Immediate Loading of Dental Implants Supporting Fixed Partial Dentures in the Posterior Mandible: A Randomized Controlled Split-Mouth Study—Machined Versus Titanium Oxide Implant Surface

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Purpose: *A split-mouth study was conducted to compare dental implants with either machined or titanium oxide (TiO) surfaces immediately loaded with fixed partial dentures in the posterior mandible.* ***Materials and Methods:*** *Ten patients with bilateral partial edentulism in the posterior mandible received 42 implants; 20 on the test (TiO) and 22 on the control (machined) side. The implants were loaded within 24 hours postsurgery. At implant placement the maximum insertion torque (IT) was recorded. Implant stability quotient (ISQ) was also evaluated at baseline (day 0) and 1, 2, 4, 12, 24, and 52 weeks following implant placement. The radiographic bone level (RBL) change was measured on periapical radiographs at baseline and 12 months after loading. Means for the 2 groups were compared by paired t test.* ***Results:*** *The overall implant success rate was 95%. No implants were lost in the test group; 2 failed in the control group. The difference between the groups in RBL change after 1 year of function was not statistically significant (*P = *.224). However, average RBL change for machined implants in distal positions was significantly higher than for TiO surface implants in the same position (post-hoc comparison;* P = *.048). ISQ and peak IT values did not differ between the groups (*P = *.414 and* P = *.762, respectively). The high IT necessary to insert the implants did not seem to affect the RBL change (*P = *.203).* ***Conclusions:*** *No significant difference was observed between machined and TiO implant surface in terms of RBL change or ISQ, although TiO implants may provide a lower RBL change compared to machined implants when utilized in the distal position. Immediate loading of implants using fixed partial dentures in posterior mandible may be considered as a treatment option if implants are inserted with IT ≥ 20 Ncm and ISQ ≥ 60 into nonaugmented bone and loaded with light centric occlusal contact.* (More than 50 references) Int J Oral Maxillofac Implants 2007;22:35–46

Key words: *dental implants, immediate loading, randomized controlled trials*

The long-term success of osseointegrated dental implants to support fixed partial dentures or full-arch restorations is well-documented in the dental literature.[1–4] According to the principles of osseointegration described by Brånemark and colleagues,[5] or those of "functional ankylosis" described by Schroeder and associates,[6] direct contact between the titanium implant surface and living bone must be achieved at completed healing after dental implant placement. The prerequisites that allow osseointegration include minimal trauma during surgery, achievement of primary stability, and avoidance of infection and micromotion. Thus, the original implant protocol suggested a healing period of several months, with the implants left submerged beneath the oral mucosa and unloaded.[7] Premature loading was considered detrimental to direct bone apposition on the implant surface; it was thought to result in fibrous tissue encapsulation.[8,9] Only recently, new clinical protocols with shortened healing periods or immediate loading of dental implants have been proposed, with clinical success rates com-

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parable to the original protocol.[10–19] In addition, a growing number of clinical reports on immediate loading showing promising results have been presented in the dental literature. However, among these, a few published studies have been randomized and controlled. To better understand the limitations in the clinical application of immediate loading, more information based on randomized controlled clinical trials is certainly needed.[20]

The main requirement to allow immediate loading of a dental implant is its primary stability when placed in the bone.[21] The implant should be able, during the early healing period, to withstand loading with micromotion below 150 μm. Above this threshold, fibrous encapsulation may occur.[22–24] Primary stability depends on bone quality and implant design. To improve the bone quality, surgical techniques have been described to enhance bone density during the implant placement,[25,26] and new implant designs have been proposed to provide high stability in low-density bone. A screw-shaped double-threaded tapered implant was developed to enhance stability in soft bone conditions (Brånemark System MK IV; Nobel Biocare, Göteborg, Sweden). An in vitro study[27] comparing performances of different implant designs in soft bone found that the highest primary stability was provided by the MK IV implant. An early clinical study on immediate loading of MK IV dental implants with turned surfaces[28] found a cumulative success rate (CSR) of 82% (90.2% in the mandible and 77% in the maxilla) after 1 year of loading. Another clinical report[29] on immediately loaded MK IV dental implants supporting single-tooth crowns and fixed partial dentures (FPDs) in the maxilla demonstrated a CSR of 90.7%.

Whereas the implant macrostructure may play a crucial role in achieving primary stability even in soft bone, the speed of bone healing over the implant and the amount of bone-implant contact seem related to the surface configuration.[30–33] In vitro studies and preclinical trials show that a positive correlation exists between increased surface roughness and bone-implant contact measured histologically as well as demonstrated by torque removal values.[34] A recently introduced titanium oxide (TiO) surface (TiUnite; Nobel Biocare)[35] has been demonstrated in animal and in vitro studies to reduce bone healing time[36] and to increase bone-implant contact[37,38] compared to the machined surface, thus retaining the primary stability in a more efficient manner and providing secondary stability in a shorter period of time. The qualities of the TiO surface seem to offer an improvement for immediate loading applications. However, despite the experimental evidence of increased bone-implant contact observed on rough implant surfaces compared to the machined surfaces,[31,32,38–41] it has not yet been proven that rough surfaces offer a significant clinical advantage for immediate loading applications.

The present study aimed to compare, clinically and radiographically, MK IV dental implants, with machined or TiO surfaces immediately loaded by means of fixed partial dentures in posterior mandibles. A split-mouth randomized controlled study model was used.

MATERIALS AND METHODS

The Ethics Committee of the University of Bologna approved the research protocol. The patients were selected from the population of patients requiring implant treatment at the Department of Prosthodontics of the School of Dentistry of the University of Bologna.

Patient Selection

All patients scheduled for implant-supported restoration were asked to participate. The patients were consecutively included in the study, provided that they fulfilled the following inclusion criteria: *(1)* bilateral edentulous sites in the posterior mandible requiring an FPD of at least 2 teeth for each side; *(2)* an adequate amount of bone volume for placement of implant with a minimum length of 8.5 mm; *(3)* same type of opposing occlusion bilaterally; *(4)* healed bone sites (at least 4 months since the last extraction); *(5)* no need for bone augmentation; and *(6)* sufficient implant primary stability. To meet the last criterion, an insertion torque (IT) of 20 Ncm and an implant stability quotient (ISQ) value of ≥ 60 were required.

Every patient received TiO dental implants in the test side and machined implants in the control side; test and control sides were randomly assigned according to a predetermined randomization table. Each implant was supported 1 tooth as part of a multiunit splinted fixed screw-retained restoration immediately loaded within 24 hours of surgery.

Patients were excluded from the study if *(1)* it was suspected that the treatment could affect the patient's health condition; *(2)* patient cooperation appeared questionable; or *(3)* the patient did not give his or her consent to participate.

Surgical Treatment

The implants were placed under local anesthesia (2% mepivacaine) (Ogna Farmaceutici, Milan, Italy) following use of prophylactic antibiotic medications consisting of 2 grams of amoxicillin (Pharmacia Italia,

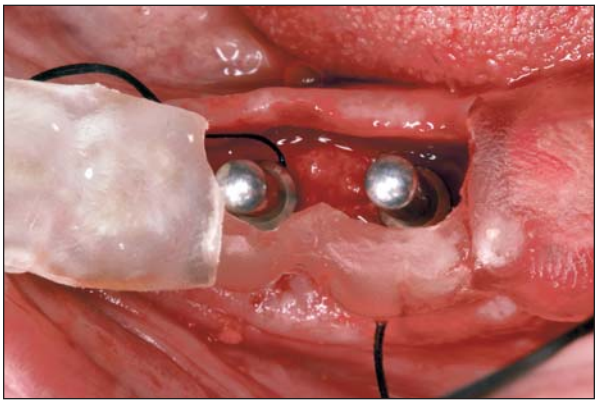


Fig 1 Preparation of the implant osteotomy according to the surgical guide.

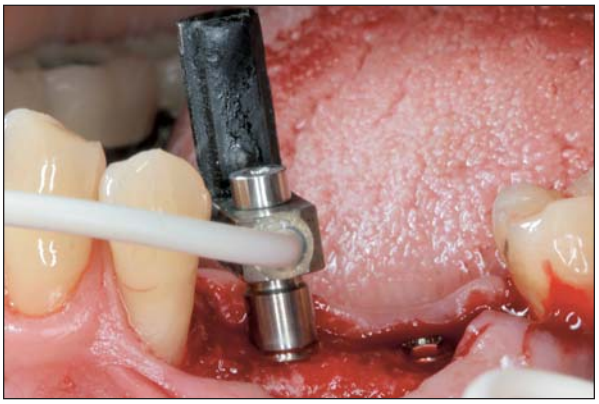


Fig 2 RFA being conducted.

Milan, Italy) 1 hour before the surgical procedure. Following crestal incision, a full-thickness flap was raised, and the implant osteotomy site was prepared using the 3-mm twist drill as the final drill. If a thick cortical bony crest was present, a 3.15-mm drill was utilized accordingly. The implant position was decided with a radiographic/surgical guide based on diagnostic waxup and computerized tomographic (CT) scan evaluation (Fig 1). The implant was inserted without screw taping. IT value was measured during the seating of the most coronal 4 to 5 implant threads by means of the Osseocare surgical unit (Nobel Biocare) and recorded as 20, 30, 40, or 50 Ncm IT. In case of IT lower than 20 Ncm, the implant was not immediately loaded; the patient was excluded from the study, and implant treatment was completed following the standard protocol.[7] Whenever the torque needed for the insertion exceeded the 50 Ncm (the maximum torque allowed by the Osseocare machine), a manual wrench (Nobel Biocare) was used, and the IT was reported as > 50 Ncm. When the torque to seat the implant was even higher than the torque provided by the manual wrench, the implant was removed, and the MK IV screw tap (Nobel Biocare) was used to prepare the coronal half of the osteotomy site. At the time of placement, resonance frequency analysis was conducted using Osstell equipment (Osstell/Integration Diagnostics, Göteborg, Sweden), and for each implant the ISQ was recorded (Fig 2). If the ISQ was less than 60, the implant was not immediately loaded; the patient was excluded from the study,[42] and implant treatment was completed following the standard protocol.[7] All the implants were placed in such a way that angulated abutments were not necessary, and all the provided restorations were screw retained. Following implant insertion, pickup impression copings were connected to the implants, and an impression was made using a polyether elastomeric material (Permadyne; 3M ESPE, St Paul, MN) according to the open-tray technique. To avoid contact between the impression material, the flap, and the underlying bone, a portion of a sterile rubber dam sheet was adapted on the copings to isolate the surgical sites during the impression procedure (Fig 3). Healing abutments were seated on the implants while an interim prosthesis was fabricated, and the flap was sutured with 5-0 suture (Polysorb; USS-DG, Norwalk, CT). Postsurgically, the patient was asked not to brush the operated areas and to rinse instead with 0.12% chlorhexidine solution (Peridex; Procter & Gamble, Cincinnati, OH) twice a day for 1 minute for 14 days for plaque control. Pain control was provided with 400 mg ibuprofen (Brufen; Boots Healthcare, Milan, Italy) as needed. No limitations to chewing function were given. Sutures were removed after 7 to 14 days.

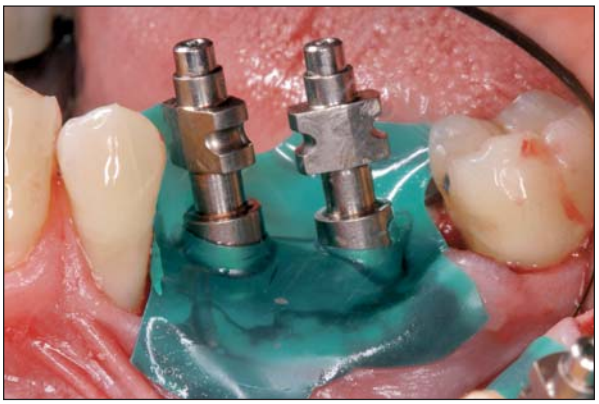


Fig 3 Pickup impression coping for open-tray impression technique being connected to the implant. A portion of a sterile rubber dam sheet was adapted on the copings to protect the surgical field from the impression material.

Prosthetic Procedure

Provisional restorations were splinted and attached to the implant using screws within 24 hours of

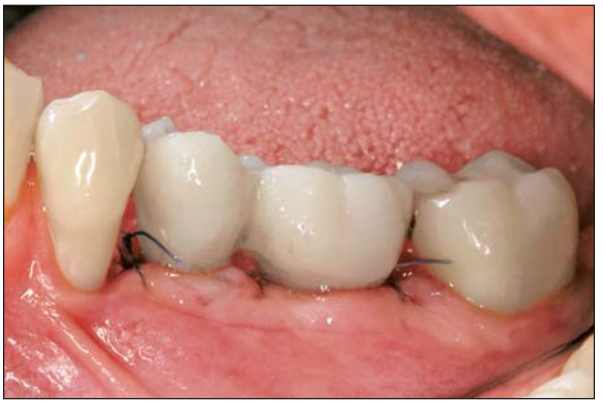


Fig 4 The temporary restoration was connected to the implant by screws within 24 hours of the surgery.

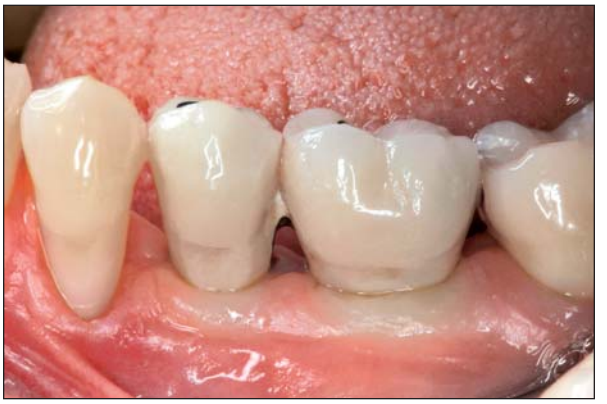


Fig 5 The final restoration in place at the time of delivery, 6 months after the surgical procedure. Note the ischemia on the gingival tissues due to compression from the proper emergence profile of the prosthesis.

implant placement (Fig 4). Depending on the thickness of the gingival tissues, provisional restorations were placed either directly onto the implant or onto indirect abutments (MUA; Nobel Biocare). The same prosthetic components were used at the test and at the control sites for each patient. An interim prosthesis was custom-made from self-curing composite resin (Protemp; 3M ESPE) using a silicon index obtained from the diagnostic waxup. The occlusal scheme of the restorations was designed with contacts in maximum intercuspal position or centric relation; working and balancing contacts were carefully removed. The contacts were adjusted in such a way that a 7-µm-thick occlusal paper could be removed from the mouth when the patient closed the teeth in contact. It could be held in place if the patient closed his or her teeth with maximum bite force.

Three to 6 months after implant placement, a final impression was made, and definitive porcelain-fused-to-metal screw-retained splinted restorations were delivered (Fig 5).

Follow-up Examinations

The patients were recalled at 1,2, and 4 weeks after surgery and at 3, 6, and 12 months. Occlusion was checked at every postoperative visit. The interim prosthesis was removed, and implant stability was measured by RFA and recorded as an ISQ. Periapical radiographs were obtained at surgery and at 12 months using a paralleling technique with a Rinn film holder (Dentsply Rinn, Elgin, IL). The radiographs were obtained in such a way that the platform and the threads were clearly visible, both mesially and distally (Fig 6).

Radiographic Bone Level

Radiographic bone level (RBL) change was measured on the periapical radiographs. A blinded examiner measured the bone on each radiograph. Image analysis software (Digora for Windows 2.1; Soredex, Milwaukee, WI) was used to measure the distance between the implant platform and the most coronal level of the bone deemed to be in contact with the implant surface. The first bone-implant contact at surgery was defined as the baseline. RBL change was calculated as the difference between the reading at 1 year and the baseline value. Mesial and distal bone height measurements were averaged for each implant.

Success and Failure Criteria

The success criteria for the implants were: *(1)* absence of radiolucency around the implant; *(2)* absence of clinically detectable mobility; and *(3)* absence of suppuration, pain, or ongoing pathologic processes. Implants that did not fulfill the success criteria were considered failures.

Failed implants were removed and replaced with TiO implants after 8 weeks of healing of the implant site. The replaced implant was loaded after 3 months of healing.

Rescued implants were those implants that presented a slight rotational movement during a follow-up visit over the first month of healing in the absence of radiographic bone loss or radiolucency. These implants were treated as follows: the restoration was removed and the implant was retightened to achieve a new primary stability. Rescued implants were counted as failures for the study protocol. Healing was allowed to continue for few months without occlusal loading until an ISQ greater than 60 was

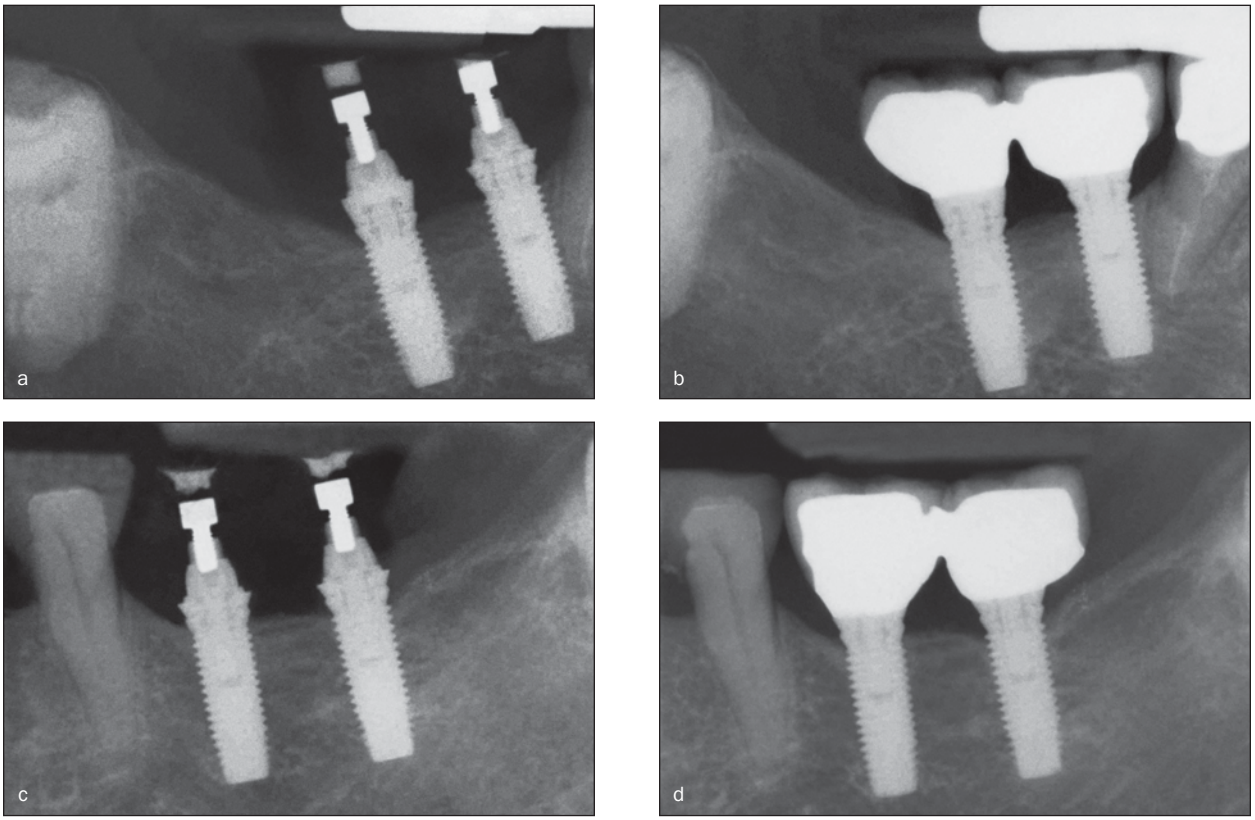


Fig 6 Radiographs of *(a)* machined implants at at baseline, *(b)* machined implants at 12 months, *(c)* TiO implants at baseline, and *(d)* TiO implants at 12 months.

measured. RBL change at complete healing had to be within the first or the second threads to proceed with implant loading. Rescued implants were used to support the definitive restorations.

Statistical Analysis

The implant success rate was expressed as a percentage of the total number of implants placed for each group (test and control). The single implant was considered the statistical unit. RBL change was the main response variable used in the study to evaluate the clinical performance of the 2 implant surfaces. An RBL change of 0.3 to 0.4 mm was considered of clinical relevance in recent comparative studies.[43] Thus, the sample-size analysis was calculated on this variable for a paired *t* test based on an α error of 5% and a power of 80%. A minimum sample size of 18 implants for each group was necessary to detect a difference of 0.3 mm with a standard deviation (SD) of 0.6 mm. (Primer of Biostatistic 5.0 statistical package).

Kolmogorov-Smirnov goodness-of-fit tests were computed for each response variable to assess whether the parameters were normally distributed. Both RBL change and ISQs were normally distributed and were considered parametric variables. Means between 2 groups were compared by paired *t* test. Two-way analysis of variance (ANOVA) for repeated measures (followed by Tukey highly significant difference [HSD] test post-hoc comparisons) was used to test the overall effect of implant surface and implant position on both RBL change and ISQ or to test the effect of the different peaks of IT on RBL 1-year variation. To test the single effect of IT on bone remodeling, 1-way parametric ANOVA and the Mann-Whitney test were used as post-hoc comparisons.

The statistical evaluation of the relationship among position of implants, implant length and IT and the different distributions of the aforementioned parameters in test and control implants was carried out by means of the χ^2 for contingency tables.

All analyses were done with Statistica software version 5.5 (StatSoft, Vigonza, Italy). The level of significance was set at 5% for all statistical tests.

RESULTS

Ten patients were consecutively treated, 4 women and 6 men with a mean age of 61.3 y (range, 37 to 74 y). One patient was a pipe smoker. Forty-two implants were placed to support 20 fixed partial dentures.

Table 1 Control and Test Implant Position, Peak IT, Implant Size, and Type of Restoration for Each Patient

	Control implants				Test implants			
Patient	Position	Peak IT (Ncm)	Length (mm)	No. of units in restoration	Position	Peak IT (Ncm)	Length	No. of units in restoration
1	46 (30)	40	11.5	2	36 (19)	40	11.5	2
	47 (31)	40	11.5		37 (18)	40	11.5	
2	35 (20)	>50	11.5	2	46 (30)	>50	11.5	2
	36 (19)	>50	10		47 (31)	>50	11.5	
3	45 (29)	>50	11.5	2	35 (20)	50	13	2
	46 (30)	40	11.5		36 (19)	30	11.5	
4	45 (29)	>50	11.5	3	36 (19)	>50	15	2
	46 (30)	50	13		37 (18)	>50	15	
	47 (31)	>50	13					
5	35 (20)	>50	11.5	2	45 (29)	>50	10	2
	36 (19)	>50	11.5		46 (30)	30	13	
6	46 (30)	>50	10	2	36 (19)	>50	11.5	2
	47 (31)	>50	10		37 (18)	>50	10	
7	45 (29)	50	13	2	35 (20)	40	11.5	2
	46 (30)	30	13		36 (19)	20	11.5	
8	35 (20)	>50	10	3	46 (30)	>50	11.5	2
	36 (19)	>50	10		47 (31)	>50	10	
	37 (18)	50	10					
9	46 (30)	40	11.5	2	36 (19)	>50	10	2
	47 (31)	20	11.5		37 (18)	50	8.5	
10	45 (29)	>50	11.5	2	35 (20)	>50	10	2
	46 (30)	50	10		36 (19)	30	8.5	

Twenty implants were placed as test implants, and 22 implants were controls.

All patients participated until the end of the study, no clinical dropout occurred. Patients healed with minor discomfort; no swelling or surgical complications were reported. However, during the provisional phase some prosthetic complications occurred. The interim prosthesis fractured in 3 patients; in all cases it was immediately repaired. All the implants placed fulfilled the requirements for immediate loading. Overall, the implant CSR after 1 year of function was 95% (2/42). No implants were lost in the test group (0/20), for a CSR of 100% while, in the control group 2 implants (2/22) were considered failures for research purposes, for a CSR of 90.5%. The difference in CSR between the test and control groups was not statistically significant ($P = .155$). Of the 2 failed implants, 1 was in mandibular right first molar position (46) in patient 7 (Table 1). It was found to be mobile and was removed at the 3-month visit. The second failure was a rescued implant in mandibular right second molar position (47) in patient 9 (Table 1). It showed a slight rotational movement at the 1-month visit and, in the absence of infection, it was possible to retighten it and achieve a new primary stability. The interim restoration was removed, and a healing abutment was placed to promote proper healing without occlusal load. At the 3-month recall visit the implant was stable, with an ISQ greater than 60 and radiographic bone loss only to the second thread, and could be utilized for the definitive restoration.

Since in both cases the 2 failed implants were supporting a 2-unit fixed partial denture, the remaining implant was left in function with a newly fabricated single-unit interim prosthesis and considered in the analysis of RBL. All patients received restorations as planned at the end of the study. Distribution of implants, implant length, and IT are reported in Table 1.

No statistical difference was observed for the implant length distribution among test and control implants ($\chi_{[4]} = 4.81$, $P = .307$) or according to implant position ($\chi_{[4]} = 2.56$, $P = .633$). Similarly, no statistical difference was observed for the distribution of IT measured in test and control implants ($\chi_{[4]} = 1.86$, $P = .762$) or according to implant position ($\chi_{[4]} = 7.33$, $P = .119$).

RBL

The RBL distribution for control and test implants is reported in Table 2. The average RBL change after 1 year of function was 1.06 mm ± 0.618 mm (range, 0.135 to 2.350 mm) for the machined group and 0.92 ± 0.649 mm (range, 0 to 2.45 mm) for the TiO group. Comparison of the 2 groups showed no statistically significant differences between machined and TiO surfaces (paired *t* test; $F = -1.26$; $P = .224$). However, in this investigation, implants with different surfaces, in the same position bilaterally, could be compared.

Table 2 RBL Change Distribution at 12 Months for Control (Machined) and Test (TiO) Implants

Δ RBL (mm)	Control implants (n = 20)	Test implants (n = 20)
≤ 0.5	1	5
>0.5–1.0	12	8
>1.0–1.5	3	3
>1.5–2.0	1	3
>2.0–2.5	3	1
> 2.5	0	0

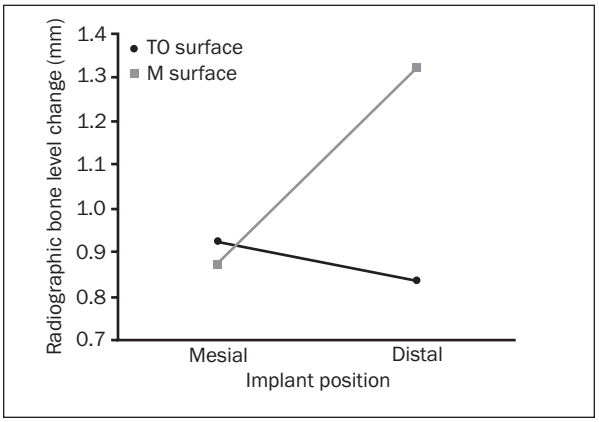
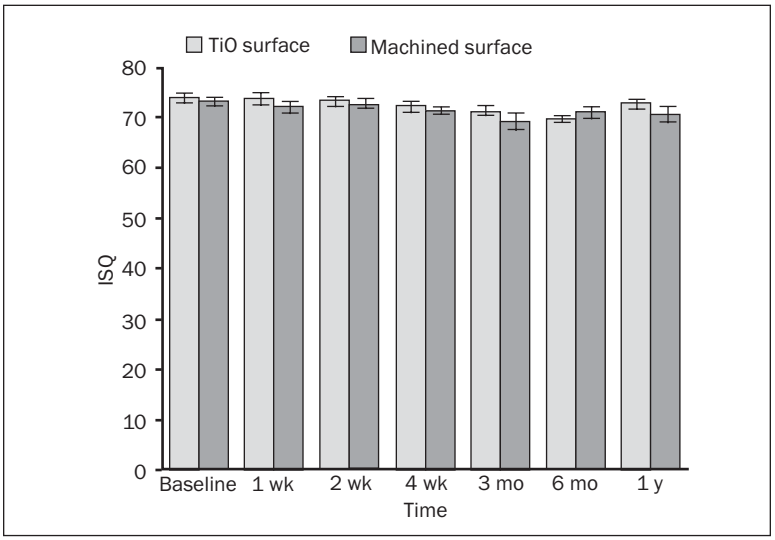


Fig 7 RBL after 1 year. Average values shown by implants categorized according to surface (machined versus TiO) and position (mesial versus distal). ANOVA 2-way interaction, $F_{[1,7]} = 6.74$; $P < .036$.

Fig 8 Mean ISQ ± SE at different time intervals for control (machined) and test (TiO) implants.



Because of the 2 failures and the exclusion of the 2 mesial implants of the 3-unit FPDs in the machined group, only 16 implants for each group could be statistically evaluated. Thus, considering implant position as a second factor besides implant surface, ANOVA for repeated measurements showed that the RBL change measured after 1 year was significantly lower (with a borderline *P* value of .0494) for the TiO than for machined surface. In the ANOVA, the analysis of the interaction between factors indicated that this tendency was attributable to the position of the implant (Fig 7). TiO implants presented a comparable average RBL change value at both mesial and distal implants (post-hoc comparison $P = .931$) and, for mesial implants, there was no difference between TiO and machined implants (post-hoc comparison $P = .986$). On the contrary, the average RBL value measured for machined implants placed in distal position was significantly higher than for TiO-surface implants placed at the same position (post-hoc comparison; $P = .048$). The power of the analysis was 46% for the effect of treatment ($P = .0494$) and 55% for interaction, respectively. The effect of IT value on RBL change was not statistically significant ($F_{[4,34]} = 1.58$; $P = .203$).

Implant Stability (RFA)

The ISQ mean value at implant placement was 73.04 ± 4.5 and 73.95 ± 3.7 for machined and TiO, respectively. The difference of ISQ average values at the same observation time is not statistically significant between machined and TiO ($F_{[1,36]} = 0.68$; $P = .414$). The ISQ values are reported in Fig 8. Considering implant position as a second factor besides implant surface, ANOVA for repeated measurements shows that the ISQ measured over a 1-year period is not influenced by the position ($F_{[1,7]} = 4.90$; $P = .063$) or

by the surface ($F_{[1,7]} = 0.19$; $P = .677$) of the implants. Similar statistical results were observed when ANOVA was carried out for the other observation periods (baseline [day 0]; 1, 2, and 4 weeks; 3 and 6 months; data not shown).

DISCUSSION

In this randomized split-mouth controlled clinical trial, MK IV dental implants with machined and TiO surfaces immediately loaded with FPDs in posterior mandibles were compared clinically and radiographically. The overall CSR of the implants was 95% 1 year after loading. The difference in CSR between the groups was not statistically significant. No implant failures were reported in TiO group. The present CSR data are in agreement with previous studies. Glauser and coworkers[44] reported a 97% CSR for immediately loaded MK IV TiO dental implants placed in the posterior region in mandible and maxilla. Among the 55 implants placed in the mandible, no failures were observed after 1 year of loading. Rocci and coworkers[45] compared machined and TiO implant surfaces under immediate loading in posterior mandible in a randomized controlled clinical trial. They reported a 10% higher CSR for the TiO implants compared to machined implants; however, different implant designs were used for the test and control groups. In the same study, the CSRs relative to the MK IV implants were 90.5% and 90% for TiO and machined surfaces, respectively.

Of the parameters that may have favored the implant success rate obtained in the present investigation, implant stability played a primary role. The implant stability at the time of placement was measured by means of RFA. All the implants placed presented an ISQ greater than 60, which is considered the threshold for immediate loading.[42] The bone quality at the implant site was quantified by the IT. IT value is a function of the pressure needed to insert the implant and is directly related to the mineralized bone density.[46] In the present report 65% (13/20) of the test implants and 72% (16/22) of control implants were inserted with an IT ≥ 50 Ncm, and no difference in IT value was found between the 2 groups. Implant insertion with high torque in such dense bone, ie, bone with such high IT values, could correspond to high pressure between the implants and the bony walls of the osteotomy site. Recent studies in dogs show that during the first 2 weeks of healing, the bone in contact with the implant, which is responsible for the primary stability, resorbs and is replaced by new vital bone. It has been speculated that the presence of a large surface of contact between the implant and the parent bone and a high magnitude of mechanical press-fit may result in bone necrosis and may jeopardize osseointegration.[47] However, in the present study, the IT value did not seem to affect RBL change. This result is in agreement with previous observations made both in animal and human studies.[48,49]

RBL change was chosen as a response variable to evaluate bone reaction to loading of the 2 implant surfaces. The extent of RBL change observed in the present work was in agreement with previous reports on immediate loading[50] and with bone remodeling data presented in the literature for 1-stage and 2-stage protocols.[51] The difference in RBL change between TiO and machined implants was not statistically significant; however, when implant position was considered, significantly greater RBL change was observed in the distal group for the machined implant compared with the TiO implant. The dissimilarity in clinical performance of machined and rough implant surfaces in the conditions of high occlusal forces and poor bone quality, which may coexist in the posterior mandible, may be explained by a different mechanism of bone healing recently described. Previous studies show direct bone deposition on rough surfaces (contact osteogenesis) versus a progressive bone formation from the host bone frontline observed on machined surfaces (distance osteogenesis).[52] The early healing process of bone over a 1-stage rough-surfaced implant (acid-etched and sand-blasted) versus a machined implant surface was recently investigated in dogs.[41] In that investigation, parallel bone fibers and lamellar bone were observed in contact with the implant as early as 1 week. Furthermore, 50% of the surface was in bone-implant contact at 2 weeks for the rough implant surface versus 20% for the machined surface. The immediate loading of an implant with machined surface may disturb the bone apposition coming from the host bone toward the implant surface. In addition, the area of the implant exposed to the most occlusal stress is the coronal area.[53] Therefore, it can be speculated that the direct bone deposition and the higher percentage of bone-implant contact observed on the rough surface compared to the machined surface might reduce the RBL change caused by immediate exposure of the implant to occlusal forces.

In the present study, all the restorations had to be unscrewed at 1, 2, and 4 weeks of healing to allow the RFA. One implant was found to have slight rotation at the 4-week follow-up examination. Since no infection or radiographic bone loss was present, the protocol for rescued implants was followed. After 1 year the same implant was in full function, with RBL at the second thread. A similar approach was reported in a

recent study on early loading of sandblasted acid-etched implants.[54] In that investigation, 3 implants were observed to have rotational movement at the time of impression making (2 or 6 weeks after placement). The rotating implants were left without load for 12 weeks. After 12 weeks, the implants were loaded; 1 year later, the amount of radiographic bone loss was not different from that of implants that did not present rotational movement.[54] Histologic evidence in animal studies shows that, immediately after placement, the implant is supported by mechanical interlocking with the bony wall of the osteotomy site.[47] During the early phase of healing, the bone in contact with the implant surface becomes necrotic and undergoes remodeling; simultaneously, newly formed bone emerges from the host bone toward the implant.[47] Between the second and fourth week of healing, the balance between newly formed bone and parent bone is critical to provide support to the implant against dislocating forces such as rotational movement. In the absence of infection, it may be possible during this period to recover lost primary stability by taking advantage of the bone formation in progress. Conversely, the presence of implant movement at a later stage (2 to 3 months after placement) is usually related to fibrous encapsulation, since the early phase of bone remodeling and formation should be completed.

Implant length is an independent variable that may influence RBL. It has been suggested that short implants may lose more bone compared to longer implants under immediate loading. In the present study, the implant length distribution was not statistically different among test and control group or according to implant positions. This may suggest that the implant length did not influence RBL change in the present study. Implant length as clinical parameter should be further investigated with a higher number of implants and a balanced distribution of implant lengths.

RFA is proposed as a noninvasive method to evaluate the boundary of the implant with the surrounding bone. At the time of placement, RFA may be used to measure primary stability. Recent investigations demonstrated that RFA value (ie, ISQ) could be correlated to the amount of cortical bone in contact with the implant on the buccal or lingual side and with the thickness of the cortical bone penetrated by the implant neck in the coronal portion.[55] After implant placement, bone remodeling and apposition on the implant surface may produce a change in the RFA values.[42] In the present investigation, the RFA value was utilized as response variable to evaluate the 2 implant surfaces during the healing process over a 1-year observation period. A reduction of ISQ was observed from the baseline value for both the test and control groups. The lowest mean ISQ value was reached at 3 months for the machined implants and 6 months for the TiO implants. A subsequent increase was observed from 3 or 6 months to 12 months. Similar results were reported by Glauser and coworkers on immediate loading of MK IV dental implants with machined surfaces over a 1-year period.[28] The same authors presented a clinical report on MK IV TiO implants immediately loaded in soft bone; in that study, a reduction of ISQ was observed at 4 weeks followed by an increase in ISQ.[56] The different sequence of events observed in the present study may be related to implant location (posterior mandible) and to the bone quality, as suggested by Balshi and colleagues.[57]

Several factors may explain the drop of the ISQ during the first 3 to 6 months. The lateral compression exerted by the tapered implant on the osteotomy walls, which allows high primary stability, may produce microfracture of the cortical bone or elastic adaptation of the trabecular bone, which may result in a decrease of the ISQ. The remodeling process of bone resorption and bone deposition that takes place during the early phase of osseointegration may reduce the stiffness of the implant-bone system. Crestal bone loss or bone dehiscence may increase the distance between the transducer device and the bone crest, reducing the ISQ.[58] Conversely, the mineralization that occurs on the cortical bone as a part of the healing reaction to surgical wounding and bone maturation around the implants explain the increase in ISQ value from the 3 or 6 months to 12 months. ISQ variation over a 1-year period, as observed in the present investigation, seems to match the timing of bone formation and maturation described by Roberts.[59] According to Roberts, in humans, the initial bone resorption and formation lasts about 4 months, and 8 more months are necessary for complete bone maturation.[59]

Since significantly greater RBL was observed on the distal machined implants, a significant reduction of ISQ was expected as well. However, no significant differences in mean ISQ value were observed ($P < .063$) when the implant position was considered. Thus, the present study did not demonstrate that the TiO implant surface was correlated with significantly greater implant stability (ie, significantly greater mean ISQ) during the early healing period compared to the machined surface, although this has been demonstrated in previous animal trials.[60]

Although all the implants in this study were placed with an ISQ value > 60, as is recommended when immediate loading is attempted,[42] 2 implant failures were observed. Similarly, Glauser and colleagues[61]

reported an implant failure rate of 11% following immediate loading of MK IV dental implants, even though an average ISQ value of 68 was achieved at the time of insertion. RFA analysis is a very interesting diagnostic tool for implant stability evaluation. However, more data based on randomized control study on its application for immediate implant loading are needed. Furthermore, although ISQ value is an important parameter, several other variables must be considered for success of immediately loaded implants, including surgical technique, bone quality, implant design, and control of occlusal forces.

CONCLUSIONS

Within the limits of the present study, it can be concluded that:

1. Immediate loading of implants using fixed partial dentures in the posterior mandible may be considered as a treatment option, provided that the implants are placed in nonaugmented bone with IT of at least 20 Ncm, ISQ of at least 60, and loaded with light centric occlusal contact.
2. Machined and TiO implants performed similarly in relation to RBL; no statistically significant differences were observed between the groups. However, when considering implant position, significantly greater RBL change was observed for machined implants in the distal position compared to TiO implants.
3. The high IT values necessary to insert the MK IV implants in this experimental setting did not seem to affect RBL change.
4. No significant differences in ISQ were observed between the test and control groups over the 1-year observation period.

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