A Randomized Controlled Clinical Trial Comparing the Effects of Three Loading Protocols on Dental Implant Stability

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Purpose: *The primary goal of this stratified randomized controlled trial (SRCT) was to compare the stability of dental implants placed under three different loading regimens during the first 16 weeks of healing following implant placement. Implants were loaded immediately, early (6 weeks), or with conventional/delayed timing (12 weeks). Secondary outcomes were to compare marginal bone adaptation for 3 years after placement.* ***Materials and Methods:*** *Single posterior implant sites in the maxilla or mandible were examined. The insertion torque value was the primary determinant of load assignment. Resonance frequency analysis was performed at follow-up appointments for the first 16 weeks (with results provided as implant stability quotients [ISQs]). Marginal bone levels were assessed via radiographs.* ***Results:*** *Forty patients each received a single 4.0-mm-diameter dental implant between 2004 and 2007. One implant failure occurred in Lekholm and Zarb type 4 bone with insertion torque value (ITV) of < 8.1 Ncm; the cumulative success rate was 97.5%. All implants, when classified by bone and loading type, increased in stability over time, with a minor reduction of 1.3 ISQ units seen at 4 weeks in the immediate loading group. The mean marginal bone loss over 3 years was 0.22 mm. The mean ITVs at implant placement for bone types 1 and 2 (grouped together), 3, and 4 were 32, 17, and 10, respectively, and were significantly different (*P < .05*).* ***Conclusions:*** *ITV was a good objective measure of bone type. Using an ITV of 20 Ncm as the determinant for immediate loading and an ITV of 10 Ncm or greater as the determinant for early loading provided long-term success for this implant and led to no negative changes in tissue response. All bone type groups and loading groups showed no reduction in stability during the first 4 months of healing.* Int J Oral Maxillofac Implants 2012;27:945–956.

Key words: *dental implants, immediate loading, implant stability, randomized controlled clinical trial, resonance frequency analysis, single-tooth replacement*

The indications for osseointegrated implants in dentistry have increased from the early investigations of Brånemark et al, which initially used titanium implants for the anterior region of the edentulous mandible,[1] then moved to placement in the maxillary arch, in posterior sites, and in the esthetic zone. In addition to increased applications for endosseous implants, there has been an interest in accelerated loading protocols. Empirically, a stress-free healing period of 3 to 6 months was initially proposed by Brånemark et al.[1] An examination of this historical research leads to an understanding that the delayed-loading protocol was an indication extrapolated from animal studies but never experimentally derived.[2]

The concept of immediate loading is not new to implant dentistry.[3–6] The research has been fueled by the knowledge of the functional and esthetic pitfalls that patients experience with many provisional removable prostheses. Early reports on immediate loading focused on implants in the parasymphyseal mandible to support cross-arch fixed complete dentures.[7,8] These results are similar to those reported for conventionally loaded implants[9] and appear to indicate that mandibular anterior implants have the potential to provide adequate support and stability for immediate loading.[10] The concept of immediate loading has been applied to other jawbone regions[5,8,11,12] and for both splinted and single-implant scenarios in the esthetic zone.[6,13,14] A recent Cochrane review analyzed 22 randomized clinical trials (RCTs) evaluating the efficacy of load timing of dental implants in multiple sites in

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edentulous and partially edentulous patients.[15] Twelve trials compared immediate with conventional loading, three trials compared early with conventional loading, and six trials compared immediate and early loading. The authors found that there were no statistically significant differences in prosthesis success, implant success, and marginal bone levels when different loading regimens were applied. However, the authors stated that it was difficult to draw conclusions because of the small number of trials, low patient numbers, and short follow-up periods (4 months to 1 year). To date, there are no RCTs comparing immediate loading to early and delayed loading for the single dental implant. With a goal to expedite treatment without decreasing success rates compared to conventional loading protocols for the single implant, studies are required to evaluate the long-term predictability of outcomes.

Biomechanically, the most challenging application of immediate loading is the single posterior dental implant. However, the number of studies of this indication are small because of the restrictive selection criteria regarding implant length, bone quantity, and insertion torque.[16–19] However, developing an immediate loading protocol for the single posterior implant would be useful, as this is the most common indication for implant dentistry today.

It is believed that the most important determinant of success with immediate loading is primary implant stability.[20–22] Without adequate primary implant stability, successful secondary stability caused by bone regeneration and remodeling cannot occur, which would lead to failure of osseointegration. It is therefore of utmost importance to be able to quantify implant stability upon placement and subsequent time points during the early healing period.

STABILITY MEASUREMENT OF IMPLANTS

Two well-recognized quantitative methods of assessing primary implant stability are insertion torque value (ITV) and resonance frequency analysis (RFA). RFA offers a clinical, noninvasive measure of implant and bone stiffness and is presumed to be an indirect measure of osseointegration.[23,24] Meredith and coworkers reported on the use of a transducer that comprised two piezoceramic elements tightened to an implant body or abutment with a screw. One of the piezoceramic elements vibrates and the other serves as the receptor of the signal. The resonance peaks from the received signal indicate the first flexural (bending) resonance frequency of the measured object.[24] Osstell (Integration Diagnostics) has combined the transducer, computerized analysis, and the excitation source into a single device. The unit of measure created for this device is the implant stability quotient (ISQ), an algorithm-derived assessment of the damping of the harmonic frequency relative to the type of implant or abutment to which it is connected. ISQ units range from 1 to 100 and are derived from the stiffness (N/μm) of the transducer/implant/bone system and the calibration parameters of the transducer. An increased ISQ value indicates an increased stiffness of the implant and surrounding bone. This device can provide prospective monitoring and shows fluctuations in stiffness of the implant interface as bone matures from primary to secondary contact. The second-generation device, the Osstell Mentor (Integration Diagnostics) substitutes the use of the L-shaped transducer for a wireless receptor called a SmartPeg, which is excited by a set of "pulse trains" from a contact-free probe.[25]

Clinically, RFA values vary based on three elements: the stiffness of an implant as a function of the geometry and material composition; the stiffness of the implant-tissue interface, which is dependent on the bone-to-implant contact area and the height of the implant above the bone; and finally the stiffness of the surrounding tissue, which is determined by the nonuniform ratio of cortical and cancellous bone and the inherent bone density.[26,27]

Another measure of primary implant stability is cutting resistance. This was originally developed by Johansson and Strid[28] and later improved by Friberg et al.[29] It was observed that the energy required by an electric motor to cut bone during implant surgery correlates to a degree with bone density and influences implant stability.[29] ITV is a numeric value given to the peak insertion torque reached by the surgical motor during the final stage of implant placement into the prepared site. ITV is a more objective, quantifiable assessment of bone density than the clinician-dependent evaluation of bone quality based on the Lekholm and Zarb classification.[30] The use of ITV to determine optimal healing periods prior to implant loading has been discussed.[31]

Although ISQ and ITV both provide quantifiable measures of implant stability, they assess different aspects of stability. ISQ measures the axial stability of the implant, and ITV measures rotational stability. Both assessments together provide the clinician with a better understanding of primary stability.

The aim of this stratified randomized controlled trial (SRCT) was to compare the stability of dental implants placed in healed ridges in areas of bounded edentulous spaces using one of three loading regimens during the first 16 weeks following implant placement. A second aim is to assess the changes in bone crestal height over the first 3 years in each loading category. Therefore the purpose of this SRCT was to compare the radiographic and tissue health outcomes of single-tooth implants

Table 1 Study Inclusion and Exclusion Criteria

Inclusion criteria	Exclusion criteria
Age 18 years or older	Smoking cigarettes or chewing tobacco within the past year, or a history of alcoholism or drug abuse within the past 5 years
Ability to understand and sign the informed consent document prior to starting the study	Severe bruxing or clenching habits
Ability and willingness to comply with all study requirements	Untreated periodontitis; presence of residual roots at the implant site; presence of local inflammation or mucosal diseases such as lichen planus; absence of more than one tooth on the left or right sides of the arch
Adequate oral hygiene (defined as an average Modified Sulcus Bleeding Index of 1 or less and an average Modified Plaque Index of 1 or less)	History of bone augmentation at the implant site in the past 6 months; history of major joint replacement requiring antibiotic coverage prior to dental treatment
Adequate bone volume to accommodate the planned endosseous dental implants (eg, sufficient height such that the implant would not encroach on vital structures such as the inferior alveolar nerve and sufficient width such that the implant could be placed within the confines of the existing bone without dehiscence or fenestration that would require significant grafting at the time of implant placement)	Placement of implant in an extraction site that had been healing for less than 8 weeks
Existing healthy and/or adequately restored teeth, and the desire for a fixed restoration supported by implants	A need for submersion of implants for esthetic reasons
A tooth-bound space for the implant in any maxillary or mandibular posterior sextant between 6 and 11 mm in mesiodistal width to accommodate a 4.0-mm-diameter implant	Requirement for grafting of bone or soft tissue at the time of implant placement which would require submersion of the implant during the healing period
If of childbearing potential, a negative pregnancy test within 1 week prior to surgery	Patients at undue risk for an outpatient surgical procedure; ASA 3
	Requirement for subacute bacterial endocarditis prophylaxis prior to treatment
	Current hematologic disorder or anticoagulant therapy; metabolic bone disorders including osteoporosis; uncontrolled or insulin-dependent diabetes mellitus; immunocompromise, such as positive HIV status; rheumatoid arthritis, systemic lupus erythematosus, or other collagen vascular disorders; herpes virus
	History of leukocyte dysfunction and deficiencies, renal failure, liver disease, or radiation treatment to the head or neck
	Current steroid treatment (any person who within the last 2 years had received for 2 weeks a dose equivalent to 20 mg hydrocortisone) or chemotherapy
	Physical disabilities that would have interfered with patient's ability to exercise good oral hygiene on a regular basis
	Use of any investigational drug or device within the 30-day period immediately prior to implant surgery

placed and loaded with one of three healing periods with a randomization criteria based on ITV.

MATERIALS AND METHODS

Patient Selection

This clinical trial was designed as a prospective, stratified, randomized study. The study received local institutional review board approval and the informed consent of all subjects. At the initial screening appointment, the subject's medical and dental history was reviewed, and defined inclusion/exclusion criteria were applied (Table 1). Only nonsmoking patients requiring one dental implant (4.0 mm in diameter, OsseoSpeed, Astra Tech) in the posterior maxilla or mandible were accepted (Fig 1). All sites had natural or restored teeth mesial and distal to the planned site of interest (bounded edentulous space). All patients had a restored stable occlusion (ie, with canine or mutually protected disclusion). Implants were 11 or 13 mm long. Clinical and radiographic examinations were used to limit the study

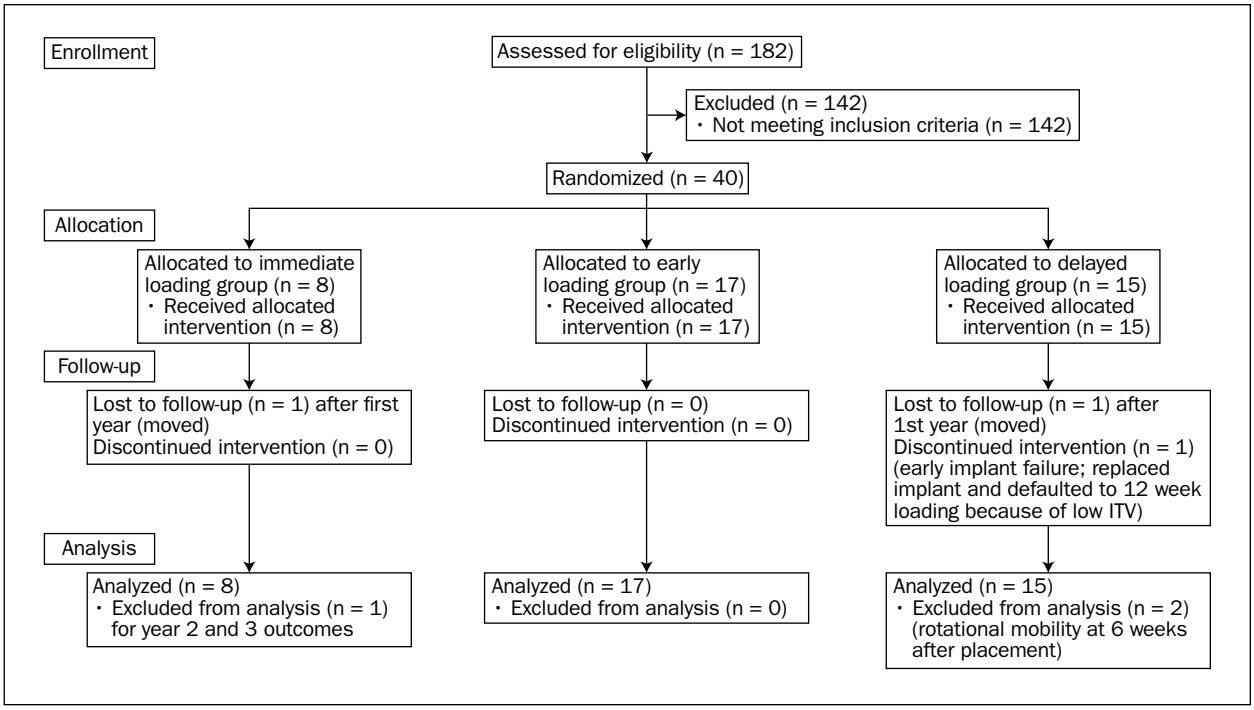

Fig 1 CONSORT 2010 clinical trial flow diagram.

to patients with sufficient bone quantity to completely encase the implant. This means there was sufficient bone height such that the implant would not encroach on vital structures such as the inferior alveolar nerve or the sinus floor. Sufficient width would exist so that the implant could be placed within the confines of the existing bone without dehiscence or fenestrations requiring significant grafting at time of implant placement. Typically, the space dimensions were: 6 mm or greater ridge width buccolingually and at least 6 mm but less than 10 mm of ridge width mesiodistally. If the implant could be placed with only a few screw threads exposed, grafting was allowed to cover these threads (freeze-dried bone allograft, Lifenet). In the occlusogingival dimension, there had to be at least 7 mm of space from the planned head of the implant to the occlusal plane. Patients selected based on these criteria were assigned a random numeric identifier to aid in the blinded assignment of loading group.

Treatment Groups

The loading groups were immediate, early (6 weeks), and conventional/delayed (12 weeks). Immediate loading was defined as provisionalization on the same day as implant placement, and early and conventional loading were defined as provisionalization at 6 or 12 weeks postplacement, respectively. Because of the risk of failure involved in immediate loading of implants with poor primary stability, a stratified RCT was designed with ITV as the primary determinant for allocation to loading group. If the ITV was less than 10 Ncm, the implant defaulted to the conventional loading (12-week) group.

Assignment and Randomization

Since assignment and randomization were stratified by the ITV measured at implant placement, two randomization lists were generated by the biostatistician: one for ITV ≥ 20 Ncm (group A) and one for ITV < 20 but ≥ 10 Ncm (group B). Subjects were assigned to a loading group in a sequential manner from the appropriate list. For group A (≥ 20 Ncm ITV), for which all three loading groups were possible, loading group allocation was randomly assigned using alternating permuted blocks of size 6 or 9 to mask any pattern. For group B (10 to < 20 Ncm ITV), allocation to either the 6-week or the 12-week loading group was performed using alternating permuted blocks of size 4 or 8. In each instance, a randomization list twice the size anticipated to be needed was prepared to accommodate unexpected variability in the distribution of ITVs. No randomization list was needed for group C (0 to < 10 Ncm ITV), since all implants default to the delayed loading group. If an implant was rotationally mobile at the time of placement, it was left undisturbed for 6 weeks, and the patient defaulted into the 12-week loading group.

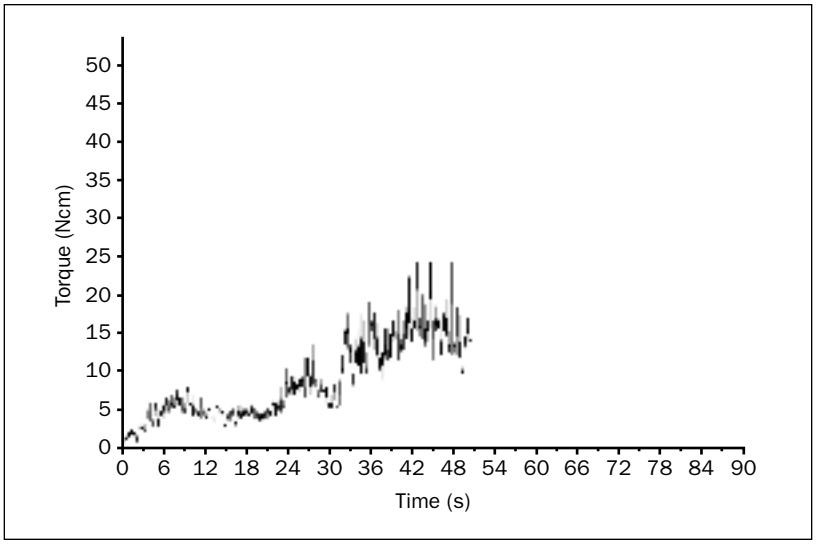

Fig 2 Graphic representation of ITVs at the time of implant insertion.

Implant Placement

All implants were placed by one periodontist after local anesthesia was achieved. The surgical field was prepared by having the patient rinse with 0.12% chlorhexidine and performance of appropriate surgical draping. A surgical guide fabricated with heat-processed resin indexed to the adjacent teeth was placed, and, using the guide hole in this prosthesis, the surgeon perforated the crestal bone at the desired implant position. The osteotomy for each site was then prepared in the following manner: the guide drill was used at 1,500 rpm with copious irrigation to perforate the cortex, followed by use of the 2.0-mm twist drill in accordance with the osteotomy position and angulation prescribed by the surgical denture. At all times, drilling was performed with copious irrigation and a constant "pumping" action. Following completed apical preparation with the 2.0-mm twist drill, the implant site was widened with a 2.5-mm twist drill, a 3.2-mm twist drill (1,500 rpm), and finally the 3.7-mm twist drill (1,500 rpm). No underdimensioned drilling (eg, omission of the 3.7-mm drill) was used to artificially alter the ITV or bone type assessment. Prophylactic antibiotic treatment was given. Patients received a 7- to 10-day postoperative antibiotic regimen based on amoxicillin (500 mg three times daily for 7 days) or clindamycin (150 mg four times daily for 7 days) for amoxicillin-allergic patients.

Bone quality was categorized as type 1, 2, 3, or 4 at time of surgery following the anatomic criteria proposed by Lekholm and Zarb.[30] This determination was obtained prior to insertion of the implant into the prepared site and was based upon the drilling resistance to site preparation during implant placement and radiographic assessment.

Torque delivery by the surgical motor (ElcoMed SA-200C, W&H) was calibrated to ensure accuracy of the ITV measured. The ElcoMed motor was calibrated to a maximum output of 45 Ncm. The torque characteristics were saved on a documentation card as a linear graph showing torque value (in Ncm) over insertion time (Fig 2), which was then downloaded onto a dedicated computer and for loading group assignment.

All implants in the 6- or 12-week loading groups received healing abutments (Zebra, 3.0 reference no. 22328 or 4.5 reference no. 22320), which were hand-torqued into position. Interrupted sutures were placed with a monofilament thread and were removed after 2 weeks.

Provisionalization

Provisional crowns were placed on the implant according to the assignment based on the stratified randomization protocol. A screw-retained implant-level provisional was fabricated indirectly using an implant-level titanium cylinder (temporary abutment

4.0 coping, reference no. 22967, Astra Tech), an abutment screw (reference no. 24132 Ti-Alloy, Astra Tech), and cold-curing acrylic resin (Jet Acrylic, Lang Dental). The abutments were hand-tightened with finger pressure to approximately 10 to 15 Ncm. Off-axis loading was minimized by narrowing the occlusal table and restricting occlusion to a single central contact in maximum intercuspation, which would allow dragging of a 10-μm shim stock with no excursive contacts. Patients were instructed to chew predominantly on the opposite side and to avoid hard foods.

Clinical and Radiographic Evaluations

Examinations were performed on the day of insertion, every 2 weeks for the first 16 weeks after implant placement, and at 1, 2, and 3 years. Implant stability was measured at the implant level with the RFA device (Osstell, Integration Diagnostics) at each visit by the first author up to 16 weeks. The transducer (SmartPeg Type 6, reference no. 100378, Integration Diagnostics) was calibrated prior to each use using an OsseoSpeed implant embedded in epoxy resin (Buehler) with a known ISQ. The healing abutment or provisional crown was removed and the SmartPeg placed via hand tightening 2 to 4 Ncm onto the implant. RFA measurements were made twice parallel to the implant and twice perpendicular to the implant in the arch owing to slight differences noted in a previous study caused by the differing densities of the buccolingual plate of bone and the interradicular bone.[32] Previous recordings on the implant were not accessed prior to RFA measurement to reduce observer bias.

At each appointment, the implants were manually tested for stability. The peri-implant marginal tissues were evaluated using the Mombelli Index and the Apse score for inflammation levels, and the probing depth was measured in the mesiodistal and buccolingual directions.[33] The patient was asked about relative pain levels and, following placement of the provisional, the patient's esthetic and functional satisfaction was determined. Any implants that presented with pain, peri-implant radiolucency, or clinical mobility were considered failures. If at any of the aforementioned visits, the ISQ fell to 45 or lower, the implant was considered a potential failure and placed under unloaded healing for the 12 weeks prior to repeat stability testing.

Radiographic Analysis

Crestal bone height was assessed radiographically at baseline (implant placement), at 16 weeks, and at 1, 2, and 3 years postloading using standard periapical films and the long-cone paralleling technique. A Rinn posterior bite block (XCP, Dentsply) was indexed to the adjacent teeth and the opposing teeth with vinyl polysiloxane (Regisil, Caulk). Each patient had their own indexed Rinn holder to ensure that the angulation of the cone was the same for all radiographs. An independent radiologist masked to subject information determined the distance from the mesial and distal crestal bone peaks to the outer aspect of the implant bevel to the nearest 0.1 mm. The changes in crestal bone height from baseline to 3 years were calculated.

Definitive Crown Procedures

All implants were restored permanently following the 16-week healing period with a cement-retained all-ceramic crown (Lava, 3M ESPE) supported by either a titanium abutment (Ti Design 4.0, Astra Tech) or a prefabricated zirconium abutment (ZirDesign 4.0, Astra Tech). If the implant was in a molar location, a titanium abutment was used. If the implant was in a premolar location, either the titanium abutment or the zirconium abutment was used, depending on implant angulation and the availability of adequate thickness for the zirconium abutment. An open-tray impression coping was used (Fixture Pick-up ST, Short, reference no. 22847, Astra Tech) with polyvinyl siloxane impression material (Aquasil, Dentsply). All of the restorations were luted with the same cement (Relyx Unicem, 3M ESPE).

Power Analysis and Sample Size Calculation

Estimated samples sizes were based upon an estimated within-treatment-group standard deviation of 5.0 for the primary outcome variable—resonance frequency—measured using ISQ, two-sided hypothesis testing, and an overall level of type I error of .05 in conjunction with a Bonferroni adjustment for three pairwise multiple comparisons of the loading groups. The number of subjects needed to obtain 80% power to detect a difference of 6 ISQ between two subgroups is 80. The present study represents the 40 subjects treated at one of two centers. The remaining 40 are being evaluated at another center, but because of changes in the implant design, abutment connection, and drilling protocols during the course of the study, the comparison group was not included in this analysis.

Statistical Analysis

Descriptive statistics were used to determine the distribution of implants according to bone type, ITV, gender, and location. Mean ISQs and standard deviations were calculated at all time points for the implants according to bone type and load type. The null hypothesis is that the change in stability from baseline to 16 weeks is equal between each pair of groups. A nonparametric statistical approach was applied, since the distribution of the data was unknown and could not be assumed to be normal. A *P* value less than 5%, calculated by means of the Wilcoxon rank sum test (exact), was defined as statistically significant and suggested a difference between groups, although adjustments for multiple comparisons

were not made. Baseline ISQ and ITV were compared for all implants, and correlation coefficients were assessed using the Spearman rank test. Implants grouped according to bone type were compared with respect to mean ITV using the Wilcoxon rank sum test, and a *P* value of .05 denoted a significant difference (StatXact, version 6.2.0).

RESULTS

The study population consisted of 40 patients between the ages of 20 and 82 years (15 men and 25 women). Patients were recruited, treated, and followed from October 2004, with active care completed in September 2007 and recall exams through May 2010. No patients dropped out in the first year. However, two patients dropped out at the 2-year evaluation. Therefore, 38 of the original 40 participants completed the 3-year follow-up.

Implant Survival

Of the 40 implants placed, one implant was lost in type 4 bone (ITV < 8.1 Ncm) in the delayed loading group; the implant was removed at week 10 because of clinical mobility and an ISQ of 45. The site was bone grafted and a new implant was placed and integrated successfully. Two implants were rotationally mobile at insertion with an ITV < 10 Ncm; they were allocated to the delayed loading group, were not evaluated for the first 6 weeks, and integrated over time. This gave a cumulative survival rate over the 3-year period of 97.5%.

Implant Site Characteristics

The characteristics of the implants and their surgical sites are presented in Table 2. Only one implant was placed in type 1 bone, and 12 implants were placed in type 2 bone, as rated by the surgeon at the time of the osteotomy. The majority of implants (19) were placed in type 3 bone, and 8 implants were placed in type 4 bone. Because of the low number of patients with type 1 bone, for statistical analysis, implants placed in sites with bone types 1 and 2 were combined into one group (type 1/2 bone). Because the randomization protocol was defined by ITV, two implants in type 3 bone were successfully placed under immediate loading, and five implants in type 4 bone were loaded at 6 weeks without negative consequence.

Implant Stability (ISQ) According to Bone Type

An analysis of stability patterns of the implants in each bone type group using descriptive statistics revealed that the type 4 bone group had a significantly lower mean initial stability (ISQ = 58 ± 5.5) than the other bone groups (type 1/2 = 72 ± 3.1, type 3 = 70 ± 4.2).

Table 2 Implant Characteristics and Sites

	Loading group			
	Immediate	Early	Delayed	Totals
ITV				
0 to < 10 Ncm	–	–	7	7
10 to < 20 Ncm	–	11	2	13
20+ Ncm	8	6	6	20
Implant length				
11 mm	2	11	11	24
13 mm	6	7	3	16
Location				
Maxilla	1	10	4	15
Mandible	7	8	10	25
Molar	3	8	8	19
Premolar	5	10	6	21
Bone quality				
Type 1	1	–	–	1
Type 2	5	3	4	12
Type 3	2	9	8	19
Type 4	–	5	3	8

There was no difference in initial stability between bone types 1, 2, and 3 (*P* = .14) (Fig 3). By week 2, only implants in types 1 or 2 bone showed significantly higher stability than those in the type 4 bone group. Similar results were observed at week 4. At weeks 6 and 8, there was no statistically significant difference in stability between all bone groups. From week 10 until week 14, the ISQ for all bone groups remained higher than 75. All bone type groups showed a progressive increase in stability over the entire 16-week period.

Implant Stability (ISQ) According to Load Type

The mean ISQ values for the immediate, delayed, and conventional loading groups are shown in Fig 4. All the implants, when controlled for loading group, demonstrated increasing levels of implant stability at each time point measured in the initial 16-week period. When loading groups were compared at each time point during the 16-week period, no statistically significant difference in stability was observed (*P* > .05).

ITV as a Determinant of Bone Type

Correlation analysis indicated that ITV was a good indicator of bone type 4 (*r* = .76) (Fig 5). The electric handpiece was calibrated to record a maximum insertion torque of 50 Ncm. Table 3 demonstrates the range of ITVs for each bone type group and the *P* values in comparing groups, indicating a statistically significant difference in ITV depending on bone type.

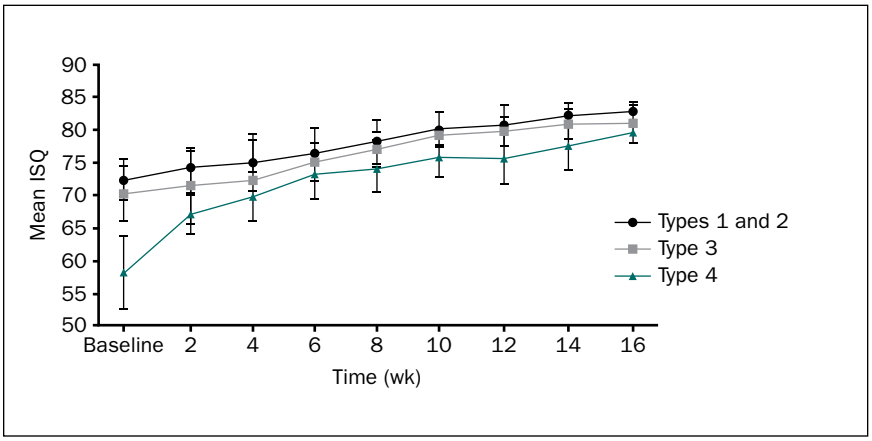

Fig 3 Changes in stability of the implants in the healing bone relative to bone type. Data represent mean ISQ values and standard deviations at each time point measured.

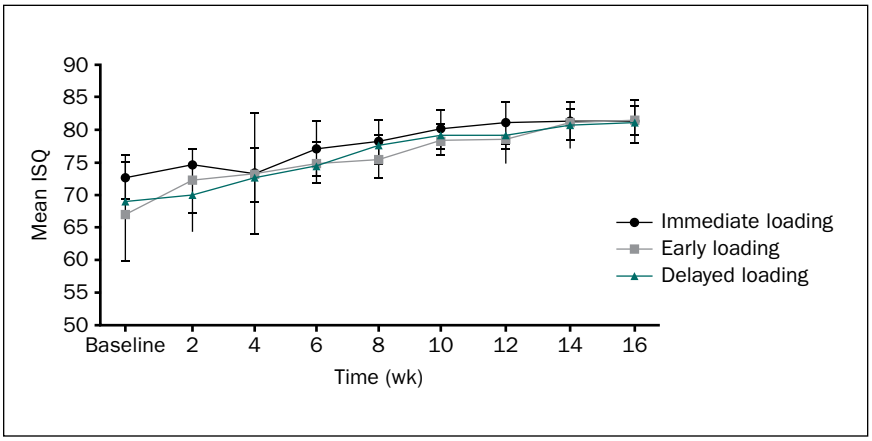

Fig 4 Changes in stability of the implants in the healing bone relative to loading time. Data represent mean ISQ values at each time point measured with associated standard deviations.

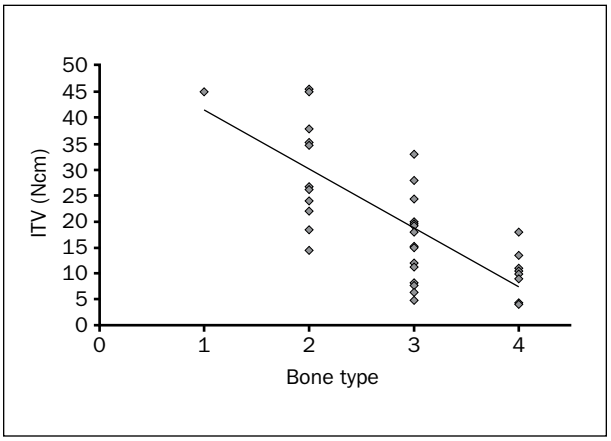

Fig 5 Correlation of two quantitative measures of implant stability: ISQ and ITV. Spearman rank test: 0.4973; $P = .0063$.

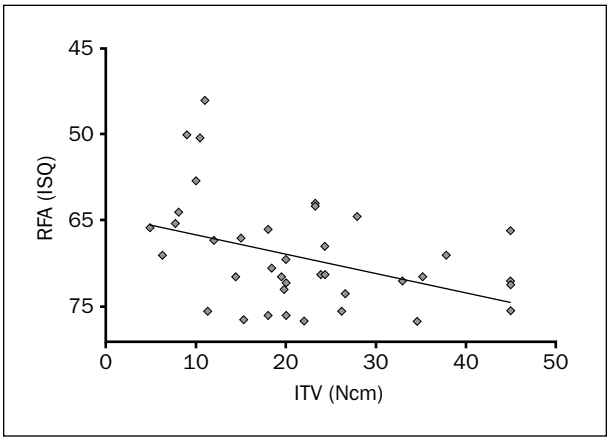

Fig 6 Correlation of two quantitative measures of implant stability: ISQ and ITV with associated *P* value. Spearman rank test: 0.4973; $P = .0063$

Correlation of ISQ and ITV

Figure 6 represents the correlation of the two quantitative measures of primary implant stability, ISQ and ITV. The correlation is considered weak ($r = 0.4973$) but statistically significant ($P = .0063$).

Radiographic Analysis

Bone loss was measured on the mesial and distal aspects of each implant at the level of the outer aspect of the implant bevel from baseline to 3 years. When implants were divided by loading group, the mean bone

Table 3 Baseline ITVs for Each Bone Type Group

		ITV (Ncm)					*P* values*		
Bone type	N	Mean	SD	Min	Median	Max	1 and 2 vs 3	1 and 2 vs 4	3 vs 4
1 and 2	13	32.28	11.04	14.40	34.60	45.50	.0002	.0000	.0349
3	19	16.61	7.78	4.90	18.00	33.00			
4	8	10.01	4.58	4.00	10.15	18.00			

*Wilcoxon rank sum test.

loss ranged from 0.16 to 0.37 mm on the mesial and 0.13 to 0.29 mm on the distal. The mean bone loss was 0.22 mm both mesially and distally. When implants were divided by bone type, the mean bone loss ranged from 0.18 to 0.33 mm on the mesial and 0.14 to 0.39 mm on the distal aspect. The mean bone loss was 0.22 mm on the mesial and 0.26 mm on the distal. There was no statistically significant difference in bone levels in all bone type groups and loading groups (Table 4). The bone levels of the five implants in type 4 bone that were loaded early were compared to those of the 12 other implants that were loaded early, and no significant difference was observed at 3 years ($P = .21$ on the mesial and $P = .60$ on distal).

Table 4 Mesial and Distal Crestal Bone Changes (mm) During the Study (Baseline to 3 Years), by Loading Time and Bone Quality

Implant group	N	Mesial	SD	Distal	SD
Loading time					
Immediate	7	−0.37	0.38	−0.29	0.37
Early	17	−0.20	0.29	−0.13	0.27
Delayed	14	−0.16	0.23	−0.29	0.33
Bone type					
1 and 2	12	−0.33	0.37	−0.39	0.27
3	18	−0.18	0.22	−0.25	0.27
4	8	−0.19	0.20	−0.14	0.26

Bone levels were measured from the mesial and distal aspects of the implant at the bevel.

DISCUSSION

The current investigation sought to test the hypothesis that dental implant stability is minimally affected when physiologic loading is applied. The study was designed as a prospective stratified randomized clinical trial with strict inclusion and exclusion criteria to remove variables that would lead to uncertainty in the validity of the data. A single prosthodontist performed all stability measurements with the Osstell device and all follow-up examinations to control for observer bias. It is understood that the primary stability of most implants in type 4 bone is unable to support occlusion in an unsplinted design. In this subject population, it was observed that the maximum ITV for implants in type 4 bone was 18 Ncm and the minimum was 4 Ncm. An ITV of 20 Ncm—rather than bone type assessment by the surgeon—was used for inclusion in the immediate loading group, creating an ethical study-design threshold to allow immediate loading of unsplinted implants in the posterior region. There is a tremendous range in the suggested ITV cutoff for immediate loading of a single implant (from 30 to 60 Ncm).[13,16,17,34] Ottoni et al suggested a torque value of 32 Ncm for immediate loading, as they observed a high failure rate at 20 Ncm with the Frialit-2 implant.[34] The implant system used in the current study has been noted to have lower ITV than other systems, likely as a result of its thread design. If a higher threshold of 30 Ncm or more had been adopted for immediate loading, significant underpreparation of the surgical site would have been required; this would have created a subjective confounding variable that was controlled in this protocol. As was shown in Table 4, type 3 bone showed the greatest variability in ITV, with 10 of the 18 implants having a maximum ITV less than 20 Ncm and two showing rotational mobility on placement. This is consistent with other studies.[17,28,29] Determination of bone type is subject to interoperator variability and difficulty in differentiation between intermediate bone types 2 and 3.35 The ITV, because it offers an objective numeric representation of resistance to drilling, may therefore become the more relevant tool for communicating bone quality. A previous RCT using rough-surfaced implants demonstrates that early loading leads to an acceptable survival rate regardless of the available bone type.[36] This study confirmed that implants in all bone types were successfully loaded at 6 weeks when ITV was used as the determinant for the timing of loading. In addition, two implants inserted in bone classified as type 3 were immediately loaded successfully when the ITV protocol was followed. The only implant failure occurred in type 4 bone with ITV < 8.1 Ncm (in the delayed loading group) and was removed at 10 weeks following placement.

It is interesting to note that the ITV and baseline ISQ measures were only weakly correlated. Da Cunha et al[37] demonstrated similar findings with the TiUnite Mk III implant and no correlation of ITV and ISQ with the machined Brånemark implant. Friberg et al[29] found a high degree of correlation between the ITV of the upper crestal third of the implant site and the resonance frequency values upon insertion. The weak and inconsistent correlation between ISQ and ITV can be attributed to the fact that these tools measure two different properties of the implant-to-bone connection. Insertion torque measures rotational resistance as the implant is being placed and is dependent on mechanical properties of the bone such as density and hardness, implant design, and site preparation.[28] RFA, on the other hand, measures the resonance of the implant in bone after placement and is dependent on the axial stiffness of the implant-to-bone area. In addition, it is possible that the sensitivity of both instruments of the implant-to-bone connection is not equal and therefore the measures do not correlate strongly. Both rotational and axial stiffness are useful prognostic indicators of success with immediate loading and together provide a better description of the primary stability of the implant. It would be advantageous for the surgeon to have access to both ITVs and ISQs to assess risks of immediate loading of an unsplinted implant. In this study, the minimum ISQ for implants with an ITV ≥ 20 Ncm category was 67 and the maximum was 77 (mean ISQ of 72). It would seem reasonable based on the success achieved in this preliminary study that if the ITV was at least 20 Ncm and the ISQ was 67 or higher, that a standard-diameter implant of 11 or 13 mm in length could be immediately loaded.

An interesting outcome of the study was that all implant groups, when divided by time of loading or bone type, showed a steady increase in stability (as measured by ISQ) over time. This is a remarkable difference, especially in type 4 bone, as compared to previous studies. In a study of unloaded implants, a decrease in the mean stability measurement occurred at 3 weeks within each bone group, with the least stability seen in type 4 bone.[32] Similar results were seen by Valderrama et al[38] with the SLA Active implant (Institut Straumann), which features a roughened surface. Balshi and coworkers observed, with Brånemark System implants (TiUnite Mk III and Mk IV), a decrease in ISQ for the first 30 days.[39] Al-Nawas et al,[40] in looking at sandblasted/acid-etched, titanium plasma–sprayed, and Mk III and IV implants, noted a decrease in ISQ during the first 8 weeks of healing. Although primary stability is assumed to be the most important determinant of success with immediate loading, the maintenance of implant stability during the transformation of primary to secondary bone contact is equally important. The implants used in this study appeared to maintain stability during the peak of the resorptive phase of bone healing (2 to 3 weeks). This is encouraging and may provide clinical support to earlier laboratory studies regarding this device.[41,42] This could also explain the high success rate obtained in this study following early loading at 6 weeks of implants in type 4 bone.

Underpreparation of the implant site, which is accomplished by not following the standard drilling sequence indicated for a particular implant, has been discussed as a means to improve primary stability.[43] Although this may improve the ISQs and ITVs for an implant and increase the confidence of the operator in immediately loading the implant, it is not known whether this will cause a greater resorptive effect, leading to a reduction in stability prior to secondary bone formation. Maintenance of secondary stability derived from the remodeling of the implant interface of an immediately loaded implant is equally important in reducing the risk of early implant failure.[27] Further investigations are required to compare underpreparation with standard preparation of implant sites and the effect of underpreparation on stability measurements and the success of immediately loaded single implants.

A generalization from the results of this trial to clinical practice should be made with caution. In this trial, the inclusion criteria were strict (Table 1) and only patients known to be ideal candidates for implant treatment were recruited, the clinical team was restricted to one surgeon and one prosthodontist, and the operators were highly experienced. On the other hand, a recent effectiveness-of-care study showed that minimal complications with early and immediate loading occurred with the same implants supporting a range of prosthesis designs in a large effectiveness field trial.[44]

CONCLUSION

Following the protocol for this stratified randomized clinical trial, no differences in bone levels were observed after 3 years of loading for all implants in the three loading groups. This indicates that a minimal insertion torque of 20 Ncm may be an important threshold determinant to consider immediate loading of single-tooth implants in the posterior region. Limitations of this study are the sample size and the complexity of the research design needed to address the research question. The observed lack of significant difference may become significant with a greater sample size, but the trend of uniformity shown in this study suggests that any difference, while statistically significant, may have limited impact from a clinical perspective. A second measure of stability is recommended and may be provided with a measurement of implant

and bone stiffness (eg, implant stability quotient [ISQ] derived from the Osstell device). A baseline reading of greater than 70 ISQ would increase the operator confidence in determination of immediately loading the dental implant. The maintenance of increasing stability levels over time is encouraging and supports the hypothesis that the timing and method of load application to the implants was within their physiologic capacity. Because of variations in in geometry and surface technology, primary stability levels and loading protocols will vary according to the implant type.

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