implants (▶) with transverse pins inserted.

TABLE 1 Results of Resonance Frequency Analysis

Locking Pin Implants			Expandable Implants		
Tooth #	ISQ at Implantation	ISQ at Sacrifice	Tooth #	ISQ at Implantation	ISQ at Sacrifice
47	61	73	46	54	44
46	57	72	44	49	64
38	44	84	45	51	71
36	67	78	38	47	48
47	45	48	45	57	78
44	53	73	37	73	45
37	53	59	34	48	55
			44	50	67

ISQ = implant stability quotient.

Norderstedt, Germany) covered with sandpaper ranging from 400 to 2000. One section was surface-stained with toluidine blue (1% in sodium tetraborax) for histologic study and quantitative analysis. The other section was left unstained for histodynamic measurements with fluorescent microscopy. Measurements were done on an image analyzer based on a personal computer connected with a SummaSketch III™ digitizing tablet (Summagraphics, Nantes, France).[13,14] The parameters listed below were determined in a reference area 1,400 μm in width, positioned at the bottom of the threads or locking pins. For expanded implants, measures were done on all threads of the pods. For other implants, only sections that made up the two locking pins were used in the present study. The following parameters were measured:

1. Bone volume per tissue volume (BV/TV) (the fraction, expressed as a percentage, of the reference space occupied by bone)
2. Bone surface covering titanium surface (BS/TiS), expressed as a percentage
3. Mineral apposition rate (MAR), expressed as μm/D, measured in contact with the implant (ie, in the reference area) and at distance from the implant (similar measurements being done around the locking pins)

RESULTS

One expandable implant was immediately lost because of fracture of the cortex during removal of the teeth in one dog. This induced a net defect of alveolar bone in the vicinity of the socket, and radiographs showed that a locking pin implant in its immediate neighborhood was not anchored. This last implant was not considered for subsequent statistical studies. In one dog, one locking pin implant could receive only one pin because of anatomic characteristics. The mean values for ISQs did not differ at the beginning of the study (expandable implants, 53.6 ± 3.0; locking pin implants, 54.3 ± 3.1) (Table 1 and Figure 5). Both types of implant exhibited similar ISQs at the beginning of the study. The mean ISQ increased in both

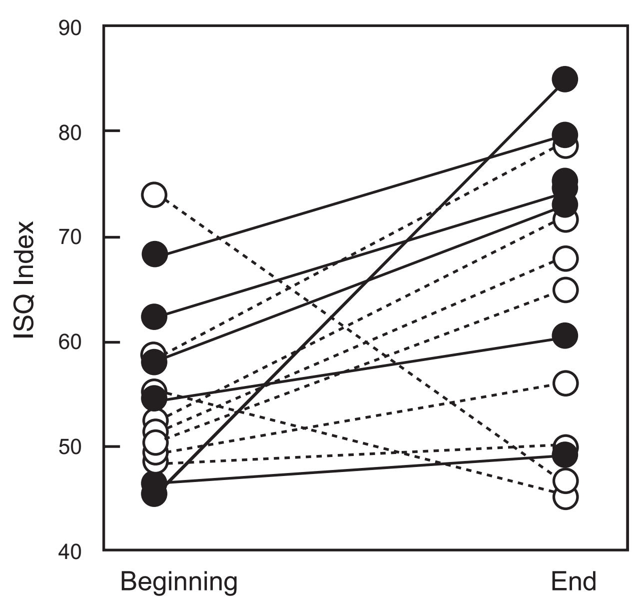

Figure 5 Results of resonance frequency analysis of expandable implants (○) and locking pin implants (●) before and after a 3-month period of loading. (ISQ = implant stability quotient).

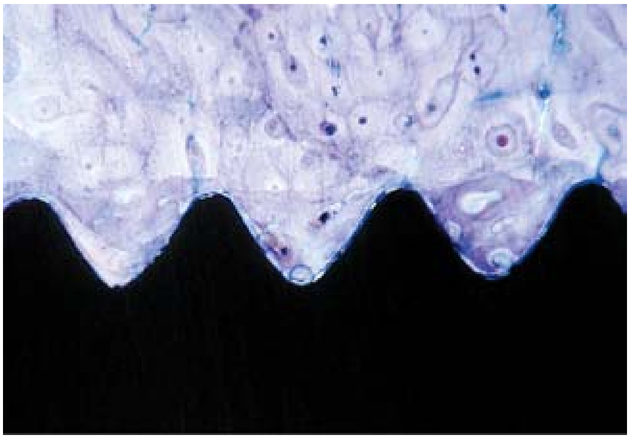

Figure 6 Histologic appearance of the threads of an expandable implant inserted in a beagle dog mandible and loaded with a gold-palladium crown for 3 months. Toluidine Blue staining (× 100 original magnification).

TABLE 2 Histomorphometric Results

	Locking Pin Implant		Expandable Implant
	Threads	Pins	Threads
BV/TV (%)	74.8 ± 3.0	38.4 ± 4.1	81.5 ± 4.1
BS/TiS (%)	58.5 ± 7.7	54.2 ± 4.4	63.2 ± 2.3
MAR_{prox} (μm/D)	1.79 ± 0.08	—	1.72 ± 1.6
MAR_{dist} (μm/D)	1.34 ± 0.13	—	1.08 ± 0.03

BS/TiS = bone surface covering titanium surface; BV/TV = bone volume per tissue volume; MAR = mineral apposition rate; MAR_{dist} = MAR measured at distance from implant; MAR_{prox} = MAR measured at distance in contact with implant.

groups, but locking pin implants had significantly higher values at the end of the study (59 ± 4.5 for expandable implants and 69.6 ± 4.5 for locking pin implants) (see Table 1 and Figure 5).

From a qualitative and histologic point of view, there were no obvious differences between the two types of implant when the bone-titanium interface was considered. Interposition of fibrous tissue was never observed (Figures 6 and 7). Some large titanium wear particles could be found in the threads (immediately in contact with the pins) or at a distance in the trabecular network. Particles were always covered by bone; they were most probably generated during the insertion phase. No statistical difference in BV/TV and BS/TiS could be observed between the two types of implant (Table 2). The volume of bone surrounding the locking pins was slightly less, but the contact interface between bone and titanium did not differ from the threads (Figure 8). In both types of implant the remodeling level, appreciated by MAR, remained

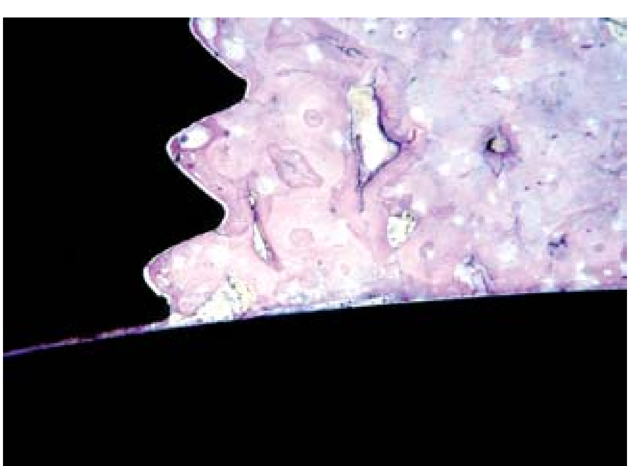

Figure 7 Histologic appearance of the threads of a locking pin implant inserted in a beagle dog mandible and loaded with a gold-palladium crown for 3 months. Part of a tip is visible at the bottom of the figure. Toluidine Blue staining (× 100 original magnification).

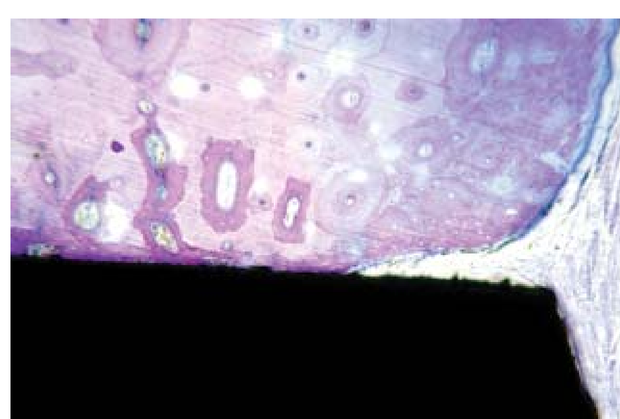

Figure 8 Histologic appearance of the surface of the tip of a locking pin implant inserted in a beagle dog mandible and loaded with a gold-palladium crown for 3 months. The tip is covered by bone; note the connective tissues of the gingiva on the right side. Toluidine Blue staining (× 100 original magnification).

significantly higher in the vicinity of the implant than at distance (see Table 2).

DISCUSSION

The development of new types of implants for better transmission of strains to bone will help to shorten the healing period and even allow for immediate loading. In 1979 Ledermann and colleagues developed the concept of immediate loading that used interforaminal implants with a bar-retained overdenture.[15] This concept was extended by others.[4,6,16] However, Sagara and colleagues reported radiographic and histologic observations indicating that immediate loading of one-stage implants resulted in a greater marginal loss of bone when compared to a classic two-stage procedure.[5] Akagawa and colleagues reported histologic findings for unloaded and immediately loaded zircon implants; the loaded implants showed greater crestal bone loss than did unloaded ones.[17] Although several authors have reported that immediate implantation after tooth extraction yields a high percentage of success,[18,19] little is known about the immediate loading of immediately placed implants after tooth extraction. In a meta-analysis, Schwartz-Arad and Chaushu reported that implants placed in freshly extracted sockets had a high rate of success.[19] Maló and colleagues reported excellent clinical results 1 and 2 years after placement of Brånemark implants in freshly extracted sites; however, in their series patients were asked to avoid chewing on the prostheses for 3 months, a condition that does not correspond to loading conditions.[20] When machined-surfaced (ie, smooth) implants were used in edentulate patients, de Bruyn and Collaert did not recommend loading immediately implants that had been installed in fresh extraction sites.[21] In the present study, the beagle dog was chosen because its masticatory function is closely related to that of humans. However, the width of the mandible is markedly reduced. This was important when the expandable implant was used because it was not possible to expand the apical pods at the maximum angle. In addition, the mandibular thinness also hampered the placement of a second locking pin in one implant. Since both types of implant were of the same titanium composition and were prepared with a similarly rough surface, it is not surprising that the BS/TiS did not differ between the two groups. In the same way, the tips were also covered by the similar percentage of bone. Surface roughness has been repeatedly described as favoring bone bonding,[22,23] and this assertion was confirmed with this type of surface treatment.[14]

The design of an implant appears to play a fundamental role in primary and long-term anchorage. Design has been shown to influence the bone remodeling rate by a modification of the transferred loads to the crestal bone.[24] Frost demonstrated that bone adapts its mass to a physiologic range of loads; a slight increase induces a compensatory and adaptable gain. On the other hand disuse or an excess load similarly induces bone resorption according to the "mechanostat" theory or "Utah paradigm."[25,26] The accumulation of strains around focal areas of hip prostheses is a well-known phenomenon and is referred to as "stress shielding" by orthopedists.[27,28] Many years ago the use of threaded fixtures was reported to permit a better adaptation of bone by optimizing the strains.[2,29] In the present study the locking pin implant was used because its design transfers the loads far from the neck region as shown by finite element analysis.[12] The transverse locking pins contribute to the primary anchorage and favor the long-term success of the implantation. The system provided better mechanical adaptation as assessed by resonance analysis than did expandable implants, which were much larger in diameter. In addition the long-term resistance of the thin pods of this type of implant to fatigue may be questionable. The findings from this pilot study suggest that the locking pin system results in a higher secondary stability than do the expandable implants.

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