Six-month Performance of Implants with Oxidized and Machined Surfaces Restored at 2, 4, and 6 Weeks Postimplantation in Adult Beagle Dogs

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Purpose: *The purpose of this study was to compare machined-surface implants (control) and oxidized-surface titanium screw-type implants (test) loaded with fixed partial dentures at 2, 4, and 6 weeks postplacement in terms of implant survival and stability.* ***Materials and Methods:*** *The beagle model was chosen for the study. Four mandibular premolars were extracted bilaterally from each dog. After 2 months of healing, 4 implants were placed in each dog. Half of the dogs (n = 6), the test group, received oxidized-surface implants; the other half (n = 6), the control group, received machined-surface implants. In each group, 2 dogs were randomly assigned to a 2-week preloading healing period, 2 to a 4-week period, and 2 to a 6-week period. Three implants were loaded in each dog; 1 was left unloaded as a control. Clinical stability and survival were monitored every 2 weeks for 6 months.* ***Results:*** *Failures were noted only among the implants assigned to the 2- and 4-week groups. Failures accounted for 9.4% (9/96) of the implants—12.5% (6/48) of the control implants and 6.3% (3/48) of the test implants. One hundred percent prosthesis stability was noted for the test-surface implant group. Stability of the test implants was significantly better than stability of the control implants (−2.6 vs −1.7,* P *< .05). Mean Periotest values at loading were 3.7 for the group loaded at 2 weeks, 1.6 for the group loaded at 4 weeks, and 0.6 for the group loaded at 6 weeks. Fifty percent of the 6-week group, 25% of the 4-week group, and 12.5% of the 2-week group had a Periotest value < 0 at loading.* ***Discussion:*** *The results reveal a qualitative difference in performance between the implant groups. Twice as many failures occurred in the control group, few failures occurred following loading, and no failures occurred after 4 weeks postplacement. The survival curves for both implants were flat after 4 weeks; however, the duration of follow-up may hide effects of time-dependent factors on survival and poses a concern for clinical inference.* ***Conclusions:*** *Early loading of both implant types was well tolerated, as only 2 failures occurred following loading. A subsequent report will review these outcomes along with histomorphometric data collected at 6 months to better understand the significance of tissue-level implant-surface interaction for survival and stability.* INT J ORAL MAXILLOFAC IMPLANTS 2004;19:350–356

Key words: *dental implants, early loading, surface properties*

Dental implants have been demonstrated to provide predictable prosthesis support for a broad range of conditions involving missing teeth.[1–5] Comparative studies between conventional and implant-supported prostheses, though limited, suggest implant-supported prostheses are effective at addressing the perceived functional burdens associated with tooth loss,[6] especially those most related to functional stability.[7]

Initial protocols outlining provision of implant support included a long treatment time, especially lengthy compared to conventional prosthetics, to allow for healing of the surgical wound created to accommodate the implant.[8] Such a delay in treatment was considered objectionable by some patients and clinicians, and earlier restoration of implants began to be accomplished to address this concern.[9–15] More recently, animal and clinical studies of immediate or early restoration of implants have been published outlining tissue-level[16–18] and clini-

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cal[19–22] outcomes. Many of these studies have investigated implant surface features that aim to improve wound healing responses to allow earlier functional use. Specifically textured surfaces have demonstrated improved bone anchorage, as measured structurally and mechanically, allowing earlier functional loading without compromised performance.[17]

The purpose of this animal study was to investigate whether a new textured-surface implant created through an oxidation process performed better than a standard control implant. Implants of both types were loaded earlier than conventional protocol demands (ie, at either 2, 4, or 6 weeks after implant placement) and followed for 6 months. This report provides the clinical outcomes of implant survival and stability from this study. Comparisons relative to bone levels and histomorphometric measures will be published separately.

MATERIALS AND METHODS

Surgery

The beagle was chosen as the animal model. Twelve adult beagle dogs (7 females and 5 males) were obtained following the review and approval of the research protocol by the Institutional Laboratory Animal Care and Use Committee of The Ohio State University. Four mandibular premolar teeth were extracted bilaterally from each dog, with extraction times ranging from 7 to 37 minutes. The use of a surgical drill for root tip removal was required in only 2 instances, in 2 different animals. Following 65 days of uneventful healing, the dogs were selected by a technician who was not involved in the study and brought to surgery for implant placement in random order.

Four control implants (3.75 × 10.0-mm commercially pure titanium machined-surface implants, lot no. 618614; Nobel Biocare, Göteborg, Sweden) were placed in 6 of the dogs; 4 test implants (3.75 × 10.0-mm commercially pure titanium oxidized-surface implants, lot no. 618612; Nobel Biocare) were placed in the other 6 dogs. The implants were placed bilaterally in the posterior mandible, with natural teeth anterior and posterior to the implants. All implants had a minimum of 1.0 mm of buccal and lingual bone encasing them at placement. They were monocortically stabilized (type 2 bone[23]); no countersinking was accomplished.

At the time of placement, polyvinyl siloxane caulk (Reprosil; Dentsply, Lakewood, CO) implant-level impressions were made of the terminal 3 implants to allow fabrication of gold fixed partial dentures (FPDs). Cover screws were placed on the implants and closure was accomplished to minimize excessive soft tissue at the ridge crest to facilitate location of the implants for FPD placement. The anterior implant served as an unloaded control. The dogs were then placed on a diet of hydrated food pellets and monitored for postsurgical complications. The diet was changed to nonhydrated pellets following FPD connection.

Fig 1 Gold fixed partial denture supported by 3 implants. Prostheses were fabricated using implant-level gold cylinders and connected to the implants using 3 gold abutment screws fastened using manual torque.

Loading Groups

The dogs were then divided into 3 groups of 4 dogs each; each group had 2 dogs with control implants and 2 dogs with test implants. One group was allowed a healing period of 2 weeks before loading, 1 group 4 weeks, and 1 group 6 weeks. At the designated postsurgical times, tissue punch access was accomplished to identify the implants. The cover screws were removed and a 3-unit gold FPD (Midas, Jelenko; Heraeus Kulzer, Hanau, Germany) was placed on the 3 implants to judge fit. Based on previous animal experience,[24] the prostheses were fabricated using implant-level "gold cylinder" connections to minimize screw loosening. Both visualization of an adequate retainer-implant relationship and lack of rocking were used to verify fit (Fig 1). The prostheses were then connected to the implants using 3 gold screws tightened by hand. Occlusal contact was checked with articulating paper. Where contact was absent, the opposing arch was restored with composite resin until contact was achieved. Because of tooth and jaw relationships, most occlusal contact was oblique in direction, as shown in Fig 2, and the implant-crown ratio was approximately 1:1. No attempts were made to quantitate the nature of the occlusal contact (eg, to determine the vector or magnitude of specific forces) as the desire was to simulate typical clinical

Fig 2 A representative example of fixed partial denture occlusion. The opposing tooth relationship and crown shape encouraged nonaxial loading of implants, creating a rigorous test of mechanical resistance. Occlusion was examined every 2 weeks; composite resin was used in the maxilla to restore tooth contact where necessary. Occlusal contact was thus maintained throughout the 6-month study.

Fig 3 Failed implant discovered at cover screw removal. All failed implants were retrieved from surgical wounds that did not demonstrate infection, inadequate bleeding, or related mucosal trauma (suggesting external force as the cause of the failure).

protocols for occlusal restoration and maintenance in humans.

Measurements

This report provides survival and stability outcomes. Measurement began at FPD connection and was continued at 2-week intervals through 6 months. Consequently, survival was determined at each stage following placement. Implants and prostheses were considered to have survived the study if they were in functional contact at completion of the 6-month loading period. Failures were recorded either prior to loading (FPD connection) or at any 2-week interval following connection.

Implant stability was measured using the Periotest device (NIVA, Charlotte, NC). To obtain a Periotest value (PTV), an impression coping was attached to each of the 3 implants using manual torque. Seating was verified clinically and the device was positioned to strike the impression coping at right angles at a mid-level location. An in vitro pilot trial of the technique was conducted to assure reliable repeated measures over time and within the same sitting, with specific attention to assuring reliable indirect coping measurements. Three PTVs were obtained for each of the 3 implants at each interval. Following collection of the PTVs, the same impression copings were used for the radiographic imaging to control for imaging geometry concerns. Following these measurements, the cleaned FPD was reattached to the implants using manual torque and occlusal contact was verified, and produced if needed, as previously described. This protocol required FPD removal at each 2-week interval for data collection.

Analyses

Implant survival is reported as cumulative survival over the 6-month time period. Implant survival and stability by implant group and loading time were analyzed using repeated-measures analysis of variance (ANOVA) ($\alpha = 0.05$). When more than 2 groups were compared, a Tukey-Kramer adjustment was used.

RESULTS

Survival

Over the course of the study, 9 of the total 96 implants failed (9.4%). In the control implant group, 6 of 48 implants failed (12.5%), 4 before loading and 2 after loading. In the test implant group, 3 of 48 implants failed (6.3%); none had been loaded. Of the 9 failures, only 7 were to be loaded by study design. Of these 7, only 2 were loaded (both for 2 weeks). The remaining 5 failures were discovered before FPD connection, when removal of the cover screw was attempted (Fig 3).

Failure occurred only in the animals assigned to the 2- and 4-week groups. In the 2-week group, 3 implants failed in 1 quadrant of 1 animal. Two of the 3 failures in this animal were the only loaded implant failures in the study; the third failure was an unloaded control. In the 4-week group, 3 implants failed in 1 dog, 2 in another dog, and 1 in a third dog. No failures occurred in the 6-week group. The implant survival curve was flat (overall and for both implant groups) from 4 weeks through 6 months. Because all failures occurred during the same interval, the cumulative survival rate at 6 months was

87.5% for the control implants and 95.7% for the test implants.

All 9 failures were identified at 4 weeks after implant placement. At this time data were collected for the first postloading interval for the 4 dogs assigned to the 2-week group, and the 4 dogs that were to have their FPDs placed (the 4-week group) were evaluated for the first time postsurgery. The failures identified at this time occurred either in the 2- to 4-week interval (in the 2-week group) or between placement and 4 weeks postsurgery (in the 4-week group). No failures occurred after this interval. Following this time interval, all implants at risk in each implant group survived until 6 months postloading.

All FPDs placed on test implants survived the duration of the study (100% prosthesis survival), even though 2 FPDs were supported by only 2 implants each (1 supported by the no. 1 and no. 2 implants, and 1 supported by no. 1 and no. 3 implants). No control implants were required to support an FPD with less than 3 implants.

Surgical time required for extraction varied from 7 to 30 minutes. Six of the 9 failures occurred in the 2 dogs with the longest average extraction time (27 minutes). One of these dogs required the use of a surgical drill for root tip removal. The remaining 3 failures occurred in the dog with the shortest average extraction time (12 minutes). Implant placement surgical times were consistent for all dogs.

Table 1 Mean PTVs

	PTV (SD)
Implant location	
1	–2.2 (2.1)
2	–2.2 (2.3)
3 (au what tooths sites)	–2.1 (2.4)
Side	
Left	–2.1 (2.3)
Right	–2.3 (3.2)
Loading group	
2 weeks	–2.3 (2.4)
Test	–2.4 (2.1)
Control	–2.1 (2.1)
4 weeks	–2.2 (1.9)
Test	–2.7 (1.9)
Control	–1.6 (2.1)
6 weeks	–2.1 (2.4)
Test	–2.8 (2.1)
Control	–1.4 (2.5)

Table 2 Mean PTVs for FPDs vs Isolated Implants and Orientation PTVs

	PTV (range)
FPD vs isolated implant	
FPD	–5.2
Isolated implant	–2.7
Difference	–2.5
Orientation	
Axial	–6.6 (–5 to –8)
Orthogonal	–1.6 (4 to –7)

Stability

The mean PTV at the time of loading varied as a function of time (3.7 for the 2-week group, 1.6 for the 4-week group, and 0.6 for the 6-week group). The percentage of implants that exhibited PTVs < 0 (signifying a more stable condition) at the time of loading also increased with healing times (12.5% of implants loaded 2 weeks postsurgery, 25% of the 4-week group, 50% of the 6-week group). As expected from previous studies, PTV was found to decrease significantly as time postsurgery increased.

For all age groups and times, the average PTV (standard deviation) was –2.2 (2.2), with a control group average of –1.7 (2.4) and a test group average of –2.6 (2.1). The difference between the implant group averages was statistically significant overall ($P < .05$) and within each loading group as well (Table 1).

PTVs from the last 2-week time interval (at 6 months) were similar for the 3 loading groups (–3.3, –3.0, and –2.9 for the 2-, 4-, and 6-week groups, respectively), but significantly different PTVs were seen between implant groups (–2.5 for the control group, –3.6 for the test group) ($P < .05$).

Because the FPDs were removed at each data collection session, the authors were able to investigate the influence of the mechanical connection of the FPD–implant complex on PTVs. Repeated measures from connected FPDs (2 each at anterior and posterior location) were compared to repeated measures from the individual, unconnected implant in each dog following removal of the FPD (3 readings per implant). In all but 1 dog, this simple comparison showed loaded implants to be more stable than individual, unloaded implants. Loaded implants were more stable than individual, unloaded implants by an average PTV of –2.5 (range 0.7 to –4.6).

Stability measurements as a function of loading direction were also investigated. After 16 weeks of continual implant survival, which suggested that a sufficient level of osseointegration had been achieved, the isolated implants were loaded axially and orthogonally (ie, at a 90-degree angle). During data collection, care was taken to orient the PTV device perpendicular to the floor for each loading direction to determine PTV differences. Comparison revealed that axially loaded implants were more stable than orthogonally loaded implants by an average factor of 4 (axial PTV = –6.6, range –5 to –8; orthogonal PTV = –1.6, range 4 to –7), suggesting that the benefits of screw threads may extend beyond their impact on initial stability (Table 2).

DISCUSSION

The results from this animal study on early loading of implants reveal a qualitatively different performance between standard machined-surface implants and geometrically identical test implants with an increased surface oxide. Twice as many failures occurred in the control compared to the test group (12.5% versus 6.3%), few failures occurred following loading, and no failures occurred beyond 4 weeks postplacement. However, the relative brevity of the follow-up period must be noted when considering the effect of time-dependent factors on survival and poses a concern for clinical inference.

The strength of the evidence in this report relates to several features of study design. The study is a comparison of comparably treated groups achieved through random allocation. While a split-mouth design could have been used, such a design requires uniformity of distribution of the disease or factors associated with the outcome of interest (implant failure).[25] Previous animal studies (baboons and minipigs) have shown multiple unilateral failures, causing some concern for a nonuniform confounding influence on failure. Another strength is that all procedures followed standard clinical surgical and prosthodontic protocols, other than loading times, and the measures included important clinical outcomes (survival and stability of the implants and FPDs). The use of 10.0-mm implants in the posterior mandible offered a rigorous test from a mechanical standpoint, and data collection was performed by individuals blinded to the implant type. The posterior mandibular location chosen also offered a rigorous test, as this area has reportedly demonstrated low survival rates with early loaded implants.[13]

Since the clinical focus was to determine at what point loading of implants can be predictably accomplished compared to the current protocol, the design decision was made to step back from current times for loading and approach the immediate loading time frame. This strategy allowed observation of negative outcomes as a function of reducing times from a clinically successful baseline, and as such can help identify the best time intervals to expand for future study. It has been reported that equivalency in bone turnover and healing rates for dogs are about 1.5 times those found in humans (ie, 1 month of bone activity in a dog compares with 1.5 months of bone activity in humans).[26] Consequently, it was decided to investigate healing periods that corresponded roughly to human healing periods of 9, 6, and 3 weeks. The present study showed that strategies to improve early loading performance may need to consider studying events that occur within the first 4 weeks postimplantation.

Weaknesses of the study include the lack of a clear etiology for the observed early failures, the utilization of a single anatomic location with a single prosthetic design, the concern for generalizability from animal to human, and the relative brevity of the follow-up period. A single location and prosthetic design were used because the sample size was small. The study was terminated at 6 months follow-up both for financial reasons and because previous studies have shown that with early loaded implants the majority of failures occur within 6 months of implantation.[13,27]

Related literature has attempted to delineate the comparative importance of surface features for dental implants. Although clinical performance for certain machined-surface implants has been demonstrated to be excellent,[1–4,8] this does not mean that investigation of surface-related wound healing and interface maintenance is not necessary. Theoretical arguments have been made that the nature of an implant surface can directly influence cellular response through the interaction of both immediate and delayed processes.[28,29] Reactions specific to a surface have been described to be critical in forming a selective molecular coating for binding to and interaction with target cells. The configuration of attachment may elicit a specific cell response.[26]

The role played by the chemical properties, surface oxide, and morphology of titanium implants on bone response has been investigated by numerous authors.[27,30–32] In an investigation of the influence on nonoral osseointegration by chemical properties, Sul and coworkers reported that titanium implants coated with Ca^{+} provided a faster and stronger bone response.[30] Related animal studies using intraoral models for early and immediate loading of fixed prostheses[33–35] were reviewed, but the variety of study designs employed and the heterogeneity of designs makes direct comparison with this study difficult.

Clinical application of early and immediate loading paralleled the study of this field in animal models. No previous study specifically investigated early loading of fixed mandibular prostheses as in the present study.[13,36] The observed failure times and the significance of the flat survival curves through 6 months are compelling. While implant failure is an adverse outcome at any point in time, less time and resources have been invested in an implant that fails early than in one that has been fully restored. The timing of failure is a critical outcome to consider from a practice standpoint and will increasingly be used to distinguish implant applications over the long term.[37] Such a consideration is important for therapies involving chronic conditions (in this instance tooth loss is managed as a chronic condition that requires maintenance observation) and may be critical for discriminating between implant devices that seem equivalent in the short term. In this study, the test surface was correlated with better survival. However, both implants performed well when considering the late failure criterion, as neither demonstrated failure after the 4-week time period (through 6 months).

Significantly, the implant groups differed in terms of stability throughout the duration of the study. Following the argument that surface features may be selective for molecular and cellular interactions that favor mechanical performance,[25,26] future studies should investigate whether clinically derived stability data is a more valid measure of clinical performance than other more gross outcomes (histomorphometry, bone loss, torque) that may not be easily obtained.

CONCLUSIONS

The results from this comparative, parallel-arm 6-month early-loading animal study revealed a qualitatively different performance between the standard machined-surface implant and a geometrically identical test implant with an increased surface oxide. Although twice as many failures occurred in the control group compared to the test group (12.5% versus 6.3%), few occurred following loading, and none occurred after 4 weeks postplacement. Stability measurements throughout the 6-month period continued to reveal more stability for the test surface, though no other outcomes measured can explain this finding.

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