Immediate Functional Loading of Single-Tooth TIO_2 Grit-Blasted Implant Restorations: A Controlled Prospective Study in a Porcine Model. Part I: Clinical Outcome

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ABSTRACT

Background: Although favorable integration occurs with immediately loaded implants, the relationship between implant outcome, levels of occlusion, and diet requires optimization.

Purpose: Pertubating load on single implant restorations immediately after placement by a hard food diet will increase the strains at the bone-implant interface, increasing the risk for failure.

Materials and Methods: Forty-eight implants replaced the first and third mandibular premolars in 12 pigs, allocated into two groups based on soft- and hard-diet feeding. Cylindrical and tapered implants replaced the first and third premolars, respectively. Each animal received at random four different masticatory loading conditions (group 1 [control]: implant with either a cover screw or a healing abutment, and group 2 [test]: implant with a crown either with or without occlusal contacts).

Results: Thirteen implants out of 44 failed in 11 animals (one with a cover screw, one with a healing abutment, three with nonocclusal, and eight with occlusal restorations). The failure rate of restored implants (either in occlusion or not) was significantly higher in the third premolar sites ($p = .007$), although diet had no significant effect ($p = .421$).

Conclusions: While diet had no effect on the failure pattern of immediately loaded single implants, the position and type of load under the masticatory mode were significant. Immediately loaded implants both in and out of occlusion were less successful than the controls, and this is probably attributed to detrimental strain induced on the bone-implant interface.

KEY WORDS: biomechanics, diet consistency, immediate loading, osseointegration, single dental implant

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The original two-stage delayed loading protocol[1] with dental implants has been questioned[2] as its recommendations were based on empirical data and were not scientifically proven.[3] Currently, immediate loading of four to five splinted implants placed in the interforaminal area of the completely edentulous mandible and restored with a prosthesis has been carried out with success rates of >90% in clinical studies; however, success rates with immediate occlusal loading of single implant restorations vary significantly (79 to 100%).[4] This variability is attributed to different levels of masticatory/occlusal forces, including parafunction, in relation to both implant design and bone quality.

Current knowledge on the effect of loading on the peri-implant bone indicates that strains in bone around dental implants above osteogenic levels should be

TABLE 1 Mean Force Values and SD (Newtons) Obtained for Five Individual Test Measurements on a Second Premolar and First Molar Location on a Plaster Model, when Pignuts Were Crushed in Horizontal and Vertical Directions

Test	HM	HPr	VM	VPr
1	183	124	115	100
2	152	90	89	96
3	114	112	84	54
4	89	74	97	71
5	110	97	111	50
Mean	130	99	99	74
SD	38	19	13	23

HM = horizontal molar; HPr = horizontal premolar; VM = vertical molar; VPr = vertical premolar.

avoided, as they are considered responsible for bone loss around the implant neck or complete failure of osseointegration.[5,6] Mastication involves a repeated pattern of cyclical forces that load both the implant components and the bone-implant interface, and results in craniofacial bones being exposed to rapid but periodic regimens of cyclical loading.[7] The masticatory loads have been described[8] as being brief in nature (0.23 to 0.3 second per tooth contact) and occur at a rate of 1 to 2 Hz for a total period of approximately 540 to 1,020 s/day.

Szmukler-Moncler and colleagues[2] described theoretical loading environments in the oral cavity (Table 1), based on: (1) diet (soft or hard pellet food), (2) implant situation (submerged or not, protruding or not), and (3) number of abutments (single post or multiunit restoration at the occlusal level or not). These factors were hypothesized to induce different mechanical environments at the bone-implant interface, but were not evaluated in a prospective experimental study.

Masticatory loads appear to be related not only to the location of the implant but also to food consistency.[9] Hobkirk and Brouziotou-Davas[10] evaluated masticatory force patterns of two occlusal schemes with various foods in mandibular implant-supported prostheses. The mean peak masticatory force and load rate were lowest when eating bread and highest when chewing nuts. In clinical practice, it is recommended that the patient's diet is limited only to soft food for the first month.[11] Pasta and fish are acceptable, whereas hard crust of some breads, raw vegetables, and fruits are contraindicated.[12]

Although the optimal level of occlusal stresses on the bone-implant interface for osseointegration has not yet been validated, it may be assumed that interface strains should be of a magnitude known to be osteogenic, otherwise too high levels of interface strains would preclude bone formation and would prevent implant integration.

This study investigates the hypothesis that modifying the load on single implant restorations (either in occlusion or not) immediately after placement by feeding with a diet of hard food will induce strains above osteogenic levels at the bone-implant interface, leading to higher risk for implant failure.

MATERIALS AND METHODS

Study Design

The study population comprised 12 female, dentally mature Berkshire pigs with a mean body weight of 120 (SD 20) kg. This animal model was selected to ensure adequate alveolar bone dimensions (height, volume) for dental implant placement. Pigs are omnivorous and have an appropriate masticatory function. The first and third premolars in the right and left mandibular sites were extracted from each animal. Following 3 months of healing, dental implants were placed in the healed extraction sites. Two groups, each of six pigs chosen randomly, received either hard (pignuts) or soft (pignuts of the same type softened and made into a soup-like swill) diet for a 10-week period after which the animals were euthanized (Figure 1). Following euthanasia, mandibular block specimens containing the implants were dissected from all the animals. Bone block sectioning and histomorphometrical analysis are carried out as part of a separate study. The study protocol was approved

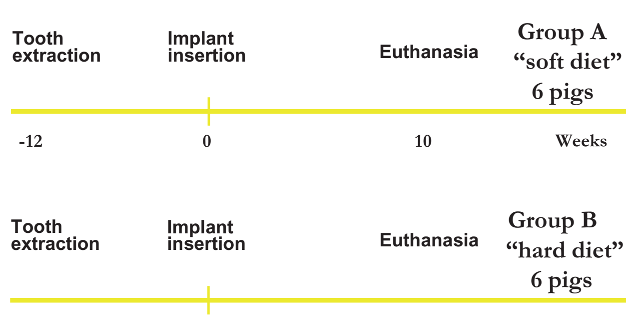


Figure 1 Study design with surgical procedures and healing times of the implants.

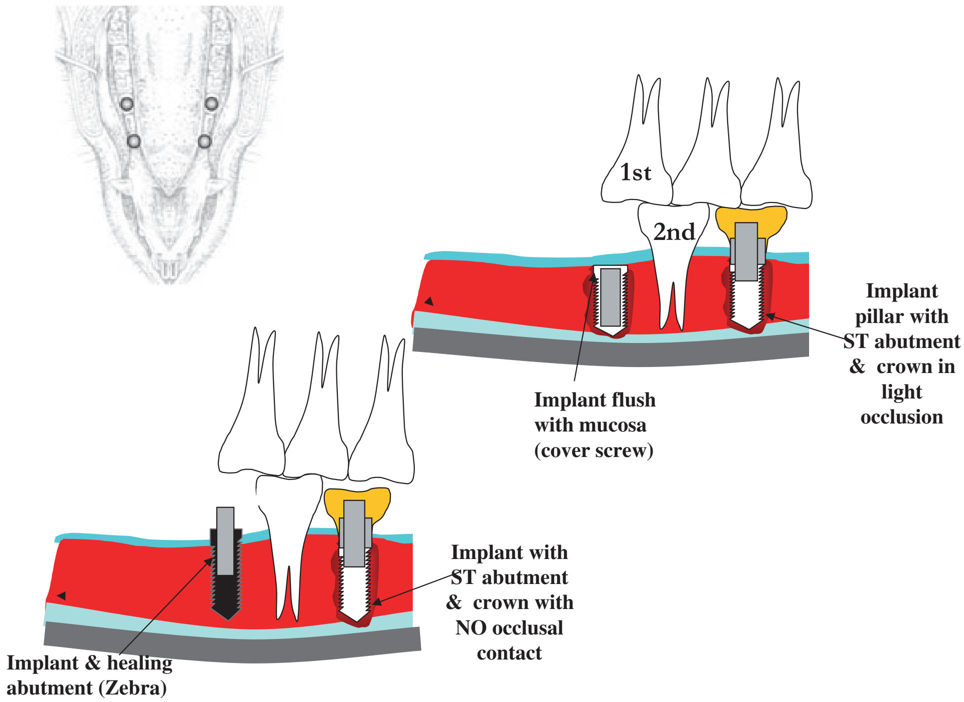


Figure 2 Implant pillars with four different loading environments under the masticatory mode.

by the Local Research Ethical Committee and UK Government regulations (Scientific Animal Procedures Act, 1986).

Mechanical Environments Obtained under the Masticatory Loading Mode

Four different locations, two anterior (rostral) left and right and two posterior (caudal) left and right, each one representing a different masticatory loading environment, were selected for implant placement in the first and third premolar sites in each pig (Figure 2). Two masticatory loading environments with restored single implants (with and without occlusal contacts) were tested, while implants with a cover screw or a healing abutment served as "unloaded" controls. Each animal served as its own control as each pig received all four loading environments, which were placed randomly in the four positions.

No Load. Implants with a long cover screw (Astra Tech AB, Mölndal, Sweden) placed flush with the mucosa. While the unloaded implant was flushed with gingival level serving as the control, the permucosal position still provided exposure to saliva and oral microorganisms as with all the implant pillars.

Nonfunctional Loading by Food Bolus without Occlusal Forces. Permucosal implants, with healing abutments (Zebra™, Astra Tech AB) extruding approximately 3 mm above the mucosa (without contact with the opposing teeth). There was some loading by the food bolus (hard) and surrounding soft tissues, because of the height of the abutment. However, its occlusal surface area is only a fraction of that of the original first premolar tooth.

Nonfunctional Loading by Food Bolus (No Occlusal Contact). Permucosal implants with the original tooth shape restored (composite veneered metal crown) but with no occlusal contact with opposing teeth. Loading by the hard food bolus and surrounding soft tissues is expected.

Functional Loading with Food Bolus and Opposing Teeth (Occlusal Contact). Permucosal implants, with the original tooth shape restored in occlusion with opposing teeth (composite veneered metal crown).

Soft and Hard Diet

Based on randomization, the animals were fed with a soft or hard diet of the same constituents (12.5%

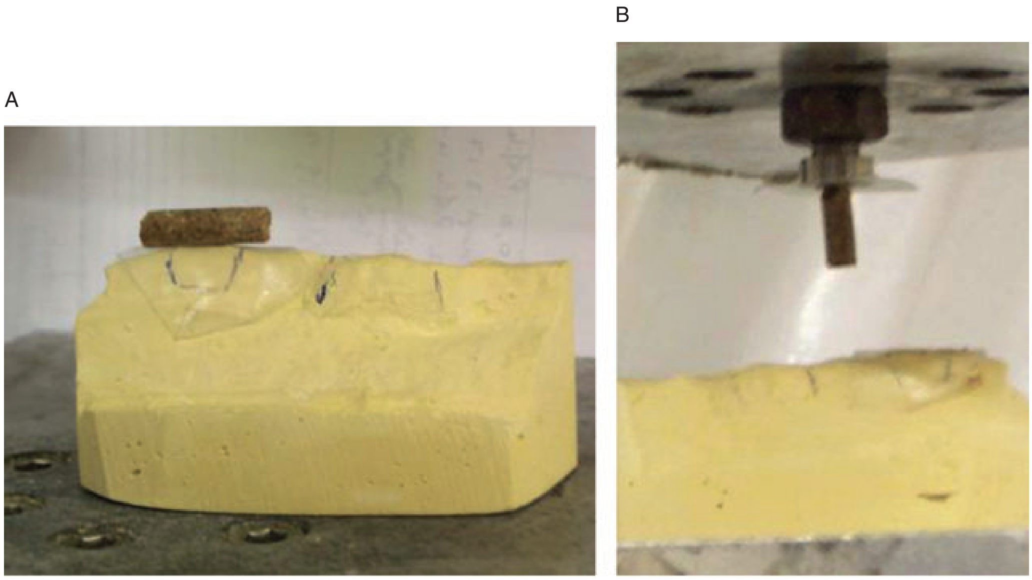


Figure 3 Testing of relative bite force generated by a pignut on the second premolar simulating crushing in (A) horizontal and (B) vertical directions.

protein, 3.5% oil, 14.5% fiber, 7.5% ash, 3,000 IUs/kg digestible energy; Charnwood Milling Company Ltd, UK). The rate of food supply was regulated to allow adequate time for natural (masticatory) stimulation of the implants. This is estimated to be 15 minutes daily, and the regimen was divided into two daily feeding courses of 6 to 7 minutes each.

Determination of Forces for Crushing Hard Food

Although mandible deformation and velocity, individual anatomic factors, and opposing dentition are completely ignored, relative bite force measurements can indicate differences within food texture (soft, hard, etc.) and dental crown surface morphology (premolar, molar).[13] A Dartec servo-hydraulic materials testing machine (Zwick Roell, Zwick Testing Machines Ltd, Herefordshire, England) was used to measure the compressive forces needed to crush pignuts (hard diet regimen). As the numbers of cusps and occlusal surface dimensions (triangular sharp in premolars, rectangular flat in molars) were expected to influence the force values, stone models were made to simulate the exact dental crown morphology.

Tests were performed for a second premolar and a first molar with cylindrical nuts (hard diet) crushed in both vertical and horizontal modes over each tooth (Figure 3). Five measurements for each of the four scenarios were made, and the relative force values were obtained. The pignut compressive test was set up at a rate of 1 mm/s to measure load.

Implant Designs and Surgical Procedures

TiO_2-blasted (CP Ti) microthread ST implants of two different designs (4.0 ST cylindrical and 4.5 ST tapered with a neck portion of 4.5 mm diameter and 3.5 mm body) were placed following the protocol described by the manufacturer (Astra Tech AB). Each animal received 2 × 9 mm 4.0 ST and 2 × 9 mm 4.5 ST implants in the first and third premolar sites in the mandible, respectively. The decision to place an implant with a wide tapered (diameter of 4.5/3.5 mm) coronal part was made on the basis of anatomical conditions (wider alveolar crest) and the larger bite forces in the third premolar sites.

Both tooth removal and implant surgery were performed under aseptic conditions and general anesthesia. Initially, prior to implant site preparation for the 4.0 ST implant, the narrow alveolar crest of the mandible in all first premolar areas was trimmed to achieve a flat crest width of 6 to 7 mm. This allowed for at least 1 mm cortical bone thickness in both the buccal and lingual sides.

The animals were sedated with Ketalar® (ketamine hydrochloride, 10 mg/kg i.m.) and azaperone (0.03 mL/kg, Stresnil®, Janssen-Cilag Ltd, Saunderton, England). Surgeries were performed under orotracheal intubation and gaseous anesthesia (isoflurane and oxygen) following induction with an intravenous injection of ketamine (10 mg/kg) and midazolam (0.1 mg/kg, Hypnovel®, Roche, Welwyn Garden City, England). Intraorally, 4.4 mL of local anesthesia (2% lidocaine with 1:80, 000 epinephrine, Xylocaine®/Adrenaline, Astra) was injected in the premolar region in each mandibular sulcus for local hemostasis and per-/postoperative analgesia.

Initially, tooth debris and calculus of the residual dentition were systematically removed, and the area was cleaned with gauze moistened in 0.2% chlorhexidine gluconate. Midcrestal incisions were used to expose the bone area, and the implant osteotomy sites were prepared under continuous external sterile saline irrigation to minimize bone damage caused by overheating. The surgical protocol followed was as described by the manufacturer (Astra Tech AB). To achieve high insertion torque, underpreparation of the implant osteotomy site was achieved during drilling.[14] After placement, the shoulder of each implant was just below the ridge of the crest and approximately 4 mm below the free gingival margin. Long cover screws, 6 mm Zebra healing abutments or specially designed "flanged" ST abutments (able to support cemented crowns) were placed on top of the implants according to the randomization sequence, and the wound was sutured (2-0 Vicryl®, Ethicon, Somerville, NJ, USA).

Insertion Torque Measurement

Implants were placed manually into the osteotomy site (approximately at 10 Ncm), and then the torque was gradually increased with a W&H implant drilling handpiece (AE 975, measures torque up to 50 Ncm).

Restorative Protocol

Prior to tooth removal, impressions (Impregum Penta™, ESPE, Seefeld, Germany) from each individual Berkshire pig were taken, and the occlusion was registered with occlusal wax bite. Stone casts were generated and used to produce surgical guides and plastic formers in the dental laboratory (UCL Eastman Dental Institute, London, England). The latter were to be used to composite veneer the metal crowns immediately after implant placement.

A specially designed "flanged" ST abutment with a wider flange of 8 mm to withstand the expected higher

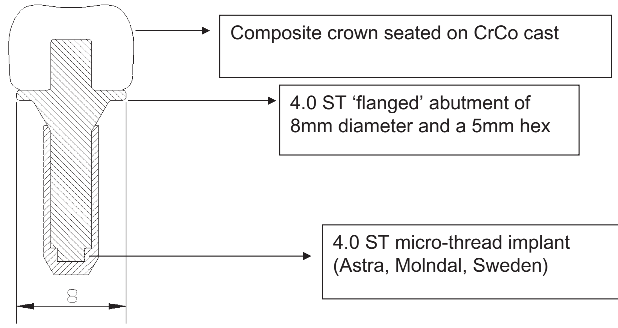


Figure 4 Design of a 4.0 ST "flanged" abutment seated on a 4.0 ST Astra Tech implant and restored with a composite veneered metal (CrCo) crown.

occlusal loads in Berkshire pigs and a hex (core) of 5 mm has been designed (Figure 4) and manufactured (Astra Tech AB) for the 4.0 ST and 4.5 ST Astra implants, respectively. The large benefit of the wider flange is that at the mucosal area, sharp edges or remnants of cement are avoided, achieving a Ti-clean area. Following implant placement, the "flanged" ST abutments were attached with a torque of 25 Ncm, in accordance with the manufacturer's recommendations (Astra Tech AB).

Thin-walled CrCo castings of small dimensions (0.5 mm), with a "spongelike" coverage that fits on top of the hexagonal central core of the flanged abutments, were fabricated in the dental laboratory (UNI-DENT, University Hospitals, Hospex, Catholic University, Leuven, Belgium). This spongelike structure facilitated mechanical retention of the composite (Tetric®, Vivoclar®). CrCo castings were then seated on the ST "flanged" abutments, and further curing (light cure unit, Davis, Claudious Ash, Potters Bar, England) of composite took place intraorally. Plastic formers, seated in the mouth on adjacent teeth, facilitated in replacing exactly the tooth crown anatomy and dimensions.

After the composite was cured, the CrCo substructures were removed, and the composite was finished and finally polished. Contact points with adjacent teeth medially and distally and properly sized interdental spaces were contoured to prevent food entrapment and to facilitate oral hygiene.

Initial checking of the occlusion (articulating paper) for the occlusal crown implant pillar took place prior to crown cementation (Figure 5). Then, the finished restoration was fitted with luting cement (composite cement, Panavia 21®), and the occlusion was evaluated again (shimstock foil 12 μm)[15] to achieve a

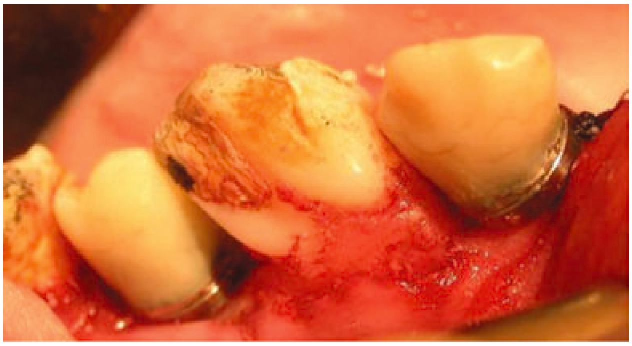


Figure 5 Occlusal first premolar and nonocclusal third premolar crowns following cementation.

light contact. Special care was taken to load implants vertically by a 1-point contact centered above the implant body and to avoid transverse loads. For the nonocclusal crown implant pillar, intraoral adjustments were performed to avoid any direct occlusal contacts.

Follow Up and Maintenance

The animals were inspected after the first few postoperative days for signs of wound dehiscence or infection and weekly thereafter to assess general health. Following implant surgery, all animals were fed a soft diet for 1 week to allow soft tissue healing, after which one group was transferred to the hard diet. Then, a systematic oral hygiene regimen was introduced for three times a week during the experimental period, consisting of tooth brushing and chlorhexidine gel 1% application (Corsodyl®, GlaxoSmithKline, Maidenhead, Ireland) to achieve mechanical and chemical plaque control, respectively.

Lost implants and damaged composite restorations were documented. Radiographic and visual assessments of the osseointegrated bone changes were made on the mandibular block specimens containing the implants after euthanasia.

Statistical Analysis

Data were presented as frequencies and percentages. Because of the relatively small numbers of animals, implants were pooled into two groups for analysis, and not in four; group 1 comprises implants with either a cover screw (flush) or a Zebra abutment, and group 2 comprises implants with either nonocclusal or occlusal crowns.

Initially, the clustering in the data (ie, the fact that each pig received the four loading environment combinations) was ignored, and univariable analyses to determine separately the effect of group, and then diet on implant failure, were performed by Fisher's tests. These were followed by a multivariable logistic regression analysis to determine the joint effect of group and diet on implant failure. Finally, a random effects logistic regression analysis was performed; this recognized the clustering of the data. An effect was considered significant if $p < .05$. Stata® version 9 (StataCorp LP, TX, USA) was used for the statistical analysis.

RESULTS

Pignut Crushing Test

The relative force values obtained are summarized (see Table 1). Measurements showed a range of forces between 80 and 140 N with higher forces applied by molar teeth when pignuts were crushed in a horizontal direction.

Clinical Findings

Eleven out of 12 animals recovered well after surgery, and no signs of infection were noted at any time during the observation period. One pig died during recovery from implant surgery. Overall, 13 implants of a total of 44 failed in the remaining 11 animals (Table 2). At euthanasia, the remaining 31 implants demonstrated healthy tissues and clinical stability. Crestal bone loss of the restored implants was evident, irrespective of the presence of occlusal contacts.

Effect of Loading Environment

Because of the relatively small numbers, nonocclusal and occlusal implants and flush and Zebra implants

TABLE 2 Functional Outcome of 44 Implants Placed in 11 Animals

		Total Implant Failures		
		4.0 ST (First Premolar)	4.5 ST (Third Premolar)	Total
Group 1	Cover screw	0/5	1/6	1/11
	Zebra abutment	0/6	1/5	1/11
Group 2	Nonocclusal	0/7	3/4	3/11
	Occlusal	1/4	7/7	8/11
Total		1/22	12/22	13/44

were combined into two groups. There was a significantly higher failure rate in the third premolar sites for implants restored with a crown (10/11 or 90%) than for implants without a crown (2/11 or 18%) (Fisher's exact test, $p = .007$; 95% confidence interval [CI] for the difference in percentages CI = 32–88%). In the third premolar sites, the failed Zebra implant was placed using a torque of 30 Ncm (in an animal within the hard diet group), while loss of osseointegration for the implant with a cover screw was caused by contact with a root of an adjacent second premolar. There was no significant difference in the failure rate between implants with and without crowns in the first premolar sites ($p > .99$).

TABLE 3 Distribution of Insertion Torque Values Related to Implant Failures

Torque (Ncm)	*n* (Implants)	%	Failed
25	1	2.3	
30	1	2.3	1 (Zebra)
32	1	2.3	
40	2	4.5	1 (occlusal)
45	3	6.8	
50	4	9.1	
>50	32	72.7	11 (7 occlusal, 3 nonocclusal, 1 flush)
Total	44	100.0	

Effect of Diet

Food hardness had no significant effect on implant failures. Overall, six implants in the soft and six in the hard diet groups failed. The failed implant with a cover screw, associated with a dental root apex, was not taken into account in this comparison as failure was not caused by loading factors. Initially, for simplicity, dependencies in the data (four implants/loading environments in each pig mandible) were ignored. Taking both premolar sites together, there was no significant effect of diet on implant failures either for group 1 (implants with a cover screw and a Zebra abutment, $p > .99$) or for group 2 (implants restored with a crown in occlusion or not, $p = .67$). The failure rates on the hard and soft diets, respectively, were 8.3 and 10% (95% CI for difference in rates = −32.8 to 26.6%) in group 1, and 41.7 and 60% (95% CI for difference in rates = −50.5 to 20.7%) in group 2.

Similarly, when logistic regression analysis was used, diet had no significant effect on implant failure (odds ratio [OR] = 1.8, 95% CI: 0.42–7.98, $p = .42$), but type of loading environment (group 1, group 2) had a significant effect on failure (OR = 10.4, 95% CI: 1.9–56.6, $p = .007$), with the odds of failure being more than 10 times greater for implants in group 2 (restored with crowns in occlusion or not).

A random effects logistic regression analysis that took the dependencies in the data (four implants/loading environments in each individual animal) into account indicated that the effect of clustering was negligible as less than 0.01 of the variation in outcome was attributable to the differences between animals. This random effects logistic regression analysis produced similar findings to the logistic regression analysis that did not account for clustering with $p = .42$ for diet and $p = .007$ for group.

Insertion Torque

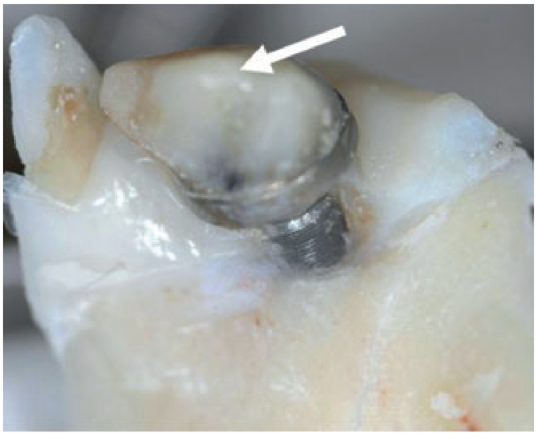
Following placement, all implants showed at a clinical level a good primary stability. A placement torque value equal or higher than 50 Ncm was achieved for 36 out of 44 of the implants (81.8%). (Table 3). However, a 50 Ncm torque value was not enough for successful osseointegration for 10 single implant restorations (seven with occlusal contacts and three without contacts failed).

DISCUSSION

Experimental models have been used to compare immediate nonocclusal loading to delayed loading[16] or immediate functional to nonfunctional implant loading[17,18] with single implants and multiunit splinted implant restorations.[14] However, no basic research has been conducted comparing the putative effect of different masticatory loading environments on implant osseointegration.

The Berkshire pig model was considered appropriate to test the effect of different masticatory loading environments on the bone-implant interface of implants at various stages during the treatment process (ie, with a cover screw, a healing abutment, an immediate nonfunctional [nonocclusal] crown, and an immediate functional [occlusal] crown). The pig is an omnivorous animal model with comparable chewing patterns to humans (higher degree of lateral excursions), in contrast to dogs that bolt their food, and a "hinge-like" chewing pattern has been reported.[18]

A



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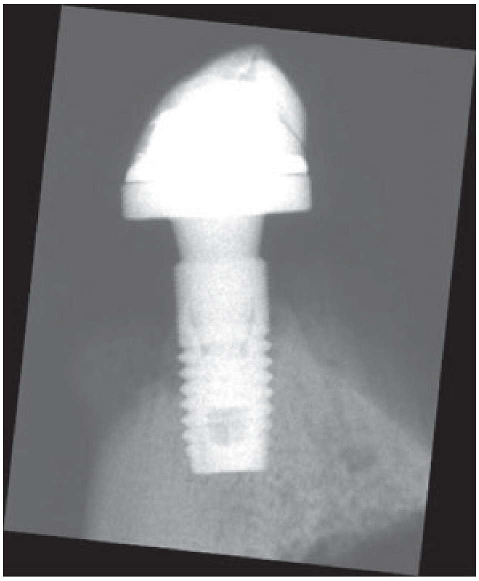

Figure 6 Bone loss around an immediately loaded 4.0 ST implant with evidence of composite wear (arrow) caused by functional loading (10 weeks after placement).

In the present study, eight occlusal and three nonocclusal implants were lost in total, although all but one was placed with a high insertion torque (>50 Ncm). Out of the eight failed occlusal implants, three demonstrated composite crown fractures, while the remaining five restored implants were not found in the oral cavity. While negligible force is applied for crushing a "soft" diet, average forces of 100 N are necessary to crush the "hard" animal food, as measured in vitro. These masticatory forces were much lower than average bite force values of 560 N, which were measured during a chewing cycle in the Berkshire pig model in the third premolar sites[19] and were considered responsible for the failure to establish a stable bone-implant interface. No effect of food hardness on implant failure pattern could be demonstrated as even numbers of implants failed in both groups of animals (six implants in soft and six in hard groups).

Previous studies in monkeys have also indicated that load over a certain threshold (premature occlusal contacts) may induce high stresses at the bone-implant interface and cause complete or partial loss of osseointegration when (osseointegrated) splinted implants were loaded from the lateral direction; however, the actual loads were not defined.[20,21] In the present study, crestal bone loss was evident around the great majority of 4.0 ST (cylindrical) and 4.5 ST (tapered) unsubmerged implants restored with a crown whether occlusal or not. This bone loss was not the result of an infectious resorption, because no exudation or inflammation was identified during clinical examinations and histology (data presented in a separate paper), thus suggesting a biomechanical etiology. The angular craterlike geometry of the alveolar defects (Figure 6) is similar to that reported in animal studies with excessive nonaxial loads around osseointegrated implants: (1) in the monkey[20,21] and dog[22] mandible and (2) in rabbit tibiae following controlled load application.[5,23]

A critical height of premature occlusal contacts on implant prostheses for crestal bone loss was demonstrated with osseointegrated implant restorations of different heights of hyperocclusions of 100, 180, and 250 μm in monkeys.[24] Interestingly, after 4 weeks of loading (occlusal force of 300 N approximately), bone loss was observed in the 180 and 250 μm group, but not in the 100 μm group. In the present study, two of the occlusal implants in the first premolar sites had signs of composite wear, and osseointegration remained at the apical part only (see Figure 6). Moreover, intentional occlusal overload, as reported in monkeys,[20,21,24] would introduce even higher forces. However, a narrow diameter cylindrical implant had been used in one of the aforementioned studies, which might have increased the susceptibility to higher crestal strains because of bending and lateral loads.

Meyer and colleagues[17] used single implants (10 mm conical screw type with a neck of diameter 4.1 mm, restored and functionally loaded immediately) to replace the second premolars in 35-kg mini-pigs, and showed high success with immediate occlusal loading (1-point light occlusal contacts, occlusion adjusted with a foil, no further details) 14 days after implant placement. Only one implant of a total of 32 (16 occlusal and 16 nonocclusal implants) had completely lost osseointegration within that short time frame in that study. It was suggested that masticatory loads had a positive effect by achieving osseointegration more rapidly. Interestingly, the average time for the occlusal implants becoming loose in the present study was 21 days (range 9th–60th) following placement and immediate restoration with occlusal contacts. It has been speculated that the bone-implant interface becomes weaker because of remodeling initially after placement/loading so constant exposure to high masticatory loads could result in loss of osseointegration eventually during that period.

Higher masticatory forces are to be expected with the Berkshire pig model as it has bigger jaw and musculature dimensions. The average bite force values within 200 to 560 N were measured in the premolar area,[19] and this might explain the high loss of the occlusal implants, predominantly in the third premolar area.

All seven nonocclusal implants survived in the first premolar areas with various degrees of crestal bone resorption irrespectively of feeding type. However, three of these seven nonocclusal crowns had notable wear of their composite surface, suggesting considerable load application. This unexpected finding was attributed to the flat shape of the palatal vault of the Berkshire pig maxilla and the presence of a hypertrophic keratinized epithelium (rugae), which was the cause of a cyclical (during chewing) load application obviously in a non-axial direction.

Overall, twelve 9-mm tapered 4.5 ST implants were lost in the third premolar sites, and only one cylindrical 4.0 ST implant in a first premolar site. Although clinical studies[25,26] have shown favorable results for single, relatively long (11–15 mm) tapered implants (4.5 ST microthread, Astra Tech AB), an implant length of 9 mm is probably less appropriate to withstand high biting forces (average 560 N measured in the third premolars) in this animal model, especially with a compromised crown/implant ratio (>1) present with occlusal and possibly with nonocclusal crowns in the third premolar sites. In the present study, a highly significant association was found between failure rates of tapered 9-mm 4.5 ST implants (both occlusal and nonocclusal) in the third premolar sites (p = .007). These findings are in agreement with the findings from a photoelastic study,[27] which indicated that "the conical nature/design of the microthread Astra Tech implant does not seem to have any influence on stress magnitudes in peri-implant bone stimulant."

To overcome high stresses at the bone-implant interface with immediate functional loading, changes in implant design to achieve a homogenous spreading of reduced stresses could be considered. Alternatively, in vivo experiments with short application of periods of controlled direct mechanical loading regimes to stimulate osteogenesis[28] could be used to influence early osseointegration of implants in the jawbones.

The influence of the time required for functional adaptation of bone was hypothesized to be a more important parameter on bone reactions than the very nature (macro design, implant-abutment interface, titanium surface roughness) of the implant itself. Enhancement of early osseointegration by terms of specific mechanical stimulation could initially be achieved with immediately restored implants with no occlusal contacts. Application of specific controlled mechanical loads of short duration[23,29] can induce osteogenic strains and bone formation and accelerate the healing time.

In the context of this animal study, clinical findings do not favorably support immediate loading of 9-mm 4.5 ST single implants in the third premolar site under such high masticatory loads. Moreover, a clear effect of the bite force stimulus on the enhancement of osseointegration with immediately loaded implants was not defined. However, physiological bite forces are more significant than the forces associated with diet, within limits of the model, in determining the loads applied to single implants and the effect on osseointegration. Future studies should aim to correlate the bone-implant interface changes to specifically induced mechanical loading regimes.

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