Preliminary 3-dimensional Surface Texture Measurement and Early Loading Results with a Microtextured Implant Surface

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Purpose: *This investigation was conducted to obtain preliminary roughness data on a microtextured implant surface and to determine its ability to sustain a 1-stage surgical procedure and early full occlusal loading of single-tooth restorations in humans.* ***Materials and Methods:*** *Three-dimensional (3D) vertical scanning interferometry was conducted on samples of the test surface (MTX) and 2 control surfaces (Osseotite and sandblasted/acid-etched [SLA]). Test implants were also placed in vivo, restored with fully occluding single-tooth restorations (n = 27) after 2 months of nonsubmerged healing, and clinically monitored for 48 months of follow-up.* ***Results:*** *Microtexture was relatively uniform on the test surface and more random and irregular on the control surfaces. MTX and Osseotite were similar in some roughness parameters, but the MTX surface had a greater number of micropits that were spaced closer together (Stylus Y λq) and with higher slope values (Stylus Y Δq). Cumulative life table results were 100% for all MTX implants placed in maxillary and mandibular jaw locations, and no discernible marginal bone changes were observed. Overall implant success was 100% after 4 years of clinical functioning.* ***Discussion:*** *The findings of this study appear promising but should be considered preliminary, because of the limitations in the number of locations measured on each product sample and the small number of implants clinically studied.* ***Conclusion:*** *Within the scope of the present study, MTX implants exhibited a uniform micropitted surface, as well as 100% survival and 100% clinical success after nonsubmerged placement, early loading with single-tooth restorations at 2 months, and 48 months of clinical functioning.* (More than 50 references.) INT J ORAL MAXILLOFAC IMPLANTS 2003; 18:729–738

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

Today it is axiomatic that a host of internal and external variables can greatly impact the process of osseointegration. Among these, implant surfaces play a critical role by dynamically interacting with both hard and soft tissues.[1–4] Two decades ago, however, uncertainty about implant surface qualities led the 1988 National Institutes of Health (NIH) Consensus Development Conference on Dental Implants to call for new research on implant surface preparations and their influence on the long-term use of dental implants.[5] Over the ensuing years, clinicians have investigated the influence of surface microtexture (roughness), which all dental implants provide in varying degrees.

Kasemo and Lausmaa[6] theorized that surface micropits measuring below about 100 µm but well above the nanometer (ie, 1/1,000 µm) scale may influence the biologic response at the bone-implant interface, since the micropits are in the same size range as cells and large biomolecules. They also surmised that micropits of about 100 µm and larger may serve a strictly mechanical function by aiding in stress transfer.[6] While the regular, horizontal grooves found in machined titanium surfaces have been observed to influence the pattern of cellular attachment at the microscopic level in vitro,[7] it is important to note that

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Table 1 Review of Studies Demonstrating Increased Bone Response to Roughened Surfaces

Study	Type of analysis	Model	Surfaces tested*	Healing time	Influence of roughness†
Piatelli et al[14]	Histology, histomorphometry	Rabbit	M, SB	1–4, 8 weeks	IBA
Baker et al[15]	Mechanical pullout	Rabbit	M, AT	1–5, 8 weeks	IPS
Ericsson et al[16]	Histomorphometry	Canine	M, GB	2, 4 months	IBA
Li et al[17]	Mechanical pullout	Canine	M, SB	2, 4, 12 weeks	ISS
Wong et al[18]	Mechanical pushout, histomorphometry	Porcine	GB, AT, HA	12 weeks	IPS, IBA
Buser et al[19]	Removal torque	Porcine	M, TPS, SLA	4, 8, 12 weeks	IRT
Trisi et al[20]	Histometry	Human	Polished, GB	3, 6, 12 months	IBA
Trisi et al[21]	Histomorphometry	Human	M, AT	6 months	IBA

*M = machined; SB = sandblasted; AT = acid-treated; GB = grit-blasted; HA = hydroxyapatite-coated; TPS = titanium plasma sprayed; SLA = sandblasted with large grit and acid-etched.
†IBA = increased bone apposition; IPS = increased pullout strength; ISS = increased shear strength; IRT = increased removal torque.

machined implant surfaces are not designed to a certain uniform roughness but can vary significantly in average roughness (Ra) values. For example, Wennerberg and coworkers[8] reported mean Ra values for machined commercially pure titanium implants that ranged from a high of 0.67 µm (SD = 0.38) (3i/Implant Innovations, West Palm Beach, FL) to a low of 0.53 µm (SD = 0.10) (Brånemark System; Nobel Biocare, Yorba Linda, CA).

An increasing number of implant manufacturers have begun to further roughen the machined implant surface through coating (eg, hydroxyapatite, titanium plasma spray); acid etching (eg, Osseotite, 3i); grit blasting (eg, MTX, Centerpulse Dental, Carlsbad, CA); or a combination of procedures (eg, SLA, Straumann, Waldenburg, Switzerland).[9] In vitro comparisons with machined surfaces have demonstrated increased osteoblast attachment[10] and faster gingival cell attachment[11] with roughened titanium surfaces. Ong and associates[12] reported that roughened surfaces placed in a simulated physiologic solution exhibited an increase in calcium and phosphorus deposition, and greater protein production and calcium uptake by osteoblast-like cells, compared to smoother surfaces.

In a short-term study conducted in rabbits, Johansson and Albrektsson[13] found that bone apposition to a machined implant surface gradually increased over a period of 1 year. Recent short-term clinical studies in both human and animal models have reported that implants with roughened surfaces achieved greater bone-to-implant apposition and interfacial strength than implants with machined surfaces (Table 1).[14–21] It is currently unknown, however, whether the roughened implant surfaces will actually maintain a higher overall percentage of bone apposition over long-term follow-up, or if the findings of these studies represent a short-term phenomenon that is limited to the early stages of osseointegration.

This article reports the findings of a preliminary surface roughness assay and short-term clinical trial of microtextured implants (Spline Twist MTX, Centerpulse Dental) that were placed via a 1-stage surgical protocol, loaded with fully occluding single-tooth restorations after 2 months, and monitored over 4 years of clinical functioning.

MATERIALS AND METHODS

Three-dimensional Surface Roughness Measurement

Five samples (1 from each of 5 different manufacturing lots) of commercially available screw-type implants were obtained from the finished goods inventories of 3 manufacturers. Each implant line featured a different proprietary "roughened" surface. The test implant samples (MTX, Centerpulse Dental) featured an uncoated, microtextured surface that was created by grit blasting with hydroxyapatite (HA), followed by washing in nitric acid (HNO_3) and distilled water to remove residual particles of the blasting medium without etching the metal surface. The control implant samples included one surface etched with hydrochloric (HCl) and sulfuric acids (H_2SO_4) (Osseotite, 3i) and a second surface that was sandblasted with large-grit aluminum oxide (Al_2O_3), then etched with HCl and H_2SO_4 (SLA, Straumann) (Table 2).

The analyses were performed with vertical scanning interferometry by an independent testing laboratory (Michigan Metrology, Livonia, MI). Immediately

Table 2 Test Samples for Surface Characterization Study

Implant name	Manufacturer	Surface treatment	No. of samples
Spline Twist MTX	Centerpulse Dental	Grit-blasted with soluble hydroxyapatite (HA), then washed in nitric acid (HNO_3) and distilled water baths	5
Osseotite Screw	Implant Innovations (3i)	Etched with hydrochloric (HCl) and sulfuric (H_2SO_4) acids	5
SLA solid screw	Straumann	Sandblasted with large-grit aluminum oxide (Al_2O_3), then etched with hydrochloric (HCl) and sulfuric (H_2SO_4) acids	5

Table 3 Primary Measurement and Analysis Parameters for Surface Characterization Study

Measurement attribute	Nominal value	Term	Definition
Magnification	20.9 ×	Ra	Average roughness
Measurement array size	368 µm × 240 µm	Rq	Root mean square roughness
Lateral sampling	0.80 µm	Rsk	Symmetry of the surface profile about the mean line (skewness)
Field of view	295 µm × 224 µm		
Height resolution	< 6 mm	Rku	Sharpness of the profile (kurtosis)
Bearing ratio offsets peak/valley	1%/1%	Rpm	Average maximum profile peak height
Stylus filter type	Gaussian	Rvm	Average maximum valley depth
Stylus X λc, λs	N/A	Rz	Average maximum height of the profile
Stylus Y λc, λs	0.2 mm/2.0 µm		
		Rp	Maximum profile peak height
		Rv	Maximum profile valley depth
		Rpk	Reduced peak height
		RK	Core roughness depth
		Rvk	Reduced valley height
		Rt	Maximum peak-to-valley height of the profile
		Mr1	Peak material component
		Mr2	Valley material component
		Δq	Slope values
		λq	Spacing between local peaks and valleys

prior to the study, the Optical profiler (WYKO NT 2000; WYKO Corporation, Tucson, AZ) and software (WYKO Vision, version 1.800; WYKO Corporation) were calibrated, and a traceable roughness (Ra) standard was measured multiple times to ensure the accuracy of the analyses. Three-dimensional (3D) surface measurements (field of view = 295×224 µm) were made according to several parameters (Table 3) along the superior flanks of exposed screw threads of each product sample. Stylus measurements were derived from 3D measurements performed with the optical profiler's low-pass Gaussian filter, which measured 2.4×2.4 µm with a vertical resolution of 0.006 µm.

To calculate mean roughness values for each proprietary surface, 8 measurements were made on 1 superior thread flank of each product sample (n = 5). The aim of this measurement was to obtain preliminary roughness data from the largest interfacial surfaces of the implants. All surface texture parameters were derived from a measurement of the heights of the various image points, and 3D surface maps were stored and archived in a database for post-analysis processing.

Early Loading Study

The study subjects were consecutive patients who were referred to a private periodontal practice for implant treatment of 1 missing tooth in the maxillary and/or mandibular jaw (Fig 1a). At the time of their referrals, all of the patients had rejected the option of preparing their adjacent healthy teeth to support a conventional fixed prosthesis and were unable to wear a removable prosthesis because of ridge soreness, personal preference, lack of interocclusal or

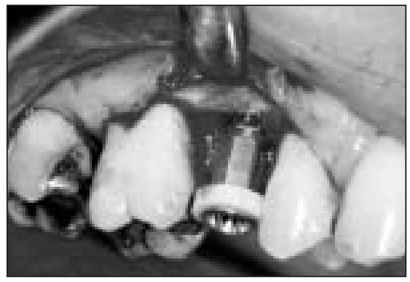

Fig 1a *(Left)* Presurgical edentulous area.

Fig 1b *(Right)* After soft tissue reflection and preparation of the osteotomy with the aid of a surgical template, the implant was screwed into place.

Fig 1c Occlusal view of the attached fixture mount illustrates acceptable parallelism with the adjacent dentition.

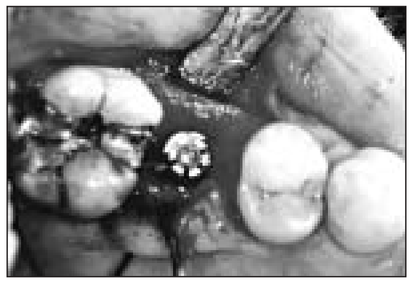

Fig 1d The Spline connection can be seen clearly after removal of the mount.

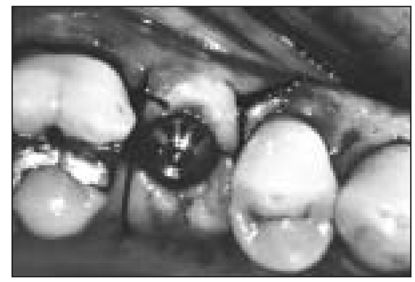

Fig 1e A healing collar is attached to the implant, and then the soft tissues are sutured around it and allowed to heal prior to early loading.

interproximal space, and/or the presence of adjacent dentition whose shape, angulation, or mobility precluded their use as abutments to help retain and stabilize the removable prosthesis.

A comprehensive diagnostic workup was performed to thoroughly evaluate each patient. During the initial interview, medical and dental histories were reviewed to help assess the patient's current health status and to identify any serious conditions that might negatively affect osseointegration (eg, blood dyscrasia, severe endocrine system diseases, severely compromised immune systems, severe musculoskeletal diseases) or long-term implant survival (eg, unresolved periodontal disease, prolonged corticosteroid or immunosuppressive drug therapy, chemotherapy, collagen diseases, history of osteomyelitis or irradiation in the region of the proposed implant site), or risk factors associated with anesthesia and surgery (eg, cardiovascular, respiratory, or renal diseases).[22] The medical and dental histories also provided an important means of identifying allergies that could dictate the use or avoidance of certain drugs or other substances in dental implant therapy.

Heavy smokers (ie, more than 20 cigarettes per day[22]) and patients with other compromising conditions were evaluated on a case-by-case basis but were not necessarily rejected from study participation if their overall anatomy, health evaluations, and other factors (eg, excellent oral hygiene, commitment to regular dental care, controlled medical conditions) suggested a positive prognosis for implant therapy. Smokers were advised of the higher risk of implant failure[23–28] and informed of smoking cessation options[29,30] but were not barred from inclusion in the study.

Radiographic and physical examinations were conducted to assess each patient for the presence of undiagnosed disease, destructive parafunctional habits, oral pathologies that required treatment prior to implant surgery, vertical height of available bone, and adjacent anatomic structures relative to the proposed implant site. Panoramic radiographs were used to provide a single 2D view of the hard and soft tissue anatomy and related structures of the maxilla and the mandible. When greater resolution was needed for observing fine anatomic details, periapical and occlusal radiography was utilized. A diagnostic cast was fabricated and mounted on a semiadjustable articulator utilizing a facebow transfer and vertical registration to determine the jaw relationships and available occlusal dimension, as well as the proposed implant position and restoration crown-to-root ratio.

The implantation process, requirements for study participation, expectations during and after treatment, and the benefits and potential complications of implant therapy were thoroughly explained to each patient, and available treatment alternatives were presented. Each patient signed an informed consent form prior to admission into the study.

A total of 20 consecutive patients ranging in age from 25 to 65 years (mean = 39 years) were selected for inclusion in the study. For each patient, a surgical template was fabricated from a diagnostic waxup

Fig 2 Criteria used for evaluating implant success in the early loading study.

Prerequisite for evaluating implant success	Criteria for implant success
At the time of evaluation, the implants have been under functional loading	≤ 1.5 mm of marginal bone loss during the first year of functional loading
All implants under investigation must be accounted for	≤ 0.2 mm of loss per annum after the first year of functional loading
The method employed to determine implant mobility must be specifically described in operative terms	Absence of implant-related pain, discomfort, altered sensation, and/or infection
Radiographs to measure bone loss should be standard periapical films with specified reference points and angulations	The resultant implant support does not preclude the placement of a planned functional and esthetic prosthesis that is satisfacory to both patient and clinician

to facilitate optimum placement of the implant relative to the proposed prosthesis. Antibiotic prophylaxis involved daily administration of amoxycillin (500 mg) beginning 1 hour before surgery and continuing for 4 days thereafter.

The patients were prepared for aseptic surgery and anesthetized with 2% lidocaine and 1:100,000 epinephrine by local infiltration in the maxilla or the inferior alveolar block in the mandible. Crestal incisions and elevation of the soft tissues were performed, and an osteotomy was sequentially prepared with internally irrigated drills in graduated diameters. The implant was screwed into place (Fig 1b) and the fixture mount was removed according to the manufacturer's protocol (Figs 1c and 1d). A conventional healing collar that extended above the mucosa was attached and the soft tissues were sutured around it (Fig 1e). After 2 months of nonsubmerged healing, the implant was restored with an occluding, metal-ceramic, single-tooth restoration. Six months postoperatively, osseointegration was clinically evaluated by radiograph, percussion, and lateral pressure.[31]

Periapical radiographs utilizing a paralleling technique (Rinn System; Rinn, Elgin, IL) were taken after implant placement, following prosthesis placement (baseline), and at annual recall visits. A transparent template with a 1-mm grid pattern enlarged 25% to help compensate for distortion was placed over each radiograph to evaluate marginal bone change relative to the top of the implant. Bone loss was recorded in increments of 0 to 1 mm, 1 to 2 mm, 2 to 3 mm, 3 to 4 mm, and more than 4 mm. Cumulative implant survival rates were calculated using life table analysis, and implant success was determined according to previously published criteria (Fig 2).[32,33]

RESULTS

3D Surface Roughness Measurement

The test data indicated various differences in surface texture among the samples (Table 4). From an adhesion point of view, parameters such as Rvk, Rsk, and Rvm may indicate the relative depth of the valleys that comprise the various surfaces. The nominal Ra surface roughness values were 0.756 ± 0.073 µm (756 ± 73 nm) for the MTX surface, 0.803 ± 0.257 µm (803 ± 257 nm) for the Osseotite surface, and 2.104 ± 0.403 µm (2104 ± 403 nm) for the SLA surface. While the MTX and Osseotite surfaces had similar average roughness (Ra) values, the skew values (Rsk) indicated that the MTX samples had a greater number of valleys that formed a uniform microtexture pattern on the implant surface. In comparison, the Osseotite samples exhibited a greater number of peaks arranged in a more random surface pattern relative to a Gaussian distribution. Surface slope values (Stylus Y Δq) indicated that Osseotite had the lowest nominal slope of 9.627 ± 1.719 degrees (0.168 ± 0.030 rad) compared to 12.089 ± 0.802 degrees (0.211 ± 0.014 rad) for MTX and 20.569 ± 2.922 degrees (0.359 ± 0.051 rad) for SLA. The dominant surface texture was spaced (Stylus Y λq) closest together for MTX (24.108 ± 1.118 µm/24,108 ± 1,118 nm), followed by Osseotite (30.489 ± 4.016 µm/30,489 ± 4,016 nm) and SLA (36.539 ± 2.773 µm/36,539 ± 2,773 nm). The bearing area parameters (eg, Rpk, Rvk) also differed among the 3 surfaces.

Table 4 Surface Roughness Assay Study: Surface Texture Measurement Data (Mean ± SD)

Value	MTX	Osseotite	SLA
Ra (nm)	756 ± 73	803 ± 257	2,104 ± 403
Rq (nm)	1,035 ± 91	1,038 ± 323	2,737 ± 476
Rsk (none)	–0.61 ± 0.14	0.42 ± 0.17	–0.41 ± 0.28
Rku (none)	6.97 ± 0.95	5.14 ± 1.45	4.29 ± 0.79
Rpm (nm)	3,863 ± 348	4,005 ± 930	8,434 ± 1,971
Rvm (nm)	–4,691 ± 371	–3,142 ± 961	–9,685 ± 988
Rz (nm)	8,554 ± 670	7,147 ± 1,875	18,119 ± 2,706
Rp (nm)	5,701 ± 353	5,180 ± 1,251	10,826 ± 2,904
Rv (nm)	–5,900 ± 439	–4,175 ± 1,268	–11,647 ± 1,401
Rt (nm)	11,601 ± 598	9,355 ± 2,461	22,473 ± 3,910
Rpk (nm)	653 ± 70	1,010 ± 348	1,846 ± 384
RK (nm)	2,091 ± 218	2,443 ± 759	6,167 ± 1,411
Rvk (nm)	1,337 ± 126	676 ± 194	3,005 ± 210
Mr1 (%)	8.0 ± 0.5	11.1 ± 1.1	8.7 ± 1.1
Mr2 (%)	86.4 ± 0.5	91.5 ± 0.5	87.3 ± 0.8
X slope Rq (mrad)	289 ± 12	227 ± 32	486 ± 69
Y slope Rq (mrad)	273 ± 14	219 ± 33	467 ± 67
S area index (none)	1.0763 ± 0.0067	1.0508 ± 0.0134	1.1926 ± 0.0452
Surface area (μm^2)	41,907 ± 1,900	43,818 ± 2,358	48,450 ± 3,729
Norm volume (BCM)	1.763 ± 0.144	1.995 ± 0.419	4.003 ± 1.069
Stylus Y Ra (nm)	608 ± 70	654 ± 207	1,677 ± 308
Stylus Y Rt (nm)	4,291 ± 347	3,764 ± 1,029	9,300 ± 1,412
Stylus Y Rz (nm)	4,291 ± 347	3,764 ± 1,029	9,300 ± 1,412
Stylus Y Rpk (nm)	700 ± 55	944 ± 288	1,635 ± 312
Stylus Y Rk (nm)	1,515 ± 227	1,799 ± 527	4,555 ± 959
Stylus Y Rvk (nm)	1,435 ± 119	716 ± 207	2,595 ± 161
Stylus Y Δq (rad)	0.211 ± 0.014	0.168 ± 0.030	0.359 ± 0.051
Stylus Y λq (nm)	24,108 ± 1,118	30,489 ± 4,016	36,539 ± 2,773
Stylus Y Pc (1/mm)	13.8 ± 0.3	10.8 ± 1.7	8.4 ± 0.9

Early Loading Study

Twenty patients were enrolled in the study, and a total of 30 implants (Spline Twist MTX, Centerpulse Dental) were placed in areas of the maxillary incisors (n = 4), maxillary premolars (n = 6), mandibular premolars (n = 8), and mandibular first molars (n = 12) (Table 5). Three test implants placed in the molar regions of 2 patients (smokers) failed prior to loading (Tables 5 and 6). These patients were censured from the study data and successfully retreated with dental implants after bone healing. All of the remaining 27 implants in 18 patients were loaded at 2 months and monitored through 4 years of clinical follow-up. Cumulative survival rates were 100% in both jaws (Table 6). Radiographs indicated no discernible marginal bone changes at any time period; all implants showed bone loss of 1 mm or less from baseline levels. Cumulative implant success was 100%.

DISCUSSION

Optical profilometry showed certain similarities in the nominal roughness (Ra) values of the MTX and Osseotite surfaces in the present study; however, MTX had a more uniform surface characterized by a greater number of valleys spaced closer together (Stylus Y λq) and higher slope values (Stylus Y Δq). The volume and surface index were evaluated relative to the finest lateral resolution of the given image. In general, the values specified should only have significant figures to 0.00 µm, since the vertical resolution was 0.006 µm. The optical profiler's low-pass Gaussian filter (2.4 × 2.4 µm) was similar to the filters described by Wennerberg and Albrektsson.[34] The latter also recommended that a total of 9 topographic measurements with optical profilometry were adequate to obtain a stable mean value of the surface roughness of screw-type implants: 3 superior or inferior thread flanks, 3 thread tips, and 3 interthread valleys.[34] In the present study, 40 topographic measurements (ie, 8 measurements of 1

Table 5 Early Loading Study: Patient Demographics

Age (y)	Medical risks	Missing dentition	Implant Length (mm)	Implant Diameter (mm)
65	Diabetes	Mandibular right first molar	13	5.0
22	None	Maxillary right central incisor	15	3.75
		Maxillary left central incisor	15	3.75
34	Smoker	Madibular right first premolar	13	3.75
35	Smoker*	Mandibular left first molar	13	5.0
		Mandibular right first molar	13	5.0
22	None	Mandibular left first premolar	13	3.75
53	None	Mandibular right second premolar	15	3.75
		Mandibular right first molar	13	5.0
45	None	Mandibular left first molar	13	5.0
62	Hypertension	Maxillary left first premolar	15	3.75
56	None	Mandibular left first premolar	15	3.75
		Mandibular left second premolar	13	3.75
		Mandibular left first molar	13	5.0
54	Diabetes	Maxillary left first premolar	15	3.75
		Maxillary right second premolar	15	3.75
50	Hypertension	Mandibular right first premolar	13	3.75
		Mandibular right second premolar	13	3.75
		Mandibular right first molar	13	5.0
26	Smoker	Mandibular right first molar	13	5.0
35	Diabetes	Maxillary right first premolar	13	3.75
28	None	Maxillary right central incisor	15	3.75
		Maxillary left central incisor	15	3.75
26	Smoker*	Mandibular right first molar	13	5.0
24	None	Mandibular left first premolar	13	3.75
50	Smoker	Mandibular left first molar	13	5.0
27	None	Maxillary right first premolar	13	3.75
40	None	Mandibular left first molar	13	5.0
		Mandibular right first molar	13	5.0
26	None	Maxillary right first premolar	14	3.75

*Implant(s) failed prior to loading.

Table 6 Early Loading Study: Life Table Analysis of Implant Survival After Loading

Category/ time (y)	No. of patients*	No. of implants*	No. lost	Survival rate (%)	Cumulative survival rate (%)
All implants					
0–1	18	27	0	100	100
1–2	18	27	0	100	100
2–3	18	27	0	100	100
3–4	18	27	0	100	100
Maxillary implants					
0–1	10	10	0	100	100
1–2	10	10	0	100	100
2–3	10	10	0	100	100
3–4	10	10	0	100	100
Mandibular implants					
0–1	8	17	0	100	100
1–2	8	17	0	100	100
2–3	8	17	0	100	100
3–4	8	17	0	100	100

*Censured from these data are a total of 3 implants that failed in 2 patients prior to loading.

Table 7 Review of Studies of Immediate/Early Implant Loading

Study	Implant system			No. of patients	Type of prosthesis‡	Immediate loading			Follow-up time (mo)
	System	Design*	Surface topography†			No. placed	No. loaded	Survival (%)	
Balshi and Wolfinger[38]	Brånemark	2	M	10	SRD	40	40	80	12–18
Randow et al[39]	MK II	2	M	16	SRD	88	88	100	18
Schnitman et al[40]	Brånemark	2	M	10	SRD	28	28	84.7	120
Horiuchi et al[41]	Brånemark	2	M	14	SRD	140	136	97.2	8–24
Chow et al[42]	Brånemark	2	M	27	SRD	123	115	98.3	3–30
Brånemark et al[43]	Brånemark	2	M	50	SRD	150	150	98	6–36
Chiapasco et al[44]	MK II	2	M	10	BO	40	40	97.5	24
Kupeyan and May[45]	MK II	2	M	10	ST	10	10	100	6
Hui et al[46]	Brånemark	2	M	24	ST	24	24	100	1–15
Tarnow et al[47]	Brånemark 3i ITI AstraTech	2 2 1 2	M AT B/E GB	10	CRD	69	69	97.1	1–60
Jaffin et al[48]	MTS ITI	1 1	M TPS, B/E	27	SRPD	149	149	95.3	6–60
Ganeles et al[49]	ITI	1	B/E	27	SRD, CRD	161	160	99.4	13–41
Røynesdal et al[50]	ITI	1	B/E	11	BA	22	22	100	24
Gatti et al[51]	ITI	1	B/E	21	BO	84	76	96.1	25–60
Chiapasco et al[52]	ITI Friatec TPS screw Mathys	1 2 1 2	B/E B/E TPS HA	226	BO	904	776	96.9	24–156
Chaushu et al[53]	Steri-Oss AlphaBio	2 2	HA HA	28	ST	28	28	88.5	6–24
Wöhrle[54]	Steri-Oss	2	HA, TPS, AE	14	ST	14	14	100	9–36
Steveling et al[55]	AstraTech	2	GB	17	ST, SRPD	44	44	100	12–60

*1 = 1-stage; 2 = 2-stage.
†M = machined; AT = acid treated; B/E = blasted/etched; GB = grit-blasted; TPS = titanium plasma spray; HA = hydroxyapatite; AE = acid etched.
‡SRD = screw-retained, multiple-unit denture; BO = bar overdenture; ST = single tooth replacement; CRD = cement-retained, multiple-unit denture; SRPD = screw-retained, multiple-unit partial denture; BA = overdenture retained by ball attachments.

superior thread flank on each of 5 samples from different manufacturing lots) were made of each surface with vertical scanning interferometry. In future studies, a more complete measurement of surface area and volume may be obtainable through the use of fractal analysis and/or incorporation of the 9-measurement guideline.

The 2-stage surgical procedure with delayed prosthetic loading developed by Brånemark and coworkers[35] has been a standard protocol for many clinicians. During the 1970s, Ledermann[36,37] introduced the technique of placing 4 dental implants with roughened titanium plasma spray (TPS) surfaces in the symphyseal region of the edentulous mandible, followed by immediate splinting and loading with a bar-supported overdenture. The rationale for the procedure was that the dense symphyseal bone and rigid splinting would prevent implant micromovement and allow osseointegration to occur during immediate functional loading. A recent resurgence of clinical interest in the immediate/early loading of dental implants with roughened surfaces has spawned a number of new clinical studies that report impressive short-term results with both 1- and 2-stage implant designs (Table 7).[38–55]

Although the sample size of the present early loading study was small, the finding of 100% success over 4 years of clinical follow-up with little or no marginal bone loss was promising. The presence of poor-quality (type 4) bone and the difficulty of achieving immediate implant stabilization still pose ongoing challenges to placing implants in the maxillary jaw, as evidenced by the number of studies over the past 20 years that have reported implant failure rates that were approximately 10% higher in the maxilla than in the mandible.[56] In the present study, the implant survival rate was 100% for both mandibular and maxillary implants.

CONCLUSIONS

Within the scope of the present study, MTX implants exhibited a uniform micropitted surface and 100% clinical success after nonsubmerged placement, early loading at 2 months, and a maximum clinical follow-up time of 48 months.

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