Lateral Alveolar Ridge Expansion in the Anterior Maxilla Using Piezoelectric Surgery for Immediate Implant Placement

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Purpose: *The purpose of this study was to evaluate the efficacy of the ridge-splitting technique in the anterior maxilla, using piezoelectric surgery for immediate implant placement. Study outcomes were compared with those of implant placement in the same patients using the conventional drilling technique.* ***Materials and Methods:*** *Ten patients received a total of 22 implants in the anterior maxilla, 11 of which were placed using a ridge-splitting procedure (test group) and the other 11 using the conventional drilling procedure (control group). Ridge width (RW), crestal bone level (BL), and implant stability quotient (ISQ) were measured at different points in time. Data were analyzed and compared between the groups using analysis of variance (ANOVA) and paired-sample t tests at a significance level of 5%.* ***Results:*** *For the test group, the gain in RW was not stable in time because at 6 months postoperatively, the RW lost some of the initial gain; however, the net gain was still significant. At 6 months postoperatively, BL was similar for both groups. The net bone loss on the mesial aspect and the average of the mesial and the distal measures did not differ significantly between both groups. ISQ values sharply increased at 3 months postoperatively in the test group. All implants met the modified Albrektsson criteria (1989) for success.* ***Conclusion:*** *The results from this study support the efficacy and safety of ridge expansion using piezoelectric surgery for implant insertion in the anterior maxilla. The modest net gain in bone width suggests that additional hard and soft tissue augmentation may be necessary, especially in the esthetic zone. ISQ values suggest a minimum healing time of 3 months before loading the implants that have been inserted using this ridge-splitting protocol.*
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The success rate of endosseous implant placement in native bone has been proven to be highly predictable. Reliable long-term results require sufficient bone thickness surrounding the implant body.[1] This is especially true in the maxillary esthetic zone, where bone thickness of 1 mm or more is necessary to prevent loss of the buccal bone margin and to maintain the integrity of the gingival architecture.

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Advanced atrophy of the alveolar process after tooth loss often necessitates ridge augmentation before dental implants of adequate dimension can be inserted in an optimal position. The correct implant position within the alveolar ridge determines the predictability of the esthetic and functional outcome of the treatment.[2]

The width of the alveolar ridge decreases significantly after the first year of tooth loss and continues afterward as a process of natural remodeling.[3,4] It has been observed that the pattern of bone remodeling occurs at the expense of the buccal bone plate, causing a shift of the alveolar crest lingually compared with its preextraction buccal contour.[5,6]

Different ridge augmentation techniques have been utilized with comparable success to regain bone thickness in a horizontally resorbed ridge. These include bone-grafting procedures such as onlay block grafts or guided bone regeneration (GBR) and expansion procedures such as bone splitting for ridge expansion.[7,8] The disadvantage of bone-grafting procedures relative to expansion procedures is that they usually require longer treatment times with additional surgeries and costs.

The bone splitting for lateral ridge expansion techniques have been used as an alternative approach to bone-grafting procedures. The edentulous ridge is sectioned lengthwise, and the buccal and lingual cortical plates are separated. Different instruments have been used for making the lengthwise cut, including chisels and mallets,[7,9,10] rotary burs,[11,12] discs,[13,14] oscillating saws,[15] or surgical blades.[16,17] The risk of damaging soft tissue due to limited oral accessibility makes these cutting procedures highly technique sensitive. Summers osteotomes or screw-shape devices have been employed to perform the spreading procedure to expand the buccolingual dimension of the split ridge, creating a space for implant placement.

With the advent of piezoelectric surgical devices, a more precise alternative technique for ridge splitting has been introduced. The Piezosurgery (Mectron) used in this study is one such device currently available. Its piezoelectric transducers create ultrasonic movement, which vibrates the cutting tip of the Piezosurgery insert to a selected frequency optimized for cutting through mineralized tissue like tooth and bone. Studies have claimed that soft tissue such as gingiva, nerves, blood vessels, and sinus membranes are safer from injury when using piezoelectric devices compared with conventional cutting methods.[18–20]

Data on ridge-splitting techniques for expansion and immediate implant insertion have been scarce, and prospective studies done using piezoelectric devices were even less common. Most of the articles have been presented as case studies, and although a few large studies have been reported, they focused mainly on the success rates. For example, one study, which used Beaver blades for ridge splitting, placed 329 implants in 170 patients with a success rate of 98.5% after 5 years.[17] In another study using an ultrasonic cutting device, 57 patients received 230 implants. The authors reported a mean of 2.8 mm gain in ridge thickness with a 96.5% success rate.[21] A 1- to 3-year multicenter follow-up study by Chiapasco et al used oscillating saws and chisels for ridge splitting, and an Extension Crest device was employed for ridge expansion. These authors reported an increase in ridge thickness by 2 to 5 mm right after the procedure.[15] In a recent study, Bassetti et al placed 17 implants in each of two cohort groups. Ridge splitting with piezoelectric surgery was employed in the study group, and implant insertion using a standard drilling protocol was used in the control group. The intercortical space was filled with Bio-Oss (Geistlich) and covered with Bio-Gide membrane (Geistlich). They reported that the mean bone width increased 4.7 mm intraoperatively. Crestal bone-level alterations after 27 months of follow-up revealed statistical differences between the study group and the control group. They observed that most bone loss occurred during the unloaded healing period after implant surgery. The implant survival rate was 100%.[22]

Although all these studies reported on the efficacy of the ridge-splitting techniques, most (except Bassetti et al) did not compare ridge splitting with conventional drilling, and none have directly compared the two techniques in the same subjects' mouths, which allows for a better comparison because it reduces intersubject variability. The current prospective split-mouth comparative study fills this gap.

In the same subject's mouth, for the test implant group (TG), implants were placed in a narrow alveolar ridge using the alveolar ridge-splitting technique for lateral expansion (RSE), and for the control implant group (CG), the conventional drilling technique was employed to place implants in a ridge with a thickness of 5 mm or more. The alveolar ridge width (RW) and crestal bone level (BL), which is the vertical distance between the implant shoulder and the marginal bone crest in both implant groups, were recorded as primary outcomes, and the implant stability quotient (ISQ) values obtained using the Osstell ISQ device (Osstell) were recorded as secondary outcomes. The data were analyzed and compared between the two implant groups. The implant success rate using modified Albrektsson criteria (1989) for success[23] was also assessed.

The purpose of the present split-mouth controlled study was to evaluate the efficacy of the RSE in the anterior maxilla, from the second premolar to the opposite second premolar, using the Piezosurgery unit and Bone Expanders (Mectron) for immediate implant placement. In addition, the study directly compares outcomes between the RSE and the conventional drilling technique.

Hypothesis

To test the efficacy and safety of ridge splitting for expansion using Piezosurgery and Bone Expanders for implant insertion in the anterior maxilla, the authors hypothesized that the primary outcomes, ie, RW and BL, and the secondary outcome, ie, ISQ, would not differ for both implant groups.

MATERIALS AND METHODS

Materials

Ten patients, five men and five women, were selected for this prospective split-mouth control study. All surgical and prosthetic treatments were performed at the first author's private clinic. The study protocol and the patient informed consent form were approved by the Veritas IRB Ethics Review Board (Veritas IRB, Montreal).

Inclusion Criteria

The inclusion criteria were as follows:

- Being at least 18 years of age

- Being systemically healthy
- Having a minimal ridge thickness of 3.5 mm at the study site, and having adequate horizontal bone volume for implant insertion without the need for bone augmentation at the control site
- A period of bone healing of at least 3 months after tooth extraction
- Demonstrated ability to maintain oral hygiene
- Willing and able to commit to follow-up appointments
- Able to understand the study procedure and provide signed informed consent

Exclusion Criteria

The exclusion criteria were as follows:

- Exhibiting extreme alveolar ridge atrophy with no cancellous bone between the buccal and palatal cortical plates
- Exhibiting excessive vertical ridge resorption that requires vertical augmentation
- Suffering from uncontrolled periodontal disease
- In need of a sinus elevation procedure in the site of the intended implant placement
- Wearer of a pacemaker in whom the use of a Piezosurgery unit is contraindicated
- Suffering from severe renal or liver diseases
- Having a history of radiotherapy of the head and neck region
- Undergoing chemotherapy for treatment of malignant tumors at the time of the study
- Being immunocompromised
- Presently on IV bisphosphonates or having taken long-term oral bisphosphonates for more than 3 years
- Being pregnant or intending to conceive during the course of the study

Each patient underwent a comprehensive examination including dental, periodontal, temporomandibular joint (TMJ)/occlusal, and routine radiographic assessment. Oral photographs were taken, and study models were obtained. A diagnostic wax-up was subsequently ordered along with a cone beam computed tomography (CBCT; Promax3D Planmeca) radiographic stent that was later modified to be used as the surgical template. Two other vacuform templates of labial and palatal extension were also fabricated for ridge mapping.

The Piezosurgery Unit

The Piezosurgery unit (Mectron) was employed for the ridge-splitting procedure. It operates at a frequency range of 24 to 36 kHz. For this study, the cortical bone-cutting mode was selected. Insert #OT7S-3 (Fig 1) was used to cut the ridge lengthwise creating a slit of 0.35 mm in width. The same insert was also used to prepare the vertical released cuts. Insert #IM1S was used for initiating implant site preparation by creating a 1-mm-diameter pilot hole.

Bone Expanders

The Bone Expanders (Mectron) are a set of screw-shaped instruments, smaller at the tip and progressively larger at the base. A slow-speed handpiece or hand-ratchet is used to screw the Bone Expanders into the slot created by the Piezosurgery tools. The slow-speed handpiece or hand-ratchet permits controlled spreading of the cortical plates. In this study, the Bone Expanders were motor driven into the pilot hole at the speed of 15 rpm, which slowly expanded the ridge. For implants of 3.5 mm in diameter used in the TG, only expanders of 2.5 mm in diameter were used.

Ridge-Mapping Templates

Two vacuform templates were fabricated for ridge mapping. In the first template, seven holes, 2 mm apart from each other, were prepared. Three of these holes corresponded to the buccal aspect of the ridge, three corresponded to the lingual aspect of the ridge, and one corresponded to the crest of the ridge at the planned implant site. This template was placed in the patient's mouth, and under local anesthetic, an endodontic file with a rubber stop was inserted in the prepared holes to measure the distance from the outer surface of the template to the resistance of the underlying bone. These measurements were transferred to their corresponding locations as dots on the cross section of a duplicated cast. By connecting these dots, the cross-section profile of the alveolar ridge was drawn on the cast. This cross-section profile was needed to fabricate a second vacuform template that was used for measuring the ridge width using the ridge-mapping caliper. On this new template, four holes were drilled into its buccal and lingual aspects, which corresponded to two vertical locations: the first one 2 mm from the summit of the crest of the ridge (location 1) and the second one 5 mm apical to location 1 (location 2). This template would provide reproducible reference points for measuring ridge width using a ridge map caliper.

Methods

Treatment Procedures. All patients were instructed to take 500 mg of amoxicillin 1 hour before surgery, and continued three times per day for 7 days. Motrin 600 mg every 4 hours as needed was prescribed for pain. Patients rinsed their mouths with chlorhexidine 0.1% immediately before the surgery.

The surgical procedure was done under local anesthetic (Carbocaine 2% with Neo-Cobefrin 1:20,000 [Carestream Health]). For both TG and CG, a midcrestal incision was performed extending along the length of the

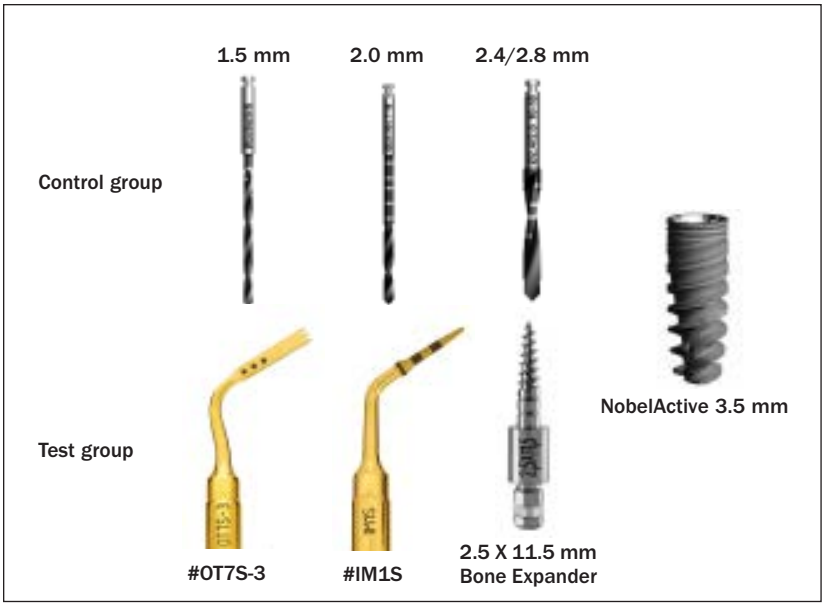

Fig 1 A summary of the sequence of the instruments used for each group. For the control group, twist drills were used to prepare space for implant insertion according to the manufacturer's protocol. For the test group, a Piezosurgery unit was employed for osteotomy using inserts #OT7S-3 and #IM1S. A Bone Expander of 2.5 × 11.5 mm was used for ridge expansion.

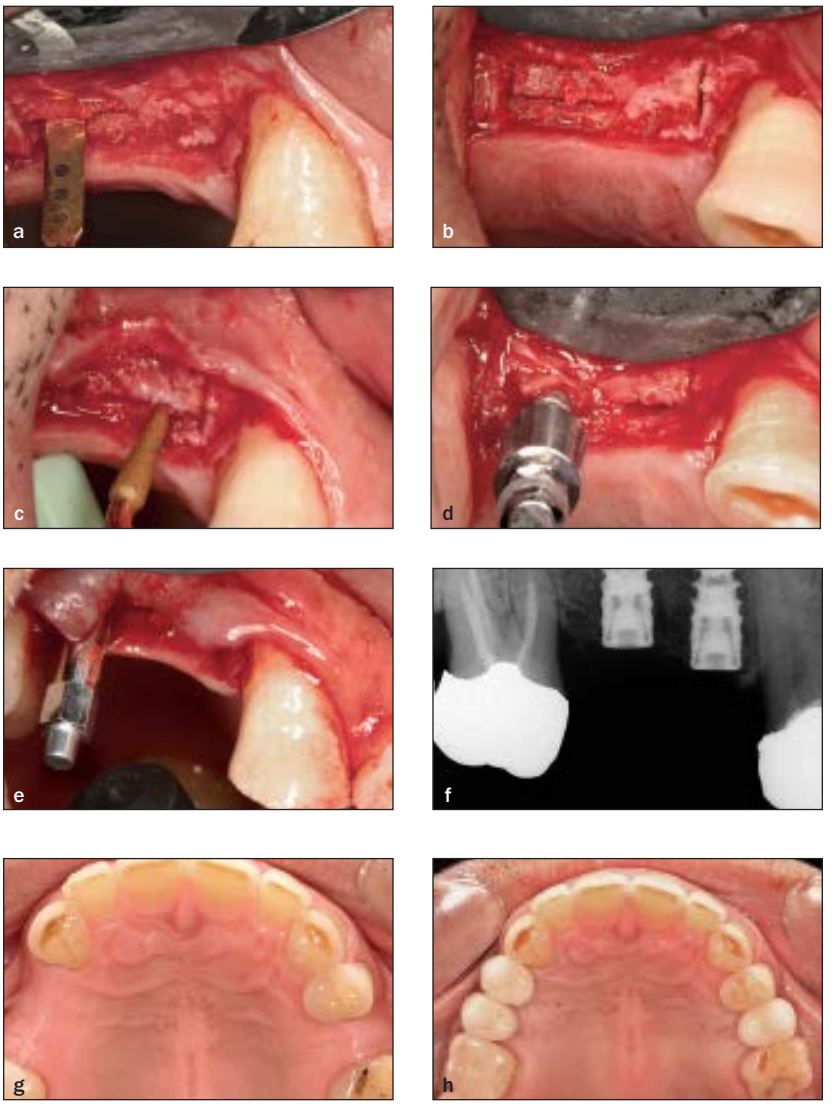

Fig 2 *(a)* The ridge was cut lengthwise using insert #OT7S-3. *(b)* Crestal and vertical released cuts were completed. *(c)* A pilot hole was prepared using insert #IM1S. *(d)* The Bone Expander was motor-driven into the prepared site. *(e)* Ostell's ISQ values were obtained. *(f)* Radiographic images were taken using the long cone parallel technique. *(g)* The preoperative occlusal photograph. *(h)* The postoperative occlusal photograph; one test implant was placed for the right first premolar, and one control implant was placed for the left second premolar.

maxillary ridge. When natural teeth were in the proximity, the incision continued into the buccal sulcus of at least one tooth at both ends. A full-thickness flap with minimal flap reflection was raised just wide enough to expose the alveolar bone crest. In most cases, when the visualization of the labial contour of the alveolar ridge was necessary for direction of the osteotomy, a split-thickness flap was performed so that the blood supply from the periosteum to the labial cortical bone plate was not severed.[24] The split-thickness flap was very mobile, thus allowing tension-free suturing to cover the expanded ridge.

For the TG, the Piezosurgery unit was employed for the osteotomy. The alveolar ridge was cut lengthwise using insert #OT7S-3. The length of the cut depended on the number of implants placed; in general, it ended 1.5 mm away from the adjacent root of the natural teeth or implants. If free space was available, the cut could extend 3 to 4 mm mesial or distal from the planned implant site. Depending on the length of the implant, insert #OT7S-3 was maneuvered in a vertical motion until 10 to 13 mm in depth was reached. Two additional vertical release cuts at the ends of the osteotomy were also prepared. With the help of the surgical template, the locations of the implants were marked, and the implant site preparation was initiated using Piezosurgery insert #IM1S. A Mectron Bone Expander of 2.5 × 11.5 mm was subsequently motor-driven into the prepared site at the speed of 15 rpm. The insertion of the screw-shaped expander applied a spreading action that slowly and gradually separated the labial and palatal bone plates, increasing the thickness of the ridge. NobelActive implants (Nobel Biocare) of 3.5 mm in diameter, 10 or 13 mm in length, were hand-driven into the preparation.

For the CG, NobelActive implants of either 3.5 or 4.3 mm (for two implants) diameter were placed according to the surgical protocol for NobelActive implants. Using the surgical template, locations of the implants were marked, and the osteotomy was prepared using a pilot drill to the full depth. Subsequently, a twist drill with a 2 mm diameter and twist step drills with diameters of 2.4/2.8 mm were used to complete the preparation. All implants were inserted at approximately 1 mm subcrestally. Osstell's ISQ values were obtained at four different locations for each implant before cover screws were mounted.

The new labiopalatal dimension of the ridge was measured using the ridge-mapping template and caliper. Since the implants were placed at 1 mm subcrestally, the first location in the template, 2 mm apical to the crest of the ridge (location 1), was now positioned at approximately 1 mm apical to the implant shoulder. The flap was repositioned and immobilized with resorbable sutures (Vycril, Ethicon). Periapical radiographs were taken, and standard postoperative instructions were given to the patients.

After 3 months, the implants were uncovered, and healing abutments were placed. Osstell's ISQ values were also obtained at this time. Provisional prostheses were fabricated and delivered. The definitive impression was taken 3 weeks later. At 6 months postoperatively, periapical radiographs were taken, labiopalatal bone thickness was measured, and Osstell's ISQ values were obtained before the definitive prostheses were placed (Fig 2).

Two months after the placement of the definitive prostheses, all implants were evaluated for success rates.

Resonance Frequency Analysis

The Osstell ISQ stability meter (Osstell) was used to evaluate the implant stability at the time of the surgery and at 3 and 6 months postoperatively. The Osstell instrument provides the ISQ, a measure of solidity at the bone-to-implant interface, based on resonance frequencies reflected from a device (SmartPeg) attached directly to the implant. ISQ values range from 1 to 100. Higher values indicate a more stable implant.

ISQ values were recorded at four locations for each implant: mesiobuccal (MB), mesiolingual (ML), distobuccal (DB), and distolingual (DL).

Radiographic Monitoring

Digital periapical radiographs (Schick 33 intraoral digital sensor #2, Sirona Dental) were taken immediately postoperatively and at 6 months postoperatively. The long cone parallel technique was performed using a sensor holder (Schick CDR Holders, Sirona Dental). Except for one fully edentulous case, in all other patients, an individualized silicone occlusal index was fabricated, which allowed the sensor holder to be positioned in the same location each time.

BL values were measured at the mesial and distal positions of the implants using an x-ray image processing software (Image Astra, Astra System). The implant length and shoulder width were used for measuring calibration.

Criteria for Success

All implants were evaluated at 8 months according to the modified Albrektsson criteria (1989) for success.
These criteria are listed as follows:

- Absence of persistent subjective complaints, such as pain, foreign body sensation, and/or dysesthesia
- Absence of a recurrent peri-implant infection with suppuration
- Absence of implant mobility
- Absence of a continuous radiolucency around the implant

Albrektsson and his co-researchers also proposed criteria of bone loss less than 0.2 mm annually following the implant's first year of service. As the present study time was less than 1 year, it did not include this criterion.

Table 1 Demographics of the Study

			Control implant			Test implant		
Patient No.	Age (y)	Sex	Location[a]	Length (mm)	Diameter (mm)	Location[a]	Length (mm)	Diameter (mm)
1	67	F	15	10	3.5	13	10	3.5
2	60	F	14	10	3.5	15	10	3.5
3	47	M	15	10	3.5	24	10	3.5
4	60	F	13	10	4.3	23	13	3.5
5	56	M	25	10	3.5	14	10	3.5
6	72	F	13	10	3.5	15	10	3.5
			23	10	3.5	25	10	3.5
7	76	M	25	10	4.3	12	10	3.5
8	56	M	12	11.5	3.5	21	11.5	3.5
9	62	M	12	11.5	3.5	22	11.5	3.5
10	49	F	25	10	3.5	15	10	3.5

[a]FDI tooth-numbering system.

Statistical Analysis

Comparison of the means for each measure (RW, BL, ISQ) at each time point was done using analysis of variance (ANOVA) and paired-sample *t* tests at a significance level of 5%. The data were first tested for normality using the Shapiro-Wilk methodology. All results were crosschecked using paired-sample Wilcoxon signed-rank tests.

RESULTS

This split-mouth control clinical study was performed between February 2013 and February 2014. Twenty-two implants were placed in the maxilla from the second premolar to the opposite second premolar of 10 patients. The patients' age, sex, implant location, and implant length and diameter are listed in Table 1.

Prosthetic restorations were comprised of seven fixed partial dentures, six single crowns, and one full-arch screw-retained prosthesis. Except for the screw-retained full-arch prosthesis, all other prostheses were cement-retained.

No complications occurred during the surgeries, and all patients healed uneventfully. At the last follow-up visit, 5 months after functional loading, all the implants met the criteria of success.

The test and control implant groups were compared on several measures to assess the efficacy of the RSE study technique, including: *(1)* widths of the alveolar ridges measured through RW at location 1 and location 2 preoperatively (T_0), immediately postoperatively (T_1), and 6 months postoperatively (T_6); *(2)* crestal bone level measured through BL immediately postoperatively and 6 months postoperatively; *(3)* implant stability measured through ISQ immediately postoperatively, 3 months postoperatively (T_3), and 6 months postoperatively.

Width of the Alveolar Ridges

The RW was measured at locations 1 and 2 at T_0, T_1, and T_6 (Tables 2 and 3). Table 4 shows the change in RW of the TG over time. The mean values were compared in time within each implant group and between the two implant groups. Figures 3 and 4 show the mean RW of the two groups at locations 1 and 2 over time.

The ANOVA showed a main effect of group by time, in which, over time, RW changed differently for CG and TG in both location 1 ($F[2,20] = 108.31$, $P < .01$) and location 2 ($F[2,20] = 41.56$, $P < .01$].

At location 1, for the CG, there was no change in RW over time ($t[10] = 1.0$, $P > .999$). For the TG, compared with the T_0 baseline, there was a gain in mean RW at T_1 of 2.7 ± 0.4 mm ($t[10] = 19.33$, $P < .01$). At 6 months postoperatively, this gain was reduced to a net gain of 1.3 ± 0.6 mm, which was also statistically significant ($t[10] = 6.3$, $P < .01$).

At location 2, for the CG, there was no change in RW over time ($t[10] = 0.4$, $P = .68$). For the TG, compared with the T_0 baseline, there was a gain in mean RW at T_1 of 1.6 ± 0.6 mm ($t[10] = 9.0$, $P < .01$). At 6 months postoperatively, this gain was reduced to a net gain of 1.0 ± 0.6 mm, which was also statistically significant ($t[10] = 4.9$, $P < .01$).

When the mean RWs were compared between TG and CG, at T_0 for location 1, TG (4.1 ± 0.2 mm) was smaller than CG (5.5 ± 0.5 mm) ($t[10] = 8.52$,

Table 2 Control Group Ridge Width

Patient No.	Implant Diameter (mm)	Location 1			Location 2		
		T_0	T_1	T_6	T_0	T_1	T_6
1	3.5	5.0	5.0	5.0	6.0	6.0	6.0
2	3.5	5.0	5.0	5.0	6.0	6.0	6.0
3	3.5	6.0	6.0	6.0	8.0	8.0	8.0
4	4.3	6.0	6.5	6.0	6.0	6.0	6.0
5	3.5	6.0	6.0	5.5	6.5	6.5	6.0
6	3.5	5.5	5.5	5.5	6.0	6.0	6.0
	3.5	5.5	5.5	5.5	6.0	6.0	6.0
7	4.3	5.0	5.0	5.0	8.0	8.0	8.0
8	3.5	6.0	6.0	6.0	6.5	6.5	6.5
9	3.5	5.0	5.0	5.0	6.0	6.0	7.0
10	3.5	5.0	5.0	5.0	6.0	6.0	6.0
Mean ± SD		5.5 ± 0.5	5.5 ± 0.5	5.4 ± 0.4	6.5 ± 0.8	6.5 ± 0.8	6.5 ± 0.8

Table 3 Test Group Ridge Width

Patient No.	Implant Diameter (mm)	Location 1			Location 2		
		T_0	T_1	T_6	T_0	T_1	T_6
1	3.5	4.0	6.0	6.0	5.0	6.5	6.0
2	3.5	4.0	7.0	5.0	4.0	6.5	5.5
3	3.5	4.0	7.0	6.5	5.0	7.0	7.5
4	3.5	4.0	7.0	5.0	5.0	6.5	5.5
5	3.5	4.5	6.5	5.0	7.0	8.0	7.0
6	3.5	4.5	7.0	5.0	5.5	6.5	6.0
	3.5	4.0	7.0	6.0	5.0	6.5	6.0
7	3.5	4.0	7.0	5.0	6.0	8.0	7.0
8	3.5	4.0	6.0	5.0	5.5	6.0	6.0
9	3.5	4.0	7.0	5.0	5.0	7.0	6.5
10	3.5	4.5	7.0	5.5	5.5	7.5	6.5
Mean ± SD		4.1 ± 0.2	6.8 ± 0.4	5.4 ± 0.4	5.3 ± 0.8	6.9 ± 0.7	6.3 ± 0.6

Table 4 Change in Test Ridge Width (mm)

Patient No.	Location 1			Location 2		
	T_1 vs T_0	T_6 vs T_1	T_6 vs T_0	T_1 vs T_0	T_6 vs T_1	T_6 vs T_0
1	2.0	0.0	2.0	1.5	–0.5	1.0
2	3.0	–2.0	1.0	2.5	–1.0	1.5
3	3.0	–0.5	2.5	2.0	0.5	2.5
4	3.0	–2.0	1.0	1.5	–1.0	0.5
5	2.0	–1.5	0.5	1.0	–1.0	0.0
6	2.5	–2.0	0.5	1.0	–0.5	0.5
	3.0	–1.0	2.0	1.5	–0.5	1.0
7	3.0	–2.0	1.0	2.0	–1.0	1.0
8	2.0	–1.0	1.0	0.5	0.0	0.5
9	3.0	–2.0	1.0	2.0	–0.5	1.5
10	2.5	–1.5	1.0	2.0	–1.0	1.0
Mean ± SD	2.6 ± 0.4	–1.4 ± 0.7	1.2 ± 0.6	1.6 ± 0.6	–0.6 ± 0.5	1.0 ± 0.6

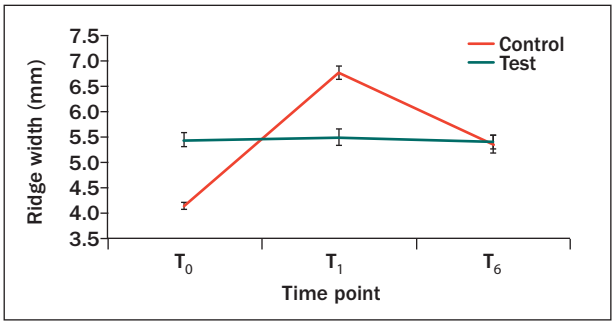

Fig 3 Ridge width at location 1 over time.

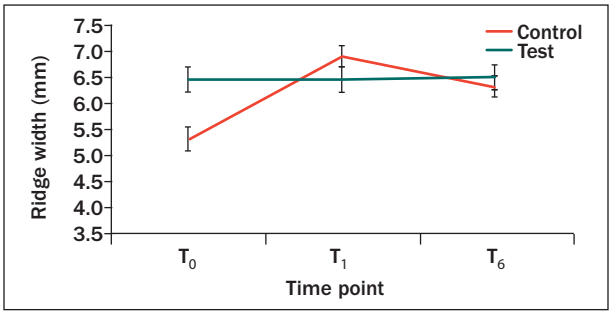

Fig 4 Ridge width at location 2 over time.

Table 5 Change in BL in Control Group

Patient No.	Implant site[a]	BL T_1	
		Mesial	Distal
1	15	–1.31	–0.48
2	14	–1.82	–1.15
3	15	–1.33	–1.3
4	13	–0.4	–0.4
5	25	–0.77	–0.33
6	13	–1.33	–1.36
	23	–0.36	–0.32
7	25	–1.2	1.72
8	12	–0.81	–0.81
9	12	–1.23	–0.72
10	25	–1.13	0.37
Mean ± SD		–1.06 ± 0.44	–0.43 ± 0.88

[a]FDI tooth-numbering system.
ΔBL = difference in BL values between T_6 and T_0; ΔBLm = ΔBL measured on the mesial aspect of implant; ΔBLd = ΔBL measured on the distal aspect of implant; ΔBLm-d = average of mesial and distal ΔBL values.

$P < .01$), and the same pattern was found for location 2: TG (5.3 ± 0.8 mm) was smaller than the CG (6.5 ± 0.8 mm) (t[10] = 4.08, $P < .01$). However, at T_1, for location 1, TG (6.8 ± 0.4 mm) was wider than CG (5.5 ± 0.5 mm) (t[10] = 5.86, $P < .01$), but for location 2, the RWs for TG (6.9 ± 0.7 mm) and CG (6.5 ± 0.8 mm) were not significantly different from each other (t[10] = 2, $P = .37$).

At T_6, TG and CG did not differ at either location: location 1: TG (5.4 ± 0.4 mm) and CG (5.4 ± 0.4 mm) (t[10] = 0.23, $P = .82$); location 2: TG (6.3 ± 0.6 mm) and CG (6.3 ± 0.6 mm) (t[10] = 1.08, $P = .31$).

The hypothesis that the first primary outcome, which is the RW, did not differ between both implant groups was supported.

Crestal Bone Loss

The vertical distance between the implant shoulder and the marginal bone crest (BL values) is presented for individual patients and averaging across patients (Tables 5 and 6). When the implants were inserted subcrestally, the measures were expressed in negative values. The mean BL on the mesial and distal aspects of the implants and the mean mesiodistal BL values at two points in time are shown in Figs 5, 6, and 7. Figure 8 compares the crestal bone loss between CG and TG.

The ANOVA showed a main effect on time, in which BL in both groups changed significantly from T_1 to T_6, F(2,20) = 148.03, $P < .01$.

At T_1, 20 of the 22 implants were placed subcrestally (negative BL values) at both the mesial and distal aspects of the implants. For the CG, the mean mesial BL was –1.06 ± 0.44 mm, and the mean distal BL was –0.43 ± 0.88 mm. For the TG, the mean mesial BL was –1.16 ± 0.46 mm, and the mean distal BL was –0.90 ± 0.33 mm. There was no difference between control and test implant groups for either the mesial location (t[10] = 0.51, $P = .62$) or the distal location (t[10] = 2.04, $P = 0.07$).

At T_6, for the CG, the mesial BL was 0.55 ± 0.57 mm, and the distal BL was 0.50 ± 0.85 mm. For the TG, the mesial BL was 0.55 ± 0.70 mm, and the distal BL was 0.73 ± 0.64 mm. The control and test implant groups did not differ at the mesial location (t[10] = –0.01, $P = .99$) or at the distal location (t[10] = –0.63, $P = .54$). The hypothesis that the second primary outcome, which is the BL, did not differ between both implant groups was supported.

Although the starting and ending BL values were similar at each site (mesial, distal) for the test and control groups, the changes in BL or bone loss from T_1 to T_6 depended on both the treatment (test, control) and the location of the measurement (mesial, distal). For the change in BL on the mesial aspect of the implant (ΔBLm), both the TG (mean ΔBLm = 1.72 mm) and CG (mean ΔBLm = 1.61 mm) showed substantial bone loss that did not differ between the two groups (t[10] = –0.36, $P = .73$). However, for the change

Mean mesiodistal	BL T_6		Mean mesiodistal	ΔBLm	ΔBLd	ΔBLm-d
	Mesial	Distal				
–0.9	0.62	0	0.31	1.93	0.48	1.21
–1.49	0.6	0.08	0.34	2.42	1.23	1.83
–1.32	–0.24	–0.42	–0.33	1.09	0.88	0.99
–0.4	1.67	1.14	1.41	2.07	1.54	1.81
–0.55	1.03	1.54	1.29	1.8	1.87	1.84
–1.35	0.42	0.82	0.62	1.75	2.18	1.97
–0.34	0.57	1.02	0.8	0.93	1.34	1.14
0.26	0.31	1.81	1.06	1.51	0.09	0.8
–0.81	0.58	–0.84	–0.13	1.39	–0.03	0.68
–0.98	0.92	–0.29	0.32	2.15	0.43	1.29
–0.38	–0.41	0.67	0.13	0.72	0.3	0.51
–0.8 ± 0.45	0.55 ± 0.57	0.5 ± 0.85	0.46 ± 0.57	1.61 ± 0.54	0.94 ± 0.75	1.28 ± 0.51

Table 6 Change in BL in Test Group

Patient No.	Implant site[a]	BL T_1		Mean mesio-distal	BL T_6		Mean mesio-distal	ΔBLm	ΔBLd	ΔBLm-d
		Mesial	Distal		Mesial	Distal				
1	13	–2	–1.06	–1.53	1.17	2.2	1.69	3.17	3.26	3.22
2	15	–0.63	–0.67	–0.65	0.75	0.78	0.77	1.38	1.45	1.42
3	24	–0.82	–1.21	–1.02	–0.42	0.55	0.07	0.4	1.76	1.08
4	23	–1.16	–1.05	–1.11	1.66	0	0.83	2.82	1.05	1.94
5	14	–0.96	–1.06	–1.01	0.11	0.34	0.23	1.07	1.4	1.24
6	15	–1.7	–1.33	–1.52	0	0.4	0.2	1.7	1.73	1.72
	25	–1.4	–1.32	–1.36	0.3	1.23	0.77	1.7	2.55	2.13
7	12	–0.61	–0.47	–0.54	0.75	0.85	0.8	1.36	1.32	1.34
8	21	–0.7	–0.57	–0.64	1.31	1.2	1.26	2.01	1.77	1.89
9	22	–1.39	–0.66	–1.03	–0.43	0.53	0.05	0.96	1.19	1.08
10	15	–1.43	–0.52	–0.98	0.89	0	0.45	2.32	0.52	1.42
Mean ± SD		–1.16 ± 0.46	–0.9 ± 0.33	–1.04 ± 0.34	0.55 ± 0.7	0.73 ± 0.64	0.64 ± 0.52	1.72 ± 0.82	1.6 ± 0.74	1.66 ± 0.62

[a]FDI tooth-numbering system.
ΔBL = difference in BL values between T_6 and T_0; ΔBLm = ΔBL measured on the mesial aspect of implant; ΔBLd = ΔBL measured on the distal aspect of implant; ΔBLm-d = average of mesial and distal ΔBL values.

on the distal aspect of the implant (ΔBLd), the TG (mean = 1.60 mm) and CG (mean = 0.94 mm) differed from each other, (t[10] = –2.24, P = .05).

When the means of the mesial and distal changes in BL values were calculated, the change in BL values (ΔBLm-d), from T_1 to T_6, in both the TG (mean = 1.66 mm) and the CG (mean = 1.28 mm) did not differ from each other (t[10] = –1.65, P = .13).

Implant Stability: Change in the ISQ Values

The mean of the ISQ values measured for each implant at four locations (MB, ML, DM, DL) were recorded at three different time points (T_1, T_3, and T_6). ISQ values for each patient at each of the four locations and at three time points are shown in Tables 7 and 8. The means across patients of these mean ISQ values were compared. Figure 9 shows the mean ISQ values across

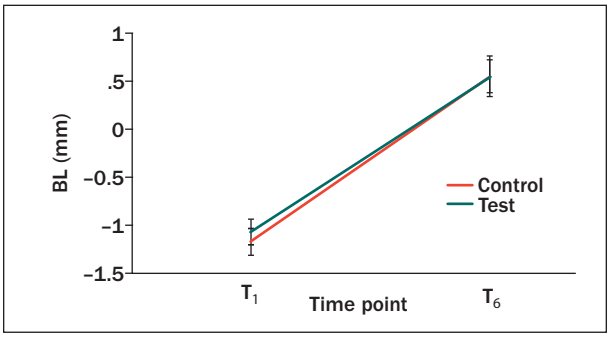

Fig 5 Mean BL at the mesial aspect of the implants.

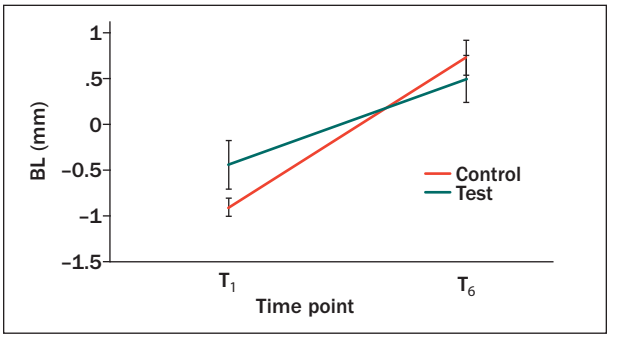

Fig 6 Mean BL at the distal aspect of the implants.

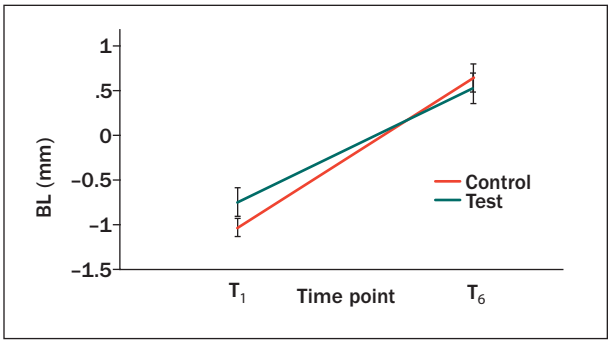

Fig 7 Mean mesiodistal average BL.

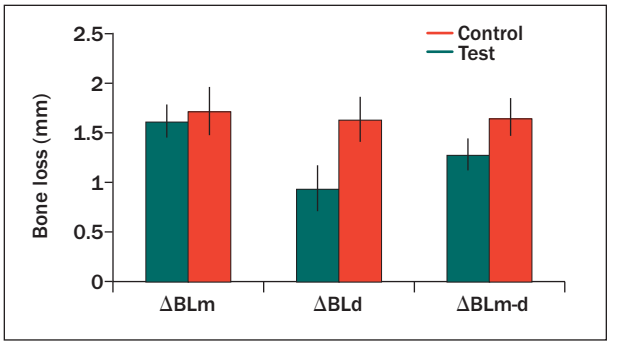

Fig 8 Change in BL (bone loss).

the four locations and across patients for each implant group (control, test) at each time point (T_1, T_3, T_6).

The ANOVA showed a main effect of group by time, in which, over time, ISQ values changed differently for CG and TG ($F[2,20] = 12.84$, $P < .05$).

Within the CG, the mean ISQ values increased gradually over time. The mean ISQ values at T_1 (63) and T_3 (67) ($t[10] = 1.2$, $P = .26$), and at T_3 (67) and T_6 (70) ($t[10] = 2.06$, $P = .07$) were not statistically significant from each other. From T_1 to T_6, there was, however, a statistically significant increase in ISQ values ($t[10] = 2.53$, $P = .03$).

Within the TG, the mean ISQ values also increased over time. The mean ISQ values at T_1 (59) and T_3 (62) did not differ significantly from each other ($t[10] = 1.12$, $P = .29$), but the mean ISQ value at T_6 (72) was significantly higher than the mean ISQ value at T_3 ($t[10] = –6.13$, $P < .01$).

When the mean ISQs were compared between groups, the value for the CG (63) was slightly higher than for the TG (59) at T_1, but the difference was not statistically significant, ($t[10] = 1.92$, $P = .08$). At T_3, the ISQ value for the CG (67) was significantly higher than that of the TG (62) ($t[10] = 2.74$, $P = .02$). At T_6, the ISQ values for both groups were similar (control 70, test 72) ($t[10] = 1.24$, $P = .24$).

The hypothesis that the secondary primary outcome, which is the mean ISQ, did not differ between both implant groups was supported.

DISCUSSION

Several studies have reported a high success rate for implant placement using alveolar ridge-splitting techniques for ridge expansion.[10,15,17,21,22,25] In the alveolar ridges that are approximately 4 mm thick, this technique allows placement of implants in the host bone within the intercortical space. The implants are protected by the solid cortical layers, thus allowing better host bone contact with the implant surface area. The intercortical space is made up of cancellous bone, which is well vascularized and highly osteogenic. An implant bed preparation in ridges of the same thickness using the conventional twist drills for 3.5-mm-diameter implants would be expected to induce bone dehiscence requiring additional bone augmentation.

The piezoelectric osteotomy and the Bone Expanders used in this study offered an alternative instrumentation for ridge augmentation. The authors observed that the piezoelectric surgery unit and its inserts permitted thinner, more precise cuts, and less vibration and tissue damage than surgical saws or burs as noted in previous studies that employed the same surgical units.[26–28]

The Bone Expanders allowed controlled expansion of the cortical plates and created space for the implant insertion. The taper shape of the NobelActive 3.5-mm-diameter implants used in this study closely matched that of the Bone Expanders, and therefore, minimal apical preparation was necessary.

Table 7 Change in ISQ Values in Control Group

	T_1					T_3					T_6				
Patient No.	MB	ML	DB	DL	Mean	MB	ML	DB	DL	Mean	MB	ML	DB	DL	Mean
1	61	62	62	60	61	59	56	56	59	58	65	64	64	65	65
2	60	60	65	60	61	60	60	60	60	60	68	67	67	68	68
3	72	72	64	72	70	63	63	63	55	61	70	70	70	62	68
4	67	62	67	62	65	75	75	75	75	75	75	75	75	75	75
5	58	58	58	70	61	67	65	65	67	66	71	70	70	71	71
6	49	49	49	49	49	75	75	75	75	75	71	71	71	71	71
	70	70	71	70	70	74	74	74	74	74	70	70	70	70	70
7	65	65	65	65	65	74	74	74	74	74	77	77	77	77	77
8	77	77	77	73	76	66	74	74	66	70	68	70	70	68	69
9	57	51	57	51	54	62	58	58	62	60	66	66	66	66	66
10	63	69	69	63	66	62	67	67	62	65	65	69	69	69	68
Mean ± SD					63 ± 8					67 ± 7					70 ± 4

MB = mesiobuccal; ML = mesiolingual; DB = distobuccal; DL = distolingual.

Table 8 Change in ISQ Values in Test Group

	T_1					T_3					T_6				
Patient No.	MB	ML	DB	DL	Mean	MB	ML	DB	DL	Mean	MB	ML	DB	DL	Mean
1	59	59	59	59	59	57	57	57	57	57	71	71	71	71	71
2	60	58	58	60	59	60	60	60	60	60	69	69	69	69	69
3	67	64	64	67	66	53	65	65	53	59	74	74	73	74	74
4	61	61	61	61	61	60	60	60	60	60	65	63	63	65	64
5	60	39	39	39	44	65	70	70	65	68	77	77	77	77	77
6	61	61	61	61	61	59	70	70	59	65	74	74	74	74	74
	67	62	62	67	65	60	60	60	60	60	74	74	74	74	74
7	69	69	69	69	69	69	68	68	69	69	72	72	72	72	72
8	71	71	71	71	71	65	70	70	64	67	73	73	73	73	73
9	32	48	48	32	40	43	53	53	43	48	70	66	69	70	69
10	44	51	51	51	49	70	70	57	70	67	69	75	75	69	72
Mean ± SD					59 ± 10					62 ± 6					72 ± 3

In the present study, the narrow mean RW was selected to study the RSE technique (4.1 mm at location 1) as compared with the wider mean RW chosen for the conventional drilling technique utilized for the CG (5.5 mm at location 1). The difference in 1.4 mm in initial RW is an important factor in a surgeon's decision to select one technique over the other.

The authors, therefore, see the need to clarify that the purpose of this study was not to compare the advantages of one technique over the other, since they are not, in fact, interchangeable, but the CG is needed to compare the outcomes between the RSE and the conventional drilling technique.

Factors that might affect treatment outcomes, such as implant system, implant diameter and length, implant location, and surgical protocol, were kept as similar as possible for all patients. Only one brand of implant was used (NobelActive), and all implants had a diameter of

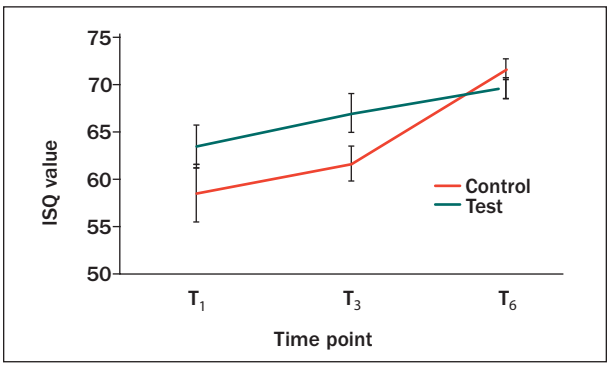

Fig 9 Implant stability as measured by ISQ values for the test and control implant groups at three time points, averaging across four measurement locations.

3.5 mm, except for two measuring 4.3 mm that were used in two control cases. Most of the 22 implants were 10 mm in length (17); four others were 11.5 mm, and one was 13 mm. The surgical sites were limited to the anterior maxilla from the second premolar to the opposite second premolar, and the same dentist applied the same treatment protocol to all patients.

In the present study, while the mean RW stayed unchanged in the CG, the mean RW in the TG changed significantly throughout the course of the study. There was a sharp increase immediately postoperatively (T_1) and a decrease in RW at 6 months postoperatively (T_6). The 2.6-mm increase in RW at location 1 (a vertical location at 2 mm from the summit of the crest of the ridge), immediately postoperatively, did not account for the 3.5-mm-diameter implants inserted in the test sites. This 1-mm discrepancy, in the authors' opinion, was most likely caused by pilot hole preparation and bone condensation during the expansion procedure.

At 6 months postoperatively (T_6), the 1.4-mm decrease from RW at T_1 was not anticipated for the TG. The surgical procedure could have played an important role in this decrease in RW at the test sites. Factors related to the surgical procedure, including surgical instrumentation, bone compression during expansion, flap reflection, and the implant system used, might need further investigation on their relation to the postoperative decrease in RW.

Interestingly, at T_6, no difference in RW between the control and test implant groups was statistically significant. After 5 months of function, hard and soft tissue appeared stable, and all the definitive prostheses showed good esthetic results and patient satisfaction. The moderate net gain in width (1.2 mm) in the TG may not be, however, sufficient for ridge reconstruction in some instances, especially in the esthetic zones, and additional hard and soft tissue augmentations may be necessary for the ridge splitting for expansion technique to be used successfully. The aforementioned observation seems to agree with the findings of a recent publication by Stricker et al,[29] who combined simultaneous ridge expansion and horizontal GBR in their case series study.

At T_6, the crestal bone level at the implant site (BL) measured at the mesial and distal aspects of the implants was similar for both the control and test implant groups. With the exception of one implant in the test group, of which the distal BL was 2.20 mm at 6 months postoperatively, the overall mesiodistal average BL of both groups (0.46 mm for control and 0.64 mm for test) were clinically acceptable.

Although the net postoperative bone loss on the distal aspect of the implants (ΔBLd) was significantly higher in the TG than in the CG, the net postoperative bone loss on the mesial aspect (ΔBLm) and on the mesiodistal average (ΔBLm-d) were comparable in both groups. Previous studies on ridge splitting have reported crestal bone loss between 0.8 and 2.0 mm.[14,22,30–32] In these studies, which employed different instruments for splitting the alveolar ridge, implants were inserted at the level of the crest of the ridge that resulted in a net bone loss being equivalent to the final BL. In the present study, ΔBLm-d for the TG was 1.66 mm, but since the implants were initially placed subcrestally, the final BL for the TG was 0.64 mm, which was relatively smaller than the final BL from other aforementioned studies. Further investigation is needed to verify the influence of implants placed subcrestally on the final BL distance.

Resonance frequency analysis, expressed as ISQ values, measures the stability of an implant in its surrounding bone. Several studies have demonstrated the correlation between bone quality and ISQ values, and it appears that the stiffness of the implant-bone interface increases as the peri-implant bone becomes denser during the healing and remodeling process.[33–35]

The present study found that at 6 months postoperatively, the quality of peri-implant bone, which was expressed as ISQ values in the test group, was comparable to that of the control group. The lower ISQ values measured at implant insertion seemed to reflect the environment in which the implants were placed in the test group: intercortical gap filled with blood clot and minimal implant surface being anchored in solid bone. The clot would be expected to be replaced with woven bone and eventually developed into load-bearing lamellar bone at the implant-bone interface. A significant increase in the ISQ values occurred only between T_3 and T_6, suggesting that the implants were probably not ready for loading before 3 months postoperatively, so a minimum delay of 3 months should be respected before the prosthetic loading for the ridge-splitting procedure.

At the end of the present study, 8 months after implant insertion, all implants met the criteria for success defined in Table 1.

CONCLUSIONS

Results from this study support the efficacy and safety of ridge splitting for expansion using Piezosurgery and Bone Expanders for implant insertion in the esthetic zones. Within the time limits of the study, the following conclusions can be drawn.

The immediate gain in bone width after the procedure may not be stable, and over time, some of this gain may disappear. The modest net gain in bone width suggests that hard and soft tissue augmentation in addition to the ridge-splitting procedure, especially in the esthetic zone, may be necessary.

The crestal bone level and marginal bone loss in the test implant group were similar to that of the control implant group.

ISQ values suggest a minimum healing time of 3 months is needed before loading the implants that were inserted with the ridge splitting for expansion using Piezosurgery and Bone Expanders.

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