Developing Stability of Posterior Mandibular Implants Placed With Osteotome Expansion Technique Compared With Conventional Drilling Techniques

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Clinical decisions regarding the stability and osseointegration of mandibular implants positioned using the bone expansion techniques are conflicting and limited. The objective was to evaluate the stability of implants placed using 2 surgical techniques, selected according to the initial width of the mandibular posterior edentulous ridge, with D_3 bone density, during a 12-week period. Fifty-eight implants in 33 patients were evaluated. Thirty-two implants in 24 patients were positioned using the osteotome expansion technique, and 26 fixtures in 17 patients were installed using the conventional drilling technique. The implant stability quotient values were recorded at weeks 0, 1, 2, 3, 4, 6, 8, 10, and 12 postsurgery and evaluated using analysis of variance, independent, and paired *t* tests. Calibrated according to the stability reading of a 3.3-mm diameter implant, the osteotome expansion group was associated with a lower bone density than the conventional group (64.96 $\pm$ 6.25 vs 68.98 $\pm$ 5.06, $P = .011$). The osteotome expansion group achieved a comparable primary stability ($ISQ_{b\text{-}0}$, $P = .124$) and greater increases in secondary stability ($ISQ_{b\text{-}12}$, $P = .07$) than did the conventional technique. A D_3 quality ridge with mild horizontal deficiency is expandable by using the osteotome expansion technique. Although the 2 groups presented similar implant stability quotient readings during the study period, the osteotome expansion technique showed significant improvement in secondary stability. The healing patterns for these techniques are therefore inconsistent.

Key Words: bone expansion technique, conventional drilling technique, implant stability quotient, mandibular implant, bone quality

INTRODUCTION

For several decades, dentists have used implants to improve patients' dental esthetics, health, and function. However, compromised ridge resorptions after tooth extraction always prevent a proper implant treatment. Investigators have adopted several techniques to remedy these consequences,[1–6] including guided bone regeneration (GBR),[2] onlay grafts,[3] distraction osteogenesis,[4] ridge expansion,[5] and revascularized flaps.[6] In a previous study, the survival rates of implants after applying these treatments were 92%–100% for GBR, 60%–100% for onlay bone grafts, 91%–97.3% for ridge expansion, and 90.4%–100% for distraction ostogenesis.[1] More than 2 surgeries are typically requisite for such ridge augmentations to complete implant therapy, which increase the treatment time, use of materials, costs, and risk of surgical complications.[7]

Summers first described the osteotome technique for expansion and condensation of the recipient sites of the alveolar ridge to accommodate installed dental implants.[8,9] Previous studies applied the osteotome technique in the maxilla to elevate the sinus floor and to increase bone density and the primary stability of the inserted implants.[10,11] However, evidence on the use of this technique for bone expansion in the mandible is limited. In addition, results from previous animal experiments provided paradoxical results on the effects of the osteotome technique on the stability and osseointegration of mandibular implants.[12–15]

Since 1997 investigators have employed resonance frequency analysis (RFA) to assess the interface between a dental implant and its surrounding bone and to evaluate implant stability in quantifiable implant stability quotient (ISQ) values.[16] Using this analytical method, the bone condition at the initial implant operation and stability changes during osseointegration could be evaluated.[17,18] The healing progress of implants and possible risks of failure could also be monitored. Previous studies have used RFA to evaluate immediate implant loading and indicate an occasion for prosthetic fabrication.[19]

The objective of this clinical study was to apply the osteotome expansion technique as well as to evaluate the

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potential for expansion of the alveolar ridge horizontally and up-regulation of bone density to increase implants stability on the posterior mandible with D_3 bone quality. The calibrated and noncalibrated implant stability quotient (ISQ) values produced using the osteotome expansion technique and conventional drilling technique were compared during a 12-week observation period. The adopted technique was selected according to the initial width and bone quality of the edentulous ridge of the posterior mandible.

Materials and Methods

Patient selection and information

Data were collected from patients who received dental implant treatment at the Dental Department of the Lin-Kou Chang Gung Medical Center. Patients with systemic diseases, such as heart disease, uncontrolled diabetes, and osteoporosis, or those who had received radiotherapy in the head and neck, taken immune inhibitors, or were allergic to any drugs, were excluded from the analyses. Smokers who consumed more than half a pack of cigarettes per day were also excluded. It was required that implant sites had no history of receiving a bone graft and at least a 3-month healing period postextraction. Prior to surgery, all patients underwent a dental computerized tomography (CT) scan, and periapical or panorama X-ray examination for the evaluation of implant sites.

The study was approved by the Ethics Committee at the Chang Gung Memorial Hospital, Taiwan (100-2382B). The patients were informed on all issues regarding the implant surgery and were inquired to provide signed informed consent.

The osteotome expansion or conventional drilling technique was selected according to the ridge width and bone quality of the mandible. The classification of bone quality was determined using Misch's mode[20] according to the surgeons' judgment and the dental CT scans. The osteotome expansion technique (tested group) was applied onto D_3 bone quality alveolar ridge that presented enough and or mild deficient alveolar width buccolingually to accommodate the diameter of the planned implant on the posterior mandible. Although the alveolar ridge was wider than the diameter of the scheduled implant, the conventional drilling technique (control group) was employed. However, when patients could not follow all the offered schedules, extensive guided bone regeneration was indicated, implants lost their primary stability, or more than 3 mm rough surface of the implant was exposed, data were excluded.

Surgical procedures

To prevent the bias caused by interoperators, 1 operator completed the survey. The length and diameter of each patient's implant was determined prior to surgery according to clinical examinations and dental CT scan (or panoramic X-ray) analysis. Procedures adhered to the surgical protocols of Straumann. After flap elevation, the recipient sites were prepared using 2.2- and 2.8-mm diameter pilot drills and a 3.3-mm tap using the standard drilling technique. A 3.3-mm diameter and a 10- or 12-mm length implant were inserted, and the resonance frequency was recorded using an Osstell Mentor (Integration Diagnostics AB, Gothenburg, Sweden). These ISQ data were recorded as the ISQ baseline (ISQ_b). The 3.3-mm diameter fixture was then withdrawn. According to the width and bone quality of the ridge, site preparation using the osteotome expansion (Osteotome Kit, Straumann, Waldenburg, Switzerland) or conventional drilling technique was selected. The osteotome expansion technique was applied in cases with inadequate ridge width with D_3 bone quality. A series of osteotomes were followed according to the instruction of manufacture until the recipient sites could accommodate the final width of 4.1- (4.1 ∅), 4.8- (4.8 ∅), or 4.8/6.5-mm (4.8/6.5 ∅) diameter implants and the anticipated 10- to 12-mm depth (Figure). When the planned implants were positioned, the primary implant stability (Week 0, ISQ_0) was recorded. The implants without primary stability were excluded. The wound was then closed using a 4–0 vicryl (Ethicon, Sommerville, NJ) suture. Antibiotics (amoxicillin, 500 mg, three times daily, for 7 days), analgesics (acetaminophen, 500 mg/tab as needed for 7 days), and a .12% chlorhexidine rinse (twice a day) were prescribed to the patients. Sutures were removed 1 to 2 weeks after the operation.

The implant stability of the 2 groups was recorded at Weeks 1 (ISQ_1), 2 (ISQ_2), 3 (ISQ_3), 4 (ISQ_4), 6 (ISQ_6), 8 (ISQ_8), 10 (ISQ_{10}), and 12 (ISQ_{12}) after implantation. The mean of 6 ISQ readings at the buccomesial, buccal, buccodistal, lingomesial, lingual, and linguodistal sites of tested implants indicated the stability of the implant.

This study aimed to achieve the following:

(1) Identify and calibrate the initial bone quality of the 2 surgical groups by evaluating the stability reading of a 3.3-mm diameter and 10-mm (or 12-mm) length implant at baseline (ISQ_b).
(2) Differentiate the implant stability between 2 tested time points in the 2 groups during the 12-week observation period ($ISQ_{b\text{-}0}$ to $ISQ_{10\text{-}12}$).
(3) Compare the primary implant stability at Week 0 (ISQ_0) with the developing stabilities at Week 1 to 12 ($ISQ_{1\text{-}12}$) post-implantation using both techniques.

Analysis of variance, independent, and paired *t* tests were applied to evaluate the significance of differences between the 2 groups ($P \leq .05$).

Results

In this study, we examined 94 patients and 152 implants. However, only 33 patients and 58 implants matched the selected criteria and completed the evaluations. Of the 33 evaluated patients, 2 were smokers, 15 were men, and 18 were women, ranging in age from 18 to 66 years, with an average age of 44 years. The installed 58 Straumann SLA implants including 24 fixtures 4.1 mm in diameter (12 in the osteotome expansion group and 12 in the conventional group), 18 fixtures at 4.8 mm in diameter (9 in the osteotome expansion group and 9 in the conventional group), and 16 taper effect fixtures (with a lower diameter of 4.8 mm and a cervical diameter of 6.5 mm; 11 in the osteotome expansion group and 5 in the

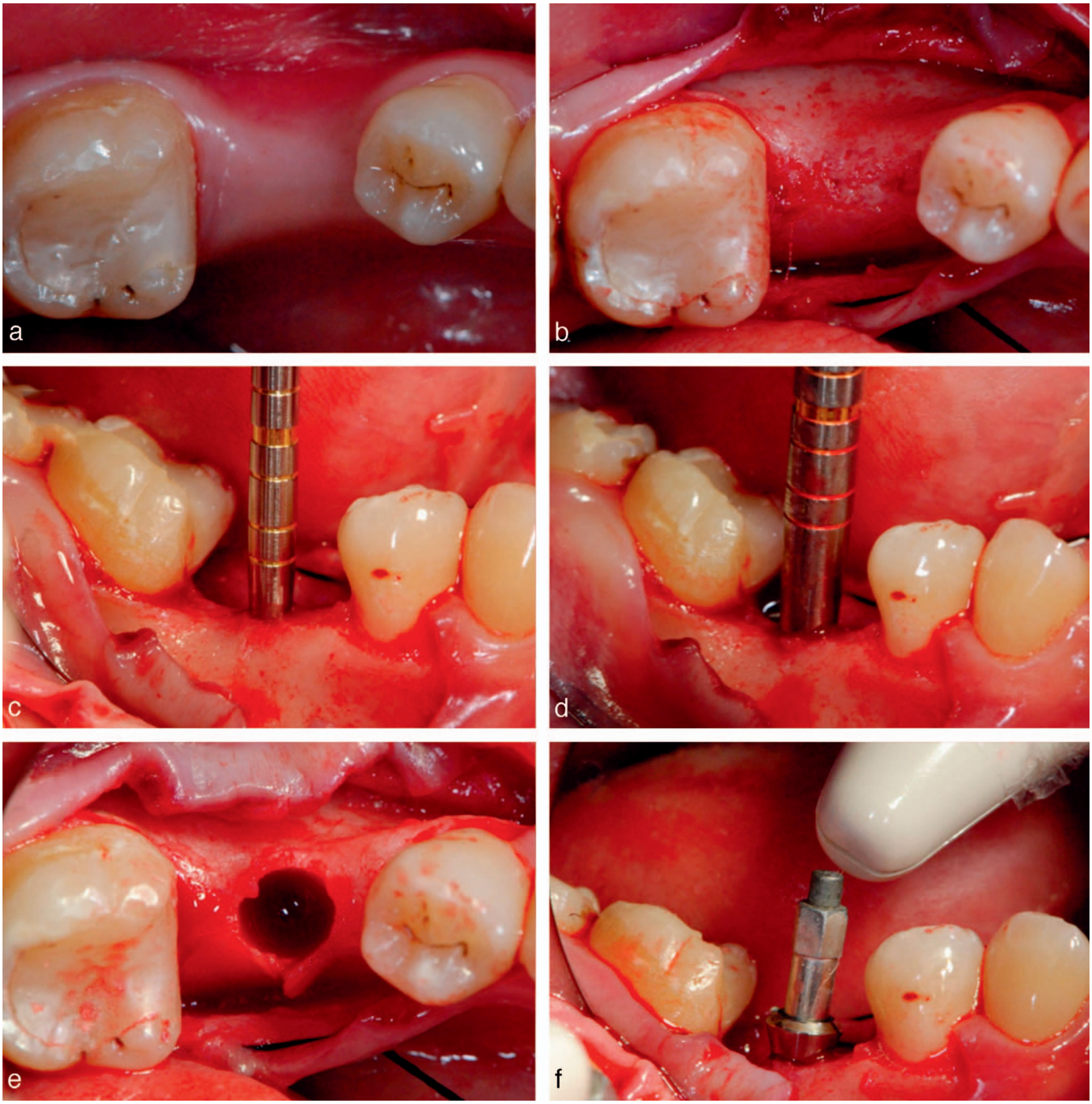

Figure. (a) #46 edentulous area with mild lateral ridge depression. (b) The osteotome expansion technique was applied to a D_3 bone quality alveolar ridge with mild width deficiency than the diameter of the planned implant. (c,d) Bone expansion was achieved using a sequence of osteotomes of various diameters by using tap or lateral compression until the scheduled implant could be positioned. (e) After using the osteotome expansion technique, the coronal third ridge was expanded. (f) After implant placement, primary implant stability (Week 0, ISQ_0) was obtained from the resonance frequency analysis measurements.

conventional group). Fifty-three fixtures were 10 mm in length, and 5 fixtures were 12 mm in length. We used the osteotome expansion technique to position 32 implant fixtures and the conventional drilling technique to position 26 fixtures. Table 1 presents the results on implant stability in the 2 groups during the 12-week period and each group was divided into subgroups according to implant diameter.

In this study, we used the stability (ISQ_b) achieved by the 3.3-mm diameter implant positioned using the conventional drilling technique, which represented the initial bone conditions of both groups, to calibrate variation between the osteotome expansion (64.96 ± 6.25) and conventional drilling (68.98 ± 5.06) techniques at the baseline. In subgroups bone quality at baseline (ISQ_b), the 4.1-, 4.8-, and 4.8/6.5-mm diameter implants demonstrated a similar ISQ_b bone quality at the baseline ($P = .699$ for osteotome expansion group and

TABLE 1

Detected ISQ values of different diameter fixtures and increased ISQ values from 3.3 mm to wider diameter implants at tested time points by different surgical techniques†

	ISQ_b	ISQ_0	ISQ_1	ISQ_2	ISQ_3	ISQ_4	ISQ_6	ISQ_8	ISQ_{10}	ISQ_{12}
Tested Time Points										
Osteotome technique										
4.1 Ø	64.06 ± 5.44	74.24 ± 4.08	75.86 ± 4.46	75.88 ± 3.79	75.85 ± 3.20	76.54 ± 2.78	78.28 ± 2.19	79.72 ± 1.92	80.37 ± 2.05	80.97 ± 2.33
4.8 Ø	66.43 ± 7.04	76.66 ± 3.47	76.99 ± 4.32	77.94 ± 4.11	78.06 ± 2.84	78.26 ± 2.81	79.14 ± 2.01	80.98 ± 2.18	82.33 ± 1.74	82.96 ± 1.62
4.8/6.5 Ø	64.77 ± 6.78	77.64 ± 6.87	79.07 ± 4.90	80.30 ± 4.82	80.06 ± 4.56	80.59 ± 4.01	80.87 ± 4.12	81.86 ± 3.15	82.59 ± 3.03	83.64 ± 2.73
P value	.699	.273	.255	.060	.033*	.021*	.123	.133	.065	.026*
Conventional technique										
4.1 Ø	69.59 ± 4.46	76.35 ± 4.98	76.96 ± 4.58	77.06 ± 3.52	76.28 ± 3.44	77.06 ± 2.61	78.10 ± 2.10	79.56 ± 1.78	79.77 ± 2.19	80.82 ± 2.31
4.8 Ø	67.91 ± 5.74	77.02 ± 3.39	78.15 ± 4.64	79.36 ± 2.96	78.93 ± 3.51	77.43 ± 4.63	78.52 ± 4.10	81.69 ± 2.80	83.06 ± 2.63	82.28 ± 3.28
4.8/6.5 Ø	69.43 ± 5.94	81.20 ± 3.63	82.87 ± 4.06	83.57 ± 1.98	83.67 ± 0.82	83.05 ± 1.31	84.13 ± 1.05	83.83 ± 2.60	84.30 ± 0.63	85.27 ± 1.13
P value	.749	.115	.066	.003*	.001*	.007*	.002*	.006*	.001*	.012*
Calibration with ISQ_b	ISQ_b	ISQ_{b-0}	ISQ_{b-1}	ISQ_{b-2}	ISQ_{b-3}	ISQ_{b-4}	ISQ_{b-6}	ISQ_{b-8}	ISQ_{b-10}	ISQ_{b-12}
Osteotome technique										
4.1 Ø	64.06 ± 5.44	10.18 ± 4.66	11.81 ± 5.93	11.82 ± 6.05	11.80 ± 6.22	12.49 ± 5.51	14.22 ± 5.29	15.67 ± 5.66	16.31 ± 6.59	16.91 ± 6.26
4.8 Ø	66.43 ± 7.04	10.23 ± 7.64	10.56 ± 7.95	11.52 ± 8.25	11.63 ± 6.84	11.83 ± 7.56	12.71 ± 7.11	15.56 ± 7.54	15.91 ± 7.83	16.54 ± 6.63
4.8/6.5 Ø	64.77 ± 6.78	12.87 ± 7.39	14.30 ± 7.33	15.53 ± 7.11	15.29 ± 6.15	15.82 ± 6.48	16.10 ± 6.44	17.09 ± 6.92	17.82 ± 6.76	18.87 ± 5.14
P value	.699	.559	.481	.357	.336	.328	.484	.697	.806	.637
Conventional technique										
4.1 Ø	69.59 ± 4.46	6.76 ± 5.44	7.37 ± 5.31	7.47 ± 4.96	6.69 ± 5.06	7.47 ± 4.76	8.51 ± 4.48	9.97 ± 4.38	10.18 ± 4.12	11.23 ± 4.67
4.8 Ø	67.91 ± 5.74	9.11 ± 7.38	10.24 ± 8.93	11.45 ± 6.99	11.02 ± 7.38	9.52 ± 7.79	10.61 ± 6.26	13.78 ± 5.57	15.15 ± 5.71	14.37 ± 6.55
4.8/6.5 Ø	69.43 ± 5.94	11.77 ± 2.95	13.34 ± 3.71	14.13 ± 5.35	14.23 ± 5.19	13.62 ± 6.67	14.70 ± 6.18	14.40 ± 7.50	14.87 ± 5.51	15.83 ± 5.76
P value	.749	.280	.230	.09	.061	.207	.126	.190	.064	.243

*ANOVA and LSD ($P \leq .05$).

†ISQ_b indicates ISQ values detected by a 3.3-mm diameter implant at baseline; ISQ_0 to ISQ_{12}, ISQ values of the implants with a diameter wider than 3.3-mm revealed at week 0 to week 12; Ø, mm diameter.

$P = .749$ for convention group respectively; Table 1). However, conventional group had a higher ISQ_b bone quality than osteotome expansion group ($P = .011$; Table 2). The ISQ_b between the 2 technical groups differed significantly predominantly in the 4.1-mm diameter subgroups ($P = .012$, Table 2).

Generally, the implants with a diameter > 3.3 mm significantly increased primary stability ($ISQ_b - ISQ_0$, $P = 0 - .006$; Table 3). The wide diameter implants (4.8- and 4.8/6.5-mm) achieved higher ISQ values than did the 4.1-mm diameter implants, particularly for the 4.8/6.5-mm diameter implants in conventional group (Table 1). However, the primary and secondary stability (ISQ_0, ISQ_{12}) of the 4.1-, 4.8-, and 4.8/6.5-mm diameter implants showed insignificant differences after calibration for both techniques (ISQ_{b-0}, ISQ_{b-12}; Table 1). It also showed the osteotome expansion reduced the differences in the ISQ values between the different diameter implants from Week 0 to Week 12 (Table 1).

Although initial bone quality presented a lower ISQ value (ISQ_b, $P = .011$; Table 2), the osteotome expanded implants achieved a primary stability comparable to which of conventional technique after calibrating against ISQ_b (ISQ_{b-0}, $P = .124$). The osteotome expansion technique achieved greater increases in ISQ values than did the conventional technique from Weeks 4 to 12 in the 4.1 ∅ + 4.8 ∅ + 4.8/6.5 ∅ subgroup ($P = .02 - .007$) and from Weeks 3 to 12 in the 4.1ψsubgroup ($P = .038 - .02$; Table 2).

Generally, both groups demonstrated a significant healing improvement in secondary stability from Week 0 to the most of tested time points. When evaluating the differences in ISQ values between 2 sequential tested times, an increased but interrupted pattern of implant stability for both techniques occurred until Week 8 in the conventional group ($P = .08$) and Week 10 in the osteotome expansion group to reached a plateau ($P = .067$, Table 3). The reductions in ISQ values at Week 3 in the osteotome expansion group ($P = .918$) and at Weeks 3 and 4 in the conventional group ($P = .115$ and $.551$, respectively; Table 3) indicated a no significant reduction in primary stability. Instead, the secondary stability increased significantly after Week 6 in the conventional drilling group and after Weeks 1 in the osteotome expansion group (Table 3).

The significant differences in ISQ values between the tested time points and ISQ_{12} declined at Week 10 for 4.1 ∅ + 4.8 ∅ + 4.8/6.5 ∅ subgroups in both techniques ($P = .067$ and $P = .360$, Table 4). On the other hand, the wide-diameter implants (4.8/6.5 ∅) achieved final stability at an earlier stage than did the standard-diameter implants, particularly for the conventional technique (Table 4).

DISCUSSION

After potential bias was eliminated, only the data on the posterior mandibular implants fulfilled the assigned criteria and were available for analysis. Considering ethics, we excluded the implants without primary stability and the patients with inexpansible alveolar ridges. Measuring removal torque after Week 1 was not a feasible scheme for this study and was not adopted. Ridge augmentation performed using osteotome expansion is predominantly indicated in cases with D_3 and D_4 bone quality.[10] However, to avoid applying various reverse torques every 1 to 2 weeks for implants with low ISQ valves

Table 2

Increased implant stability quotient (ISQ) values from 3.3 mm to wider diameter fixtures of 2 surgical techniques at tested time points†

Implant Diameter	Time Points Technique	ISQ_b	ISQ_{b-0}	ISQ_{b-1}	ISQ_{b-2}	ISQ_{b-3}	ISQ_{b-4}	ISQ_{b-6}	ISQ_{b-8}	ISQ_{b-10}	ISQ_{b-12}
4.1 Ø +	Osteotome	64.96 ± 6.25	11.12 ± 6.49	12.31 ± 6.96	13.01 ± 7.10	12.95 ± 6.40	13.45 ± 6.49	14.44 ± 6.18	15.84 ± 6.52	16.72 ± 6.83	17.48 ± 5.90
4.8 Ø +	Conventional	68.98 ± 5.06	8.54 ± 5.96	9.53 ± 6.75	10.13 ± 6.19	9.64 ± .49	9.36 ± 6.47	10.43 ± 5.74	12.14 ± 5.62	12.80 ± 5.37	13.20 ± 5.69
4.8/6.5 Ø	*P* value	.011*	.124	.130	.109	.056	.020*	.014*	.026*	.021*	.007*
4.1 Ø	Osteotome	64.06 ± 5.44	10.18 ± 4.67	11.81 ± 5.93	11.82 ± 6.05	11.80 ± 6.22	12.49 ± 5.51	14.22 ± 5.29	15.67 ± 5.66	13.61 ± 6.59	16.91 ± 6.26
	Conventional	69.59 ± 4.46	6.76 ± 5.44	7.37 ± 5.31	7.47 ± 4.96	6.69 ± 5.06	7.47 ± 4.76	8.51 ± 4.48	9.97 ± 4.38	10.18 ± 4.12	11.23 ± 4.67
	P value	.012*	.112	.066	.067	.038*	.026*	.009*	.011*	.013*	.020*
4.8 Ø	Osteotome	66.43 ± 7.04	10.23 ± 7.64	10.56 ± 7.95	11.52 ± 8.25	11.63 ± 6.84	11.83 ± 7.56	12.71 ± 7.11	14.56 ± 7.54	15.91 ± 7.83	16.54 ± 6.63
	Conventional	67.91 ± 5.74	9.11 ± 7.38	10.24 ± 8.93	11.45 ± 6.99	11.02 ± 7.38	9.52 ± 7.79	10.61 ± 6.26	13.78 ± 5.57	15.15 ± 5.71	14.37 ± 6.55
	P value	0.631	0.756	0.936	0.982	0.858	0.531	0.515	0.806	0.817	0.495
4.8/6.5 Ø	Osteotome	64.77 ± 6.78	12.87 ± 7.39	14.30 ± 7.33	15.53 ± 7.11	15.29 ± 6.15	15.82 ± 6.48	16.10 ± 6.44	17.09 ± 6.92	17.82 ± 6.76	18.87 ± 5.14
	Conventional	69.43 ± 5.94	11.77 ± 2.95	13.43 ± 3.71	14.13 ± 5.35	14.23 ± 5.19	13.62 ± 6.67	14.70 ± 6.18	14.40 ± 7.50	14.87 ± 5.51	15.83 ± 5.76
	P value	.208	.756	.808	.702	.744	.541	.689	.494	.408	.308

*Paired *t* test ($P \leq .05$).
†Ø indicates mm diameter.

(<55), which would impede the healing process and reduce implant stability, we excluded cases with D_4 bone quality from our analyses. Inserting an implant into a D_1–D_2 bone by using osteotome expansion is impractical and could also severely physically and mentally harms the patient. We also excluded implants without primary stability, and patients with inexpansible ridges or seriously compromised recipient sites, from our evaluations. To minimize statistical variation, only patients with

Table 3

Subtracted implant stability quotient (ISQ) values between 2 sequential tested time points†

Tested Time Points	ISQ_b– ISQ_0	ISQ_0– ISQ_1	ISQ_1– ISQ_2	ISQ_2– ISQ_3	ISQ_3– ISQ_4	ISQ_4– ISQ_6	ISQ_6– ISQ_8	ISQ_8– ISQ_{10}	ISQ_{10}– ISQ_{12}
Osteotome technique									
4.1 Ø	64.06 ± 5.44	74.24 ± 4.08	75.86 ± 4.46	75.88 ± 3.79	75.85 ± 3.20	76.54 ± 2.78	78.28 ± 2.19	79.72 ± 1.92	80.37 ± 2.05
	74.24 ± 4.08	75.86 ± 4.46	75.88 ± 3.79	75.85 ± 3.20	76.54 ± 2.78	78.28 ± 2.19	79.72 ± 1.92	80.37 ± 2.05	80.97 ± 2.33
P value	0.000*	.037*	.975	.948	.215	.005*	0.000*	.095	.205
4.8 Ø	66.43 ± 7.04	76.66 ± 3.47	76.99 ± 4.32	77.94 ± 4.11	78.06 ± 2.84	78.26 ± 2.81	79.14 ± 2.01	80.98 ± 2.18	82.33 ± 1.74
	76.66 ± 3.47	76.99 ± 4.32	77.94 ± 4.11	78.06 ± 2.84	78.26 ± 2.81	79.14 ± 2.01	80.98 ± 2.18	82.33 ± 1.74	82.96 ± 1.62
P value	.004*	.569	.176	.915	.513	.308	.062	.006*	.394
4.8/6.5 Ø	64.77 ± 6.78	77.64 ± 6.87	79.07 ± 4.90	80.30 ± 4.82	80.06 ± 4.56	80.59 ± 4.01	80.87 ± 4.12	81.86 ± 3.15	82.59 ± 3.03
	77.64 ± 6.87	79.07 ± 4.90	80.30 ± 4.82	80.06 ± 4.56	80.59 ± 4.01	80.87 ± 4.12	81.86 ± 3.15	82.59 ± 3.03	83.64 ± 2.73
P value	0.000*	.101	.077	.875	.514	.685	.398	.346	.291
Average value of	64.97 ± 6.25	76.09 ± 5.15	77.28 ± 4.64	77.98 ± 4.54	77.92 ± 3.96	78.42 ± 3.61	79.41 ± 3.08	80.81 ± 2.56	81.68 ± 2.51
4.1 Ø +	76.09 ± 5.15	77.28 ± 4.64	77.98 ± 4.54	77.92 ± 3.96	78.42 ± 3.61	79.41 ± 3.08	80.81 ± 2.56	81.68 ± 2.51	82.44 ± 2.54
4.8 Ø +									
4.8/6.5 Ø									
P value	0.000*	.006*	.042*	.918	.148	.013*	.004*	.007*	.067
Conventional technique									
4.1 Ø	69.59 ± 4.46	76.35 ± 4.98	76.96 ± 4.58	77.06 ± 3.52	76.28 ± 3.44	77.06 ± 2.61	78.10 ± 2.10	79.56 ± 1.78	79.77 ± 2.19
	76.35 ± 4.98	76.96 ± 4.58	77.06 ± 3.52	76.28 ± 3.44	77.06 ± 2.61	78.10 ± 2.10	79.56 ± 1.78	79.77 ± 2.19	80.82 ± 2.31
P value	.001*	.204	.881	.007*	.231	.066	.008*	.636	.158
4.8 Ø	67.91 ± 5.74	77.02 ± 3.39	78.15 ± 4.64	79.36 ± 2.96	78.93 ± 3.51	77.43 ± 4.63	78.52 ± 4.10	81.69 ± 2.80	83.06 ± 2.63
	77.02 ± 3.39	78.15 ± 4.64	79.36 ± 2.96	78.93 ± 3.51	77.43 ± 4.63	78.52 ± 4.10	81.69 ± 2.80	83.06 ± 2.63	82.28 ± 3.28
P value	.006*	.269	.250	.536	.095	.178	.010*	.054	.271
4.8/6.5 Ø	69.43 ± 5.94	81.20 ± 3.63	82.87 ± 4.06	83.57 ± 1.98	83.67 ± 0.82	83.05 ± 1.31	84.13 ± 1.05	83.83 ± 2.60	84.30 ± 0.63
	81.20 ± 3.63	82.87 ± 4.06	83.57 ± 1.98	83.67 ± 0.82	83.05 ± 1.31	84.13 ± 1.05	83.83 ± 2.60	84.30 ± 0.63	85.27 ± 1.13
P value	.001*	.039*	.552	.917	.528	.303	.745	.705	.162
Average value of	68.98 ± 5.06	77.51 ± 4.49	78.51 ± 4.87	79.11 ± 3.86	78.62 ± 4.12	78.34 ± 3.96	79.40 ± 3.62	81.12 ± 2.78	81.78 ± 2.86
4.1 Ø +	77.51 ± 4.49	78.51 ± 4.87	79.11 ± 3.86	78.62 ± 4.12	78.34 ± 3.96	79.40 ± 3.62	81.12 ± 2.78	81.78 ± 2.86	82.18 ± 2.97
4.8 Ø +									
4.8/6.5 Ø									
P value	0.000*	.019*	.227	.115	.551	.008*	.001*	.080	.360

*Paired *t* test ($P \leq .05$).
†Ø indicates mm diameter

TABLE 4

Varied implant stability quotient (ISQ) values of different diameter implants from tested time points to week 12†

Tested Time Points	ISQ_b–ISQ_{12}	ISQ_0–ISQ_{12}	ISQ_1–ISQ_{12}	ISQ_2–ISQ_{12}	ISQ_3–ISQ_{12}	ISQ_4–ISQ_{12}	ISQ_6–ISQ_{12}	ISQ_8–ISQ_{12}	ISQ_{10}–ISQ_{12}
Osteotome technique									
4.1 Ø	64.06 ± 5.44	74.24 ± 4.08	75.86 ± 4.46	75.88 ± 3.79	75.85 ± 3.20	76.54 ± 2.78	78.28 ± 2.19	79.72 ± 1.92	80.37 ± 2.05
	80.97 ± 2.33	80.97 ± 2.33	80.97 ± 2.33	80.97 ± 2.33	80.97 ± 2.33	80.97 ± 2.33	80.97 ± 2.33	80.97 ± 2.33	80.97 ± 2.33
P value	0.000*	0.000*	.001*	0.000*	0.000*	0.000*	0.000*	.011*	.025*
4.8 Ø	66.43 ± 7.04	76.66 ± 3.47	76.99 ± 4.32	77.94 ± 4.11	78.06 ± 2.84	78.26 ± 2.81	79.14 ± 2.01	80.98 ± 2.18	82.33 ± 1.74
	82.96 ± 1.62	82.96 ± 1.62	82.96 ± 1.62	82.96 ± 1.62	82.96 ± 1.62	82.96 ± 1.62	82.96 ± 1.62	82.96 ± 1.62	82.96 ± 1.62
P value	0.000*	.002*	.007*	.013*	.002*	.002*	.001*	.040*	.394
4.8/6.5 Ø	64.77 ± 6.78	77.64 ± 6.87	79.07 ± 4.90	80.30 ± 4.82	80.06 ± 4.56	80.59 ± 4.01	80.87 ± 4.12	81.86 ± 3.15	82.59 ± 3.0
	83.64 ± 2.73	83.64 ± 2.73	83.64 ± 2.73	83.64 ± 2.73	83.64 ± 2.73	83.64 ± 2.73	83.64 ± 2.73	83.64 ± 2.73	83.64 ± 2.73
P value	0.000*	.003*	.002*	.011*	.006*	.003*	.018*	.131	.291
Average value of 4.1 Ø + 4.8 Ø + 4.8/6.5 Ø	64.97 ± 6.25	76.09 ± 5.15	77.28 ± 4.64	77.98 ± 4.54	77.92 ± 3.96	78.42 ± 3.61	79.41 ± 3.08	80.81 ± 2.56	81.68 ± 2.51
	82.44 ± 2.54	82.44 ± 2.54	82.44 ± 2.54	82.44 ± 2.54	82.44 ± 2.54	82.44 ± 2.54	82.44 ± 2.54	82.44 ± 2.54	82.44 ± 2.54
P value	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	.001*	.067
Conventional									
4.1 Ø	69.59 ± 4.46	76.35 ± 4.98	76.96 ± 4.58	77.06 ± 3.52	76.28 ± 3.44	77.06 ± 2.61	78.10 ± 2.10	79.56 ± 1.78	79.77 ± 2.19
	80.82 ± 2.31	80.82 ± 2.31	80.82 ± 2.31	80.82 ± 2.31	80.82 ± 2.31	80.82 ± 2.31	80.82 ± 2.31	80.82 ± 2.31	80.82 ± 2.31
P value	0.000*	.006*	.006*	0.000*	0.000*	0.000*	.001*	.042*	.158
4.8 Ø	67.91 ± 5.74	77.02 ± 3.39	78.15 ± 4.64	79.36 ± 2.96	78.93 ± 3.51	77.43 ± 4.63	78.52 ± 4.10	81.69 ± 2.80	83.06 ± 2.63
	82.28 ± 3.28	82.28 ± 3.28	82.28 ± 3.28	82.28 ± 3.28	82.28 ± 3.28	82.28 ± 3.28	82.28 ± 3.28	82.28 ± 3.28	82.28 ± 3.28
P value	0.000*	.005*	.038*	.028*	.006*	.012*	.053	.564	.271
4.8/6.5 Ø	69.43 ± 5.94	81.20 ± 3.63	82.87 ± 4.06	83.57 ± 1.98	83.67 ± 0.82	83.05 ± 1.31	84.13 ± 1.05	83.83 ± 2.60	84.30 ± 0.63
	85.27 ± 1.13	85.27 ± 1.13	85.27 ± 1.13	85.27 ± 1.13	85.27 ± 1.13	85.27 ± 1.13	85.27 ± 1.13	85.27 ± 1.13	85.27 ± 1.13
P value	.004*	.044*	.174	.022*	.069	.008	.233	.402	.162
Average value of 4.1 Ø + 4.8 Ø + 4.8/6.5 Ø	68.98 ± 5.06	77.51 ± 4.49	78.51 ± 4.87	79.11 ± 3.86	78.62 ± 4.12	78.34 ± 3.96	79.40 ± 3.62	81.12 ± 2.78	81.78 ± 2.86
	82.18 ± 2.97	82.18 ± 2.97	82.18 ± 2.97	82.18 ± 2.97	82.18 ± 2.97	82.18 ± 2.97	82.18 ± 2.97	82.18 ± 2.97	82.18 ± 2.97
P value	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	.042*	.360

*Paired *t* test ($P \leq .05$).
†Ø indicates mm diameter.

D_3 bone quality were included. Although the ISQ_b difference between 2 techniques were significant ($P = .011$, Table 2), the subgroups showed a similar bone quality for both techniques ($P = .699$ and $P = .749$, Table 1).

Previous studies have indicated that implant length exerts no significant effects on implant stability, particularly when the differences in implant length are less than 2 mm.[21,22] Therefore, in this study, we evaluated implants 10 mm and 12 mm in length. However, bone quality, implant diameter, and surgical technique can all exert significant effects on implant stability. The implants with wider diameter associated with higher ISQ values were noted for all subgroups in both techniques (ISQ_0 and $ISQ_{b\text{-}0}$; Table 1). These results are consistent with those from a previous study that indicated that wide implants are associated with higher ISQ stability than are narrow implants.[21]

In general, wide-diameter implants showed higher ISQ values during the 12-week healing period, especially for the conventional technique. However, wide-diameter implants exhibited limited effects on primary stability and secondary stabilities after calibrating the ISQ_b values for both techniques ($ISQ_{b\text{-}0}$ to $ISQ_{b\text{-}12}$; Table 1). The benefit of using wide-diameter implant in osteotome expansion group to increase ISQ values was inconsequential in this study. A smaller sample size of wide diameter implants, and higher lateral expansion pressure accompanied with wider diameter implants caused compromised crestal bone healing for both techniques might partially explained the insignificance.

In a previous animal study, histomorphometric and fluorescence microscopic analyses confirmed that the osteotome technique up-regulated mineralization around dental implants and increased bone-to-implant contact during the early stage of healing. The authors concluded that bone expansion by using an osteotome might increase new bone formation and the osseointegration of dental implants.[12]

However, another related animal study reported contrasting findings, describing that the conventional preparation technique achieved a higher bone-to-implant contact ratio, and required a larger removal torque than did the osteotome technique during the early healing stage.[13] The study's RFA findings revealed that implant stability achieved using the 2 techniques exhibited no significant differences. The authors described that osteotome condensation causes micro bone fractures at the peri-implant interface, leading to increased pressure on blood vessels and negative effects on early osseointegration. The species of animals evaluated, the inspected positions, and the bone quality of the alveolar ridge might account for the observed variations. Evidence to confirm that osteotome bone expansion increases implant primary stability and osseointegration during the healing period is limited.

The significant discrepancy of ISQ_b stability supported the rationale for adopting the selected osteotome or conventional technique ($P = .011$; Table 2). However, the calibrated ISQ_b data enabled the dentist to standardize the initial bone quality and compared the different healing progress of the 2 techniques objectively. The calibrated results showed osteotome expansion reduced the ISQ differences between 2 techniques since Week 0 ($ISQ_{b\text{-}0}$), and achieved a greater ISQ increase than did the conventional technique from Weeks 4 to 12 (Table 2). However, applying osteotome expansion technique on the ridge with a higher ISQ reading, osteotome expansion would compromise the bone integrity of recipient site and cause an unexpected healing pattern.[23]

Although the effects of osteotome tapping on ridge expansion are controversial, the improving efforts are persisting. Hahn et al proposed preserving the periosteum flap to retain blood supply and compensate for ischemia caused by osteotome compression.[10] However, in Osborn and Müller, osteocyte integrity was maintained when the applied compression forces were $<$10–20 MPa.[24,25] Nkenke et al further introduced an osteotome instrument with measurable torque force to prevent inappropriate widening.[12]

We observed some reductions in ISQ values from Weeks 2 to 4 in the osteotome expansion and conventional groups, which were consistent with the observations of previous studies.[12,13,21] These reductions in ISQ values indicated declining primary stability. Buser et al speculated that the bone damage resulting from recipient site preparation and ensuing oseteoclast metabolism around an implant fixture might cause reductions in primary stability.[21] Instead, subsequent increases in ISQ values indicated increases in secondary stability, osseointegration, and overall implant stability. Bone expansion performed using an osteotome might reduce the extent of reduction in primary stability and or increase secondary stability to a greater extent than that performed using conventional drilling, which would increase bone density around the dental implant and reduce the declines in stability caused by bone remodeling during healing. Nevertheless, more implant and bone contact surfaces associated with wide-diameter fixtures could also play a significant role in stability development, and explain some inconsistencies between the subgroups of the different techniques.

A 3- to 4-month follow-up period after implant insertion is the traditional protocol to achieve effective bone remodeling and implant osseointegration prior to prosthetic fabrication. However, proclivity toward immediate implant placement, early loading, and immediate loading has developed because of patient requests and improvements in implantology.[26,27] Glauser et al suggested that the immediate loading of an implant is feasible following the achievement of an ISQ reading of 60.[19] This study did not intend to challenge the indications of immediate and or early implant placement (or loading), the authors were interested in exploring if the healing patterns of 2 surgical techniques were similar after calibration. The developing ISQ in healing pattern of implant stability reached a plateau at Week 10 postoperatively for both techniques, and wide-diameter implants achieved a plateau stability earlier than did the standard-diameter implants in our results (Table 4). Consistent with the previous reports, bone healing and remodeling could persist for 10 to 12 weeks postoperatively, irrespective of the application of the conventional drilling or osteotome expansion technique. However, effects of occlusal loading on stability during the healing period need further research.

Based on ethical concerns, a case-selected trial was applied for this study. Although ISQ calibration was offered, the bias such as 2 techniques compared on the basis of dissimilar bone quality and quantity could cause some significant implications. Additional randomized control trials with increased sample size are required to fully elucidate the healing pattern of implant stability for both techniques. Furthermore, the examinations of long-term success rate and possible complication of buccal bone resorption of the implants that were placed using osteotome expansion are required. The effects of bone substitutes, guided bone regeneration, and other positions of the jaw on implant stability also warrant further investigation.

Overall, the results of this investigation confirm that applying the osteotome expansion technique can expand the D_3 bone in the mandibular posterior area in which the ridge width is marginally narrower than the diameter of the intended implant and achieve comparable ISQ stability to that obtained using the conventional drilling technique, thereby avoiding the requirement for additional surgery and reducing the overall duration of treatment. Preserving a greater amount of osteogenetic cells by using the osteotome expansion technique rather than by using the conventional technique might partially account for these results.

Conclusion

A D_3 quality ridge with mild horizontal deficiency is expandable by using the osteotome expansion technique. Osteotome expansion would gain more secondary implant stability than did the conventional technique after ISQ calibration. Although wider implants presented a higher ISQ value, the increased primary and secondary ISQ stability were inconsequential after calibration.

Abbreviations

GBR: guided bone regeneration
ISQ: implant stability quotient
RFA: resonance frequency analysis

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