Pilot Study in the Identification of Stability Values for Determining Immediate and Early Loading of Implants

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This pilot study assessed the impact of implant stability criteria on implant loading time. Insertion torque (IT) and baseline implant stability quotients (ISQ) from resonance frequency analysis were recorded for 41 tapered-screw implants placed in the mandibles of 20 patients. Immediate (IL), early (EL) (6 weeks postoperative), or delayed (DL) (12 weeks postoperative) prosthetic loading was performed based on results and study criteria. Postoperative ISQ values were also recorded at 6 time intervals for the IL and EL groups and after healing for the DL group. All implants were definitively restored after 6 weeks of provisionalization. There were no failures, complications, or stability differences based on loading time. At week 12 of follow-up, ISQ values were slightly higher for IL implants compared with EL implants. IL and EL implants showed significantly higher cumulative ISQ values compared with DL implants. High IT and baseline ISQ values in all groups corresponded to high implant survival. Postoperative ISQ values in the IL and EL groups were less certain indicators of implant survival because of fluctuations relative to baseline values. Small sample size and inequitable patient distribution across groups skewed results. More research is needed before definitive results can be drawn. IL and EL were safely performed within the IT and ISQ ranges in this study, but it is unknown whether EL criteria would have also sufficed for IL.

Key Words: resonance frequency analysis, implant stability quotient, insertion torque, immediate loading

Introduction

Implant stability is crucial for achieving and maintaining osseointegration.[1] Primary stability is accomplished by mechanically engaging the implant in bone at the time of placement. The degree of achievable stabilization depends on 3 important variables: implant type (design and surface), surgical technique (initial bone-implant interface), and bone type (quality and volume).[2–5] Secondary stability relates to the degree of osseointegration that occurs during bone formation and remodeling at the bone-implant interface. Variables that can influence the amount of achieved osseointegration include the degree of primary stability that was initially achieved, the quality of the surrounding bone, and the character of the implant surface.[2–5] If primary stability is high, such as when implants are placed in dense cortical bone, the osseointegration process may only provide a modest increase in secondary stability.[3] In contrast, implants with poor primary stability in low-density trabecular bone can gain markedly in secondary stability as the bone-implant interface develops through the osseointegration process.[3]

During the developmental period of modern implant dentistry clinicians generally used a 2-stage surgical procedure to prevent implant micromove-

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ments that could destroy the matrix of regenerating bone around the implant and thereby prevent osseointegration.[2,6–13] In the 1970s Ledermann[14–16] demonstrated that primary bone repair could occur around rigidly splinted implants placed in dense bone of the mandibular symphysis and immediately loaded with a bar-supported overdenture. More recently high survival rates have been reported for implants restored with fixed prostheses placed into immediate or early occlusal loading in both partially and completely edentulous jaws.[13,16–20]

The decision whether or not to immediately load an implant hinges on the degree of its primary stability.[21] Common clinical methods of discerning primary implant stability are generally rudimentary, however, and include tactile perceptions of resistance to movement and turning and radiographic evaluation for the presence of any peri-implant radiolucency.

In recent years other methods of evaluating implant stability have been reported in the dental literature, but none has offered a definitive guideline for determining adequate stability for immediate or early loading. For example, some clinicians have advocated insertion torque (IT) values of 40 Ncm as a suitable standard of primary stability for immediate loading based on attendant tactile perceptions of mechanical stability and resistance to removal,[22,23] while others[24] have identified clinical variables that can skew IT values, such as inefficient bone tapping by the implant during placement. Likewise, ultrasonic vibration probing (Periotest, Siemens AG, Bensheim, Germany) values have documented varying degrees of implant stability over time, but data can be skewed by such variables as the length of the attached abutment, location of probe impact, and angulation of the handpiece.[24,25] Implant stability quotients (ISQ) derived from resonance frequency analysis (RFA) have also been used to document implant stability changes over time,[3,4,26–32] but no definitive ISQ value has been identified as an appropriate level of stability to warrant immediate or early loading.

As an initial step toward the establishment of formal criteria to facilitate clinical decision making, this pilot study evaluated the efficacy of 3 preselected sets of implant stability values as predictors of adequate primary implant stability for immediate or early implant loading.

MATERIALS AND METHODS

Instrumentation

All implants were placed with a manual torque wrench (Torque-Lock, Intra-Lock International, Boca Raton, Fla) that registered IT from 10 to 50 Ncm, and the values were recorded. If the actual IT value exceeded or failed to meet the torque limits of the gauge, values of 50 or 10 Ncm were recorded for the implant, respectively. A transducer was attached to the implant mount, and RFA equipment (Ostell, Integration Diagnostics AB, Gothenburg, Sweden) was used to determine the implant's resistance to movement against applied oscillation waves. The RFA values were translated into an index (ISQ) with a scale from 0 (implant mobility) to 100 (rigid bone-implant interface).[31,32] Direct correlations have been reported in the dental literature between ISQ values and several variables, including IT value, implant diameter, bone density, peri-implant bone height, abutment length, and implant design (macrofeatures and surface topography).[27,32,33]

Implant selection

Since primary implant stability is paramount for successful immediate loading, a preliminary test was conducted to evaluate the initial stability of 2 different implant designs from the same manufacturer (Zimmer Dental Inc., Carlsbad, Calif): a straight-screw design with a single external thread pattern (Screw-Vent MTX) and a tapered-screw design with a triple external thread pattern (Tapered Screw-Vent MTX). Both implants measured 3.75 mm $\times$ 13 mm and had microtextured surfaces.

In the mandible of an 8-month-old Yorkshire pig cadaver, a full-thickness flap was elevated and 2 adjacent osteotomies were prepared according to the implant system's protocol. Straight- (n = 1) and tapered-screw (n = 1) implants were placed side by side into the adjacent osteotomies with a calibrated torque wrench, and IT values were recorded (Figure 1a and 1b). After placement, a transducer was attached to the same location on the delivery post of each implant and RFA values were obtained (Figure 1c and 1d). The same procedures were performed on the contralateral side of the jaw so that data could be collected on 2 straight- and 2 tapered-screw implant designs.

During placement, the mean IT value for the straight-screw implant design increased significantly to a depth of 6 mm and then maintained a constant torque level until the implant was completely placed. In contrast, the mean IT value for the tapered implant design was insignificant for the first 4 mm and then gradually increased until the implant was completely placed (Figure 2). Tapered implants achieved slightly higher mean IT values (IT = 49 Ncm) and significantly higher ISQ values (ISQ = 70) than the straight implants (IT = 45 Ncm, ISQ = 62).

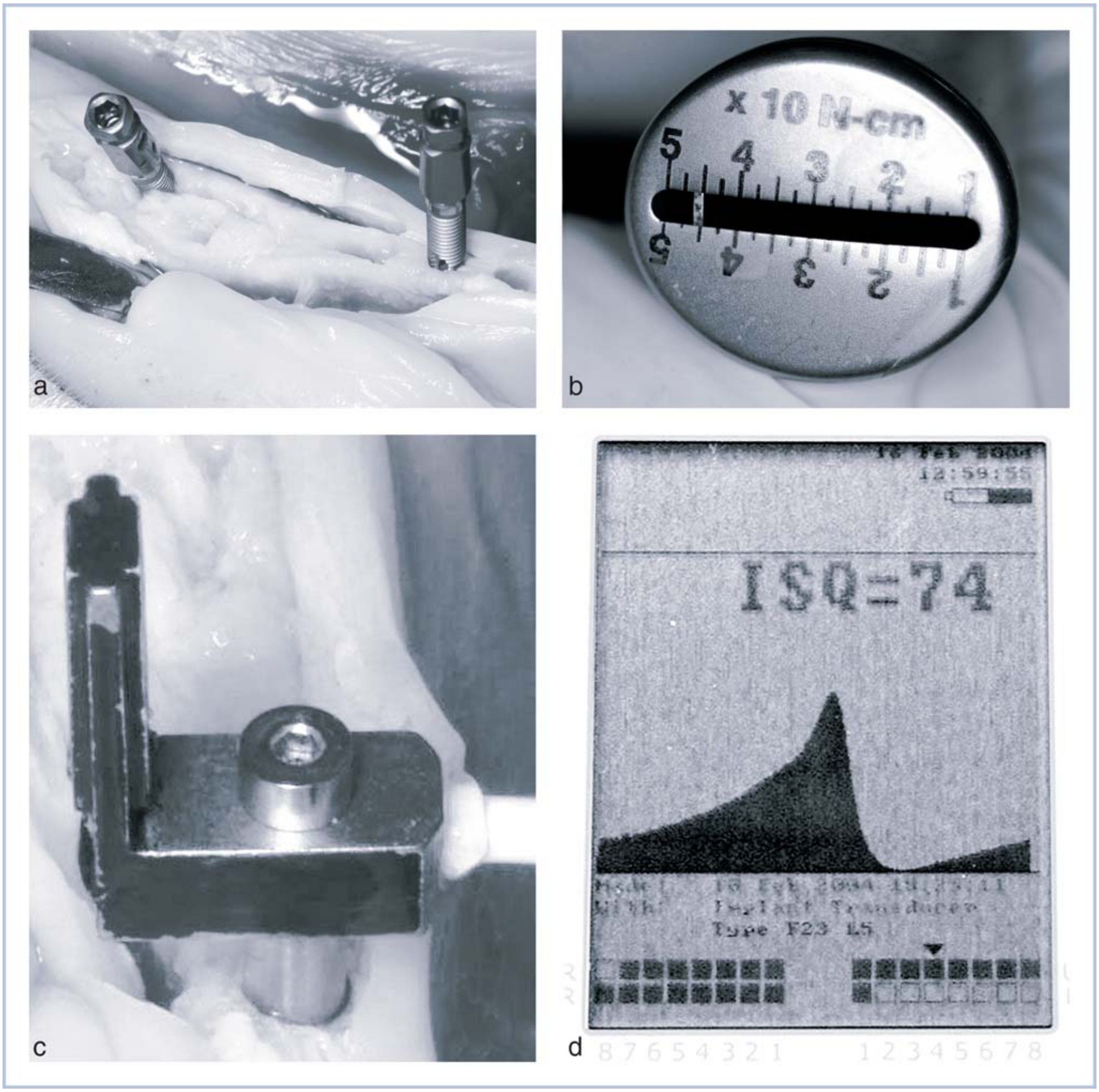

FIGURE 1. (a) Preliminary stability comparison: Tapered- (left) and straight-screw (right) implants being placed in a mandibular pig cadaver. (b) Insertion torque was measured with a gauged torque wrench. (c) A transducer is attached to the implant mount to measure implant stability through resonance frequency analysis. (d) Resonance frequency analysis registered stability according to an implant stability quotient.

Based on these findings, the tapered implant design was selected for the study. Numerous other studies have reported higher failure rates for straight implants less than 10 mm in length.[34–36] To mitigate the additional instability imposed by prosthetic loading prior to achieving osseointegration, implants in the present study were limited to a minimum of 10 mm in length.

Patient selection and evaluation

Study candidates were selected patients who presented in the investigator's private dental practice for treatment of 1 or more missing mandibular teeth. All patients received a preliminary evaluation that included careful review of their medical and dental histories, detailed clinical and radiographic examina-

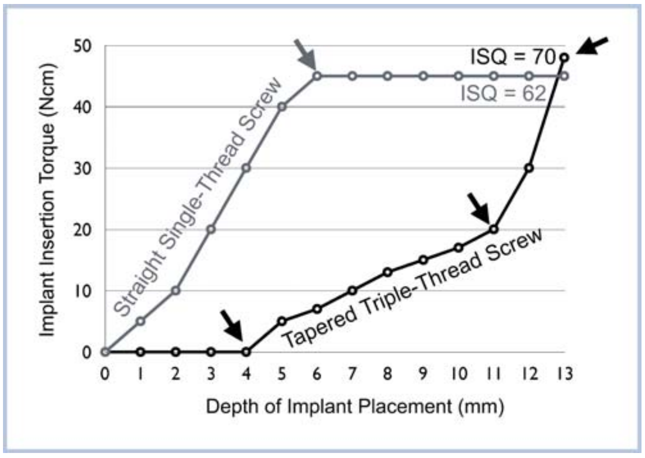

Figure 2. Implant stability in a porcine mandible. A comparison of straight and tapered implant designs. Preliminary testing indicated that the tapered-screw implant offered greater stability than the straight-screw implant.

tions, evaluation of oral hygiene, and preferences for oral rehabilitation. A diagnostic work-up was performed to evaluate the volume and location of available bone, patient esthetic and functional needs, and the desires of the patient. Diagnostic casts were fabricated and mounted on a semiadjustable articulator using a face-bow transfer and occlusal registration to determine the jaw relationships, proposed implant position, crown-root ratio, and potential complications. The mounted casts facilitated a prosthetic wax-up and fabrication of a surgical template to guide placement of the implants relative to the planned prosthesis. Treatment alternatives were presented, and signed consent forms for treatment and inclusion in the study were obtained before patients were admitted as participants. A total of 20 patients (6 men, 14 women) ranging from 35 to 67 (mean = 51.4) years were enrolled as study participants (Table 1).

Table 1

Distribution of Patients and Treatment

		Distribution of Patients by Sex and Age (No.)				
		Sex		Age (years)		
Patient Data	Total patients (No.)	Men	Women	Mean	Mode	Range
	20	6	14	51.4	55	35–67

		Distribution of Implant Placement by Diameter, Length, and Bone Tap Use (No.)					
		Diameters		Lengths		Bone tap use	
Implant Data	Total implants (No.)	3.7 mm	4.7 mm	10 mm	13 mm	Yes	No
	41	6	35	33	8	4	37

Distribution of Implant Placement by Tooth Location and Bone Density (No.)										
Incisor			Bicuspid		Molar		Bone density[37]			
Central	Lateral	Cuspid	1st	2nd	1st	2nd	D1	D2	D3	D4
1	1	1	6	6	12	14	4	21	15	1

		Time of Placement by Prosthesis Type (No.)			
Prosthesis Data	Total prostheses (No.)	Loading time	Single tooth§‖	Fixed partial denture§¶	Screw-retained denture¶
		Immediate*	1	1	3
	23	Early†	2	11	2
		Delayed‡	None	3	None

*Immediate loading indicates loaded at time of implant placement.

†Early loading indicates loaded 6 weeks postoperative.

‡Delayed loading indicates loaded 12 weeks postoperative.

§Cement-retained prosthesis.

‖Prosthesis supported by 1 implant.

¶Prosthesis supported by 2 or more implants.

Table 2

Study Criteria for Determining Bone Density and Provisional Prosthesis Loading Time

Bone Density	If the IT* value is . . .	Then the bone is considered	And classified as[37]
	>45 Ncm before 60% of implant is placed	High density	D1
	≥45 Ncm before 60% of implant is placed	Moderately high density	D2
	>30 Ncm but <45 Ncm before 60% of implant is placed	Moderately low density	D3
	≤30 Ncm before 60% of implant is placed	Low density	D4

Provisional Prosthesis Loading Time	Types of loading time		Criteria for determining prosthesis loading time			
			Minimum implant length required	Bone density[37]	Primary stability	
	Time of loading	Category			IT (Ncm)	ISQ*
	Implant placement	Immediate	10 mm	D1–D2	>45	>70
	6 weeks postoperative	Early	10 mm	D1–D3	~30–45	~40–70
	12 weeks postoperative	Delayed	None	D1–D4	<30	<40

*IT indicates insertion torque value; ISQ, implant stability quotient from resonance frequency analysis.

Surgical procedures

Antibiotic prophylaxis (Augmentin 500 mg, GlaxoSmithKline, Middlesex, United Kingdom) was administered 2 hours before surgery and for 4 days postoperative. On the day of surgery the patient was anesthetized by local infiltration with articaine HCl 4% with epinephrine (1:1 000 000) (Septocaine, Spécialités Septodont, Saint-Maur-des-Fossés, Cedex, France). Midcrestal and terminal releasing incisions were made, followed by elevation of mucoperiosteal flaps that were kept small to preserve the periosteal vascular supply. Osteotomies were prepared according to the manufacturer's protocol using sequential cutting with internally irrigated drills and guided by a surgical template.

Implants were placed with a manual torque wrench, and maximum IT values were recorded. Using these data, an assessment of bone density was made based on specified study criteria (Table 2) and previous research that showed a positive correlation between bone density and IT values.[37] Four categories of bone density (D1, D2, D3, D4)[38] were present in the study population. In cases (n = 4) in which dense bone (D1)[38]

Table 3a

Distribution of Insertion Torque and Implant Stability Quotient Values: Immediate-Loading Group

		ISQ Over Time								
			Follow-up (weeks)							
Patient No.	IT (Ncm)	Baseline*	1	2	3	6	8	12	Average	SD†
1	48	70	66.0	66.0	68.0	75.0	71.0	71.0	69.5	2.8
1	50	78	72.0	72.0	78.0	80.0	78.0	78.0	76.3	2.9
1	35	69	70.0	72.0	62.0	72.0	72.0	72.0	70.0	2.7
1	40	60	56.0	56.0	60.0	70.0	70.0	80.0	65.3	8.0
<1>‡	<35>‡	<57>‡	<53>‡	<52>‡	<52>‡	<55>‡	<55>‡	<55>‡	<53.7>‡	<1.3>‡
3	50	72	70.0	69.0	71.0	73.0	73.0	73.0	71.5	1.5
6	48	78	70.0	70.0	72.0	77.0	75.0	80.0	74.0	3.3
6	45	78	70.0	70.0	72.0	77.0	75.0	80.0	74.0	3.3
14	50	81	75.0	75.0	75.0	77.0	76.0	78.0	76.0	1.0
14	50	79	77.0	74.0	75.0	76.0	76.0	77.0	75.8	0.9
			1	2	3	6	7	8	5.3	3.3
Average	46.2	73.9	69.6	69.3	70.3	75.2	74.0	76.6	72.5	$R^2 = 0.84$
SD	4.1	5.5	3.8	3.8	4.7	2.4	2.2	3.0	12.1	

*Baseline indicates time of implant placement.

†SD indicates standard deviation.

‡Outlier data removed from statistical analysis to prevent distortion of statistical inferences.

was present, the implant was immediately removed, the osteotomy was further prepared with a bone tap, and the implant was fully placed (Tables 1 and 2). It is interesting to note that all of the pretapped sites occurred in mandibular molar regions. After placement, a transducer was attached to the implant mount, RFA was used to determine a baseline ISQ value, and the result was recorded in the patient's chart. The mount was removed from the implant.

Based on the IT and baseline ISQ values, the prosthetic loading time for the implant was determined according to study criteria (Table 2). In the immediate loading group (10 implants/4 patients), procedures for restoring the implants with a provisional prosthesis were immediately commenced at the time of implant placement. In the delayed-loading (6 implants/5 patients) and early-loading (25 implants/13 patients) groups, a transmucosal healing abutment was attached to the implant with 15 Ncm of torque. The soft tissues were sutured around the healing abutment with 3-0 Vicryl sutures (Ethicon, Inc, Somerville, NJ). Sutures were removed after approximately 1 week, and the implants were allowed to heal nonsubmerged for 6 (early-loading group) or 12 (delayed-loading group) weeks. At patient reappointment the healing abutments were removed from the implants in preparation for provisional restorative procedures.

Restorative procedures

A transitional abutment was attached to the implant with 20 Ncm of torque and provisionally restored with a cemented acrylic prosthesis. In the immediate-loading group, the soft tissues were sutured (3-0 Vicryl) around the provisional prosthesis and removed after maturation approximately 1 week later. The 20 patients in this study were treated with 41 implants that were loaded (1) immediately (n = 10 implants/4 cases), (2) after 6 weeks (n = 25 implants/13 cases) of healing, or (3) after 3 months (n = 6 implants/3 cases) of healing. After 6 weeks of provisional loading all implants were definitively restored with ceramometal or acrylic prostheses (Table 1) that were entirely supported by 1 or more implants, depending on the type of restoration.

Postoperative data collection

In the immediate- and early-loading groups, the healing abutments or provisional prostheses were removed at weeks 1, 3, 4, 6, 8, and 12 postoperative. The implant mounts were reattached to the implants, and follow-up ISQ values were recorded to measure any changes in implant stability. After the data were recorded in the patients' charts, the healing abutments or provisional restorations were reattached until the next ISQ measurement interval and/or commencement of provisional or definitive restorative procedures. After 12 weeks of nonsubmerged healing in the delayed-loading group the healing abutment was removed and the implant mount was reattached. A post-healing ISQ measurement was made, and then the implant was provisionally restored.

Results

There were no implant failures or complications, and all implants functioned according to treatment plan. The IT and ISQ values are presented in Tables 3a–c. For all implants placed, average IT was 43.2 Ncm (range = 32.5 to 46.2 Ncm) and average ISQ was 71.8 (ISQ range = 69.5 to 72.6). A paired Student's t-test was performed to determine the average difference in ISQ means between the immediate-loading and early-loading data sets. Prior to analysis outlier data set 5 for patient 1 was removed (Table 3a) because the values were so far outside the range of the remainder of the data that they distorted statistical inferences. There was no statistically significant difference between the means (0.33), which meant that differences in loading time between these 2 groups did not, as a whole, affect implant stability. However, the immediate-loading group showed slightly higher ISQ stability at week 12 of follow-up (average ISQ = 76.6) compared with the early-loading group (average ISQ = 74.2).

A Student's t-test was not performed between the delayed-loading group and either the immediate- or early-loading group because the former lacked corresponding interval ISQ measurement data. In comparing cumulative average ISQ values, however, there was a significant difference between the delayed-loading group (overall average ISQ = 69.5) and either the immediate-loading (overall average ISQ = 72.5) or early-loading (overall average ISQ = 72.6) groups.

Table 4 presents a summary of ISQ value changes by loading group. When ISQ values were examined by postoperative time intervals, 90% of the immediately loaded implants exhibited a slight decrease by week 1, a 100% increase by week 6, and stabilization (50%) or continued increase (50%) by week 12. In the early-loading group, the majority of implants remained stable through week 3, increased stability in week 6, and then stabilized or continued to increase stability through week 12. Evaluation of the baseline and cumulative average postoperative ISQ values within each group revealed a slight ISQ decrease (–1.4) for immediately loaded implants and a slight ISQ increase

Table 3b

Distribution of Insertion Torque and Implant Stability Quotient Values: Early-Loading Group

		ISQ Over Time								
			Follow-up (weeks)							
Patient No.	IT (Ncm)	Baseline*	1	2	3	6	8	12	Average	SD†
2	48	73	72.0	72.0	72.0	75.0	75.0	75.0	73.5	1.5
2	48	66	66.0	66.0	66.0	68.0	68.0	68.0	67.0	1.0
2	50	76	76.0	76.0	76.0	78.0	78.0	78.0	77.0	1.0
2	48	76	74.0	74.0	76.0	79.0	79.0	79.0	76.8	2.2
2	48	64	64.0	64.0	66.0	68.0	68.0	68.0	66.3	1.7
5	48	68	68.0	68.0	68.0	68.0	70.0	70.0	68.7	0.9
5	38	66	66.0	66.0	66.0	68.0	68.0	68.0	67.0	1.0
7	45	74	76.0	75.0	75.0	75.0	76.0	76.0	75.5	0.5
7	46	75	80.0	77.0	76.0	76.0	76.0	76.0	76.8	1.1
7	40	60	61.0	60.0	60.0	79.0	64.0	66.0	65.0	5.0
8	50	72	73.0	73.0	73.0	76.0	76.0	76.0	74.5	1.5
8	50	76	75.0	74.0	74.0	74.0	74.0	74.0	74.2	0.3
9	48	70	70.0	68.0	67.0	66.0	70.0	72.0	68.8	1.8
10	45	71	70.0	70.0	72.0	77.0	75.0	80.0	74.0	3.3
11	50	80	78.0	78.0	72.0	68.0	76.0	75.0	74.5	3.0
11	48	71	74.0	74.0	74.0	68.0	75.0	73.0	73.0	1.7
12	46	74	74.0	75.0	71.0	74.0	74.0	74.0	73.7	0.9
13	48	75	75.0	74.0	76.0	78.0	79.0	79.0	76.8	1.8
13	50	76	76.0	74.0	76.0	79.0	79.0	79.0	77.2	1.8
15	35	66	68.0	66.0	66.0	75.0	77.0	77.0	71.5	4.8
15	38	70	70.0	68.0	71.0	76.0	72.0	72.0	71.5	1.8
16	35	66	68.0	66.0	68.0	70.0	71.0	71.0	69.0	1.7
16	35	68	68.0	64.0	68.0	70.0	71.0	71.0	68.7	2.0
19	45	82	78.0	80.0	79.0	79.0	85.0	85.0	81.0	2.7
20	45	74	74.0	75.0	70.0	74.0	74.0	72.0	73.2	1.4
Average	45.1	71.6	71.8	71.1	71.1	73.5	74.0	74.2	72.6	$R^2 = 0.73$
SD	3.8	4.1	3.9	4.3	3.6	3.7	3.4	3.5	4.0	

*Baseline indicates time of implant placement.

†SD indicates standard deviation.

for implants in the early-loading (+1.0) group. The ISQ values for implants in the delayed-loading group were evaluated only at baseline and after nonsubmerged healing, and they exhibited a slight ISQ increase (+1.4); however, it is important to note that implants in this group had not yet been subjected to provisional loading.

Discussion

High IT and baseline ISQ values (Table 3a–c) indicated that the implants achieved primary stability regardless of bone density. The finding that a slight decrease in ISQ values occurred at postoperative week 1 for the majority (90%, n = 9/10) of immediately loaded implants and for 24% (n = 6/25) of the early-loaded

Table 3c

Distribution of Insertion Torque and Implant Stability Quotient Values: Delayed-Loading Group

		ISQ Values Over Time							
			Follow-up (weeks)						
Patient No.	IT (Ncm)	Baseline*	1	2	3	6	8	12	Stage 2†
4	30	68	N/A	N/A	N/A	N/A	N/A	N/A	74.0
4	35	68	N/A	N/A	N/A	N/A	N/A	N/A	72.0
7	35	74	N/A	N/A	N/A	N/A	N/A	N/A	73.0
17	30	68	N/A	N/A	N/A	N/A	N/A	N/A	70.0
18	30	66	N/A	N/A	N/A	N/A	N/A	N/A	67.0
2	35	64	N/A	N/A	N/A	N/A	N/A	N/A	70.0
Average	32.5	68.1	N/A	N/A	N/A	N/A	N/A	N/A	69.5
SD	2.5	6.6	N/A	N/A	N/A	N/A	N/A	N/A	2.7

*Baseline indicates time of implant placement.

†Stage 2 indicates ISQ value assessed after osseointegration but prior to loading.

TABLE 4
Summary of Cumulative Implant Stability Quotient Value Changes by Loading Group

		ISQ* Value Changes from Baseline								
		Changes in ISQ by time interval (% of implants per loading group)						Cumulative ISQ changes		
Loading Group	Type of change	Week 1	Week 2	Week 3	Week 6	Week 8	Week 12	Baseline	Postoperative†	Difference
Immediate	Increase	10%	10%	60%	100%	—	50%			
	Decrease	90%	30%	10%	—	50%	—	73.9	72.5	−1.4
	Stabilize‡	—	60%	30%	—	50%	50%			
Early	Increase	28%	12%	32%	68%	44%	12%			
	Decrease	24%	44%	24%	12%	12%	12%	71.6	72.6	+1.0
	Stabilize	48%	44%	44%	20%	44%	76%			
Delayed	Increase	N/A	N/A	N/A	N/A	N/A	N/A			
	Decrease	N/A	N/A	N/A	N/A	N/A	N/A	68.1	69.5	+1.4§
	Stabilize	N/A	N/A	N/A	N/A	N/A	N/A			

*ISQ indicates implant stability quotient.

†Postoperative indicates cumulative average of postoperative ISQ values.

‡Stabilize indicates no change in average ISQ value from previous measurement interval.

§ISQ value assessed after osseointegration but prior to loading.

implants was of interest, but results were skewed by differing quantities of implants in the 2 groups. In both cases, provisional prostheses were removed at 6 different intervals to monitor ISQ changes. All implants remained stable, and there was no indication to suggest that these procedures may have contributed to the observed initial decrease in ISQ values, especially in the immediately loaded group.

In contrast, other researchers[39] have attributed similar fluctuations in ISQ values to events that occur at the bone-implant interface. Placing dental implants into functional loading generates microstrains at the bone-implant interface. If those microstrains fall within a physiologically acceptable range below a threshold of micromotion, the bone will respond by increasing in density at the bone-implant interface through microremodeling.[40–42] An ongoing microremodeling process could account for some or all of the ISQ fluctuations during the early stages of healing but may not indicate why the cumulative average of ISQ values (Table 4) was lower than the baseline ISQ value for the immediate-loading group.

The rate of microremodeling and the degree of acquired density increase depends, in part, on the initial density of the host bone. In a US government study[40] of bone density changes around 3006 implants, high-density bone (D1)[38] reached optimal stability within 6 to 12 months after loading, while the length of time to reach optimal stability increased as bone density decreased: 9 to 12 months for D2 bone, 6 to 18 months for D3 bone, and 9 to 18 months for D4 bone.[38,40] In the present study, surgical sites in both the immediate- and early-loading groups primarily consisted of moderately dense (D3)[38] bone; however, 16% of the early-loading sites also consisted of highly dense (D1)[38] bone, which may have partly skewed the early-loading data toward a higher rate of ISQ stabilization for that group at week 1.

The high baseline ISQ values (Table 3a–c) in this study suggested that intimate bone contact with the implant body was achieved at the time of placement, which the surgeon was able to tactilely discern as firm anchorage. The torque applied during the last revolution reached or surpassed 45 Ncm for the majority of implants in this study (Table 3a–c) and thus exceeded the 30 to 40 Ncm of torque previously recommended for immediate or early loading.[43] It is important to note, however, that there is currently no professional consensus on minimum IT values for immediate and early loading and that an implant's ISQ value may be significantly higher than its IT value might suggest, as the present research found in the preliminary testing of straight and tapered implant designs.

There were some cases with low-density bone (D4)[38] in this study. External threads were originally designed to stabilize implants by engaging cortical bone, preferably in both the crestal and basal locations of the receptor site.[2] In low-density bone, however, the cortical layer may be completely undifferentiated or only present as a thin shell. Increasing bone density through osteocompression and the creation of a tight interface between the implant and bone can greatly enhance immediate implant stabilization, especially in low-density (D4)[38] bone.[44–47] In the present study, a surgical technique designed to gradually condense walls of the osteotomy to a maximum of 0.9 mm at the crest of the ridge was used to increase mechanical stability. Studies have shown that when a receptor site is prepared as little as 100 μm smaller in diameter than the maximum diameter of the implant, the force-fitting stresses generated during placement will increase IT and implant stability.[48] This technique was designed to produce axial and lateral densification of the soft bone and achieve maximum thread engagement by the implant body for immediate stability in ridges with adequate width.

The small sample size and unequal distribution of patients within the experimental groups of this pilot study preclude any definitive identification of baseline IT and ISQ criteria for determining immediate or early loading. Nonetheless, the results of this pilot study suggest a strong correlation between high IT values and implant survival, while correspondingly high ISQ values at baseline may be less certain indicators since they are more susceptible to fluctuations by micro-remodeling at the bone-implant interface.

Conclusions

Immediate and early loading of dental implants was safely performed within the IT and ISQ ranges specified in this study. It is unknown, however, whether the criteria used for early loading might have sufficed for immediate loading as well.

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