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Clinical and Radiographic Evaluation of Piezoelectric versus Conventional Implant Osteotomy Preparation

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ABSTRACT

Background: Preparation of the implant osteotomy influences primary stability, tissue response, and subsequent osseointegration. Piezoelectric osteotomy has been proposed as a more controlled alternative to conventional rotary drilling because of its selective cutting action and irrigation-assisted operating mechanism.
Objective: To compare clinical implant stability and radiographic bone-density changes following implant osteotomy prepared with piezoelectric inserts or conventional drills.
Methods: Eight adult patients received 16 implants in the maxillary anterior or premolar region. Eight implant sites were prepared using conventional drills (control group) and eight using dedicated piezoelectric inserts (study group). Implant stability was recorded with the Osstell device immediately after implant placement and at 6 months. Standardized digital periapical radiographs were obtained immediately after placement and at 3 and 6 months. Relative radiographic bone density was assessed at the mesial, distal, and apical regions using Digora software.
Results: Implant stability increased significantly in both groups over 6 months. At baseline, the difference between groups was not statistically significant (57.4±5.4 versus 53.8±5.6 ISQ; P=0.209), whereas the piezoelectric group showed a significantly higher 6-month value than the conventional group (76.6±5.1 versus 66.6±6.0; P=0.003). Radiographic bone density also increased significantly with time in both groups. At 6 months, total bone-density values were 195.7±4.1 in the piezoelectric group and 180.4±6.8 in the conventional group (P<0.001). A significant positive correlation between implant stability and radiographic bone-density measurements was observed at 6 months (r=0.568, P=0.022).
Conclusion: Within the limitations of this small clinical study, piezoelectric osteotomy was associated with greater improvement in implant stability and radiographic bone density during the 6-month healing period than conventional drilling in maxillary implant sites.

Keywords: *Dental implants; piezoelectric surgery; conventional drilling; implant stability; osseointegration; radiographic bone density.*

INTRODUCTION

Dental implants have become an established method for replacing missing teeth and restoring masticatory function. Successful implant therapy depends on the development and maintenance of a stable bone–implant interface. The preparation of the osteotomy is therefore an important surgical step because the quality of the prepared bone can influence primary stability and subsequent biological healing (1).

Conventional implant osteotomies are generally prepared with sequential rotary drills selected according to implant geometry. Although this technique is predictable, drilling may generate mechanical trauma and heat. Excessive temperature elevation during osteotomy preparation can compromise bone vitality and potentially interfere with osseointegration. The amount of heat generated is influenced by drill geometry and material, cutting speed, applied pressure, irrigation, drill wear, and bone characteristics (2,3).

Piezoelectric surgery was introduced as an alternative approach for cutting mineralized tissues. Ultrasonic microvibrations allow controlled osteotomy preparation while maintaining continuous irrigation. The technology is characterized by selective cutting of mineralized tissue and has been proposed to reduce inadvertent injury to adjacent soft tissues. Piezoelectric systems commonly operate in the ultrasonic range, with the device used in the present study operating at approximately 25–29 kHz (6,7).

Experimental and clinical investigations have suggested that piezoelectric osteotomy may provide favorable conditions for bone healing and implant integration. Reported mechanisms include reduced surgical trauma, effective irrigation and cavitation, improved control of the osteotomy, and preservation of tissue vitality. Histological and molecular studies have also reported differences in inflammatory response and osteogenic activity when piezoelectric preparation is compared with conventional drilling (10,11).

Despite these proposed advantages, the clinical evidence is not uniformly conclusive, particularly regarding primary implant stability. Some investigations have reported higher stability or more favorable stability patterns with piezoelectric preparation, whereas others have found no statistically significant difference between the two approaches (12,13,25). Differences in implant design, bone quality, surgical protocol, and assessment methods may contribute to these findings.

The present study was undertaken to compare implant stability and radiographic bone-density changes following osteotomy preparation with conventional drills and piezoelectric inserts in maxillary implant sites. The study also examined the relationship between clinical implant stability and radiographic bone-density measurements during the 6-month healing period.

PATIENTS AND METHODS

Ethical approval and informed consent

The study was conducted following approval by the Research Ethics Committee of the Faculty of Dentistry, Suez Canal University. All participants were informed about the study procedures, and written informed consent was obtained before treatment.

Study design and participants

This clinical trial included eight patients attending the outpatient clinic of the Oral and Maxillofacial Surgery Department, Faculty of Dentistry, Suez Canal University, for implant treatment. Sixteen implants were distributed equally between two treatment groups. Group I comprised eight implants for which the osteotomy was prepared using conventional drills. Group II comprised eight implants for which the osteotomy was prepared using dedicated piezoelectric inserts.

Eligibility criteria

Participants were adults aged 18–50 years of either sex with missing maxillary anterior teeth or premolars and adequate bone volume and quality at the proposed implant sites. Adequate oral hygiene was required. Patients were excluded when they had vertical or horizontal ridge defects, systemic or bone disorders likely to affect healing, inadequate interarch space, smoking, bruxism or unfavorable oral habits, previous surgery or grafting at the planned implant site, osteoporosis, or other bone diseases.

Materials and equipment

K1 line conical-connection dental implants were used. The piezoelectric unit operated at 25–29 kHz with power up to 16 W and incorporated oscillation control. Piezoelectric implant-site preparation was performed with dedicated inserts (IM1S, IM2A, IP2-3, IM3A, IP3-4, and IM4A). Implant stability was measured with the Osstell device, and radiographic bone-density assessment was performed using Digora software.

Preoperative assessment

A dental and medical history was obtained, and the soft tissues and oral hygiene were assessed. Patients requiring periodontal debridement underwent scaling and polishing before surgery. Interocclusal space was evaluated clinically and the available ridge width was assessed. Preoperative cone-beam computed tomography was obtained to confirm bone dimensions and quality at the planned implant site. Imaging was performed using a Scanora-3D CBCT system with a CMOS flat-panel detector and an isotropic voxel size of 133 µm.

Surgical procedure

All procedures were performed under local anesthesia with 4% articaine hydrochloride containing 1:100,000 epinephrine. Local infiltration was administered buccally and palatally. Before incision, patients rinsed with 0.125% chlorhexidine, and 10% povidone-iodine was applied to the surgical field. A pyramidal mucoperiosteal flap was raised using buccal releasing incisions positioned at least 2 mm mesial and distal to the operative site.

In Group I, osteotomy preparation was performed with the conventional drill sequence supplied with the implant system. The initial 1.8-mm bur was used at 800 rpm and 30 Ncm, followed by sequential tapered drills at approximately 500–800 rpm under saline irrigation until the planned osteotomy dimensions were achieved.

In Group II, the osteotomy was prepared using piezoelectric inserts. IM1S was used for the initial pilot osteotomy, followed by IM2A, IP2-3, IM3A, IP3-4, and IM4A to progressively enlarge and optimize the osteotomy. The appropriate implant diameter and length were then selected and placed.

All implants were initially seated manually to approximately two-thirds of their length and subsequently advanced using a torque wrench until positioned approximately 2 mm below the alveolar crest. Implant stability was recorded immediately after placement using the Osstell device and a SmartPeg. Cover screws were placed, the flaps were repositioned, and closure was achieved with 3-0 silk sutures. All procedures were performed by the same surgeon using a standardized technique.

Postoperative care and follow-up
Patients received amoxicillin trihydrate/potassium clavulanate 1 g every 12 hours and ibuprofen 600 mg every 8 hours for five days, together with postoperative cold-pack instructions. Chlorhexidine mouth rinse was advised three times daily during the first postoperative week. Clinical implant stability was reassessed at 6 months.

Standardized digital periapical radiographs were obtained immediately after implant placement and at 3 and 6 months. Images were analyzed with Digora software to determine relative bone-density changes at the mesial, distal, and apical regions surrounding each implant.

Outcome measures
The primary clinical outcome was implant stability measured by Osstell resonance frequency analysis. Radiographic outcomes comprised relative bone density at the mesial, distal, and apical implant surfaces and the combined total bone-density measurement. The association between implant stability and radiographic bone density was also evaluated.

Statistical analysis
Data were analyzed using SPSS version 26 (IBM Corp., Armonk, NY, USA). Normality was assessed using the Shapiro–Wilk test. Continuous variables were summarized as mean±standard deviation. Independent-samples t tests were used for between-group comparisons, while one-way analysis of variance was used to evaluate changes across follow-up periods within each group. Pearson correlation analysis was used to assess the relationship between implant stability and radiographic bone-density measurements. A two-sided P value <0.05 was considered statistically significant.

RESULTS
Demographic characteristics
Eight patients were included. Three were male (44.4%) and five were female (55.6%). The mean age was 36±8.5 years among males and 25.7±7.4 years among females. The reported comparisons did not demonstrate statistically significant differences in sex distribution or mean age (Table 1).

Table 1. Gender and age distribution of participants

Sex	n	%	Mean age (years) ± SD
Male	3	44.4	36.0 ± 8.5
Female	5	55.6	25.0 ± 7.4
Total	8	100	28.11

No postoperative infection or clinically evident peri-implant inflammatory complication was reported in either group during follow-up. The mucosa surrounding the implants remained clinically normal at the recorded assessments.

Implant stability
Mean Osstell values increased significantly from immediate postoperative assessment to 6 months in both groups. The piezoelectric group increased from 57.4±5.4 to 76.6±5.1, corresponding to a 33.6% increase, whereas the conventional group increased from 53.8±5.6 to 66.6±6.0, corresponding to a 24.0% increase. The between-group difference was not significant immediately after implant placement (P=0.209), but was significant at 6 months (P=0.003), with higher values in the piezoelectric group (Table 2).

Table 2. Implant stability measurements by Osstell resonance frequency analysis

Time point	Piezoelectric Mean±SD	Conventional Mean±SD	t	P
Immediate	57.4 ± 5.4	53.8 ± 5.6	1.3	0.209
6 months	76.6 ± 5.1	66.6 ± 6.0	3.58	0.003**
Change	+19.3 (+33.6%)	+12.9 (+24.0%)		

Radiographic bone density
Bone density increased progressively during follow-up in both groups. At the mesial aspect, the 6-month mean values were 188.0±5.0 in the piezoelectric group and 168.9±8.0 in the conventional group (P<0.001). At the distal aspect, corresponding values were 185.6±5.2 and 174.3±7.4 (P=0.003). At the apical region, 6-month values were 213.5±4.3 and 197.6±9.9, respectively (P=0.001). The total radiographic bone-density measurement at 6 months was 195.7±4.1 in the piezoelectric group and 180.4±6.8 in the conventional group (P<0.001).

Table 3. Radiographic bone density at the mesial implant aspect

Time	Piezoelectric Mean±SD	Conventional Mean±SD	t	P
Mesial—Immediate	153.6 ± 6.1	153.0 ± 7.3	0.186	0.850
Mesial—3 months	171.3 ± 7.4	160.9 ± 7.4	2.797	0.014**
Mesial—6 months	188.0 ± 5.0	168.9 ± 8.0	5.734	<0.001**

Table 4. Radiographic bone density at the distal implant aspect

Time	Piezoelectric Mean±SD	Conventional Mean±SD	t	P
Distal—Immediate	153.3 ± 6.4	161.0 ± 4.6	2.77	0.015**
Distal—3 months	168.3 ± 4.6	163.6 ± 7.1	1.55	0.144
Distal—6 months	185.6 ± 5.2	174.3 ± 7.4	3.54	0.003**

Table 5. Radiographic bone density at the apical implant region

Time	Piezoelectric Mean±SD	Conventional Mean±SD	t	P
Apical—Immediate	190.0 ± 8.0	183.8 ± 5.9	1.78	0.097
Apical—3 months	199.6 ± 8.3	188.9 ± 9.0	2.48	0.026**
Apical—6 months	213.5 ± 4.3	197.6 ± 9.9	4.17	0.001**

Table 6. Total radiographic bone density around the implant

Time	Piezoelectric Mean±SD	Conventional Mean±SD	t	P
Total—Immediate	165.6 ± 5.1	165.8 ± 3.9	0.129	0.900
Total—3 months	179.7 ± 4.7	171.0 ± 6.2	3.11	0.008**
Total—6 months	195.7 ± 4.1	180.4 ± 6.8	5.51	<0.001**

Correlation between clinical and radiographic outcomes

There was no significant correlation between implant stability and radiographic bone-density measurements at baseline ($r=-0.108$, $P=0.691$). At 6 months, a significant positive correlation was identified ($r=0.568$, $P=0.022$), indicating that higher implant stability measurements were associated with higher radiographic bone-density values at the end of the follow-up period.

Table 7. Correlation between implant stability and radiographic bone density

Follow-up	r	P	R^2
Immediate	-0.108	0.691	0.012
6 months	0.568	0.022**	0.323

DISCUSSION

The present clinical trial compared two approaches to implant osteotomy preparation and evaluated their effects using both a clinical measure of implant stability and serial radiographic assessment of bone density. The principal findings were that implant stability increased significantly during the 6-month healing period in both groups, while the piezoelectric group demonstrated a greater increase and a significantly higher stability value at 6 months. Radiographic bone density also increased over time, with significantly higher values in the piezoelectric group at several follow-up points.

The biological response to implant placement is influenced by the quality and vitality of the bone surrounding the implant. Conventional rotary osteotomy remains widely used because it is efficient and familiar, but heat generation and mechanical trauma are important considerations. The temperature produced during drilling depends on drill dimensions, speed, pressure, irrigation, and the condition of the cutting instrument (2,3). Excessive thermal injury may compromise cellular activity and bone regeneration, potentially affecting the establishment of a stable bone–implant interface.

Piezoelectric osteotomy provides an alternative cutting mechanism based on ultrasonic microvibrations. Its selective action on mineralized tissues, together with continuous irrigation and cavitation, may permit controlled preparation of the osteotomy while limiting unintended soft-tissue injury. Experimental work has described favorable bone responses following piezoelectric preparation, including changes in inflammatory and osteogenic activity (10,11). These biological considerations provide a plausible explanation for the progressively greater radiographic bone-density values observed in the present study.

In the current sample, immediate postoperative implant stability did not differ significantly between groups. This finding is important because primary stability is largely determined by the mechanical interaction between the implant and the prepared bone at the time of placement. The lack of a significant baseline difference suggests that the two osteotomy techniques produced broadly comparable initial mechanical stability under the conditions of this study.

By 6 months, however, the piezoelectric group demonstrated significantly higher Osstell values. The mean increase was 33.6% in the piezoelectric group compared with 24.0% in the conventional group. This pattern is consistent with the concept that the quality of the healing environment may influence the transition from primary mechanical stability to biologically mediated secondary stability. Previous investigations have reported higher or more favorable implant-stability patterns following piezoelectric osteotomy, although the literature is not completely consistent and some studies have found no significant difference between preparation techniques (12,25,37).

The radiographic findings showed a similar temporal pattern. Bone density increased from immediate postoperative assessment through 3 and 6 months in both treatment groups. At the mesial aspect, the piezoelectric group showed significantly higher density than the conventional group at both 3 and 6 months. At the distal aspect, the groups differed immediately and at 6 months, but not at 3 months. At the apical region, between-group differences became significant at 3 months and remained significant at 6 months. These regional variations indicate that bone remodeling around an implant does not necessarily occur at an identical rate at all surfaces.

The total radiographic bone-density values provide an overall view of these changes. The groups were comparable immediately after implant placement, while the piezoelectric group showed higher values at both 3 and 6 months. By 6 months, the mean total density was 195.7±4.1 in the piezoelectric group compared with 180.4±6.8 in the conventional group. The magnitude and direction of these changes support the clinical stability findings and suggest a more pronounced radiographic maturation around implants prepared using the piezoelectric technique in this cohort.

The significant positive correlation observed at 6 months between Osstell stability and radiographic bone density further supports the relationship between the clinical and radiographic outcomes. No significant association was present immediately after placement. This is biologically plausible because immediate stability primarily reflects mechanical engagement, whereas later stability is progressively influenced by bone remodeling and the developing bone–implant interface.

Standardized digital periapical radiography was selected for serial evaluation because it permits reproducible follow-up using a parallel technique and allows quantitative assessment with image-analysis software. Digora software was used to assess relative radiodensity, providing a numerical approach to detecting changes that may be difficult to appreciate visually. Nevertheless, radiographic density measurements should be interpreted as relative measurements rather than direct histological measurements of bone quality.

The choice of the maxillary anterior or premolar region was also relevant to the clinical protocol. These sites can provide a suitable setting for evaluating implant stability and bone healing while limiting the confounding effects associated with more complex posterior implant procedures. The present results therefore apply primarily to the selected maxillary sites and should not automatically be generalized to posterior mandible or other clinical situations.

The study has several limitations. The sample was small, with only eight patients and 16 implants, and the follow-up period was limited to 6 months. The study also evaluated a restricted anatomical region and used a single implant system and a specific piezoelectric protocol. The findings therefore require confirmation in larger randomized clinical studies involving different bone qualities, implant designs, anatomical regions, and longer follow-up periods. Additional assessment of marginal bone loss, peri-implant clinical parameters, and biological markers could provide further insight into the mechanisms underlying the observed differences.

Despite these limitations, the combined clinical and radiographic findings indicate that piezoelectric osteotomy may provide favorable conditions for implant healing. The absence of a significant baseline difference followed by higher stability and bone-density measurements during follow-up strengthens the interpretation that the observed differences developed during the healing period rather than reflecting a clear initial stability advantage.

CONCLUSION

Within the limitations of this clinical study, both conventional drilling and piezoelectric osteotomy were associated with progressive improvement in implant stability and radiographic bone density during 6 months of healing. Piezoelectric osteotomy demonstrated significantly higher implant stability at 6 months and higher radiographic bone-density measurements at several follow-up assessments. A significant positive correlation between implant stability and radiographic bone density was also observed at 6 months. Piezoelectric osteotomy may therefore be considered a useful approach for implant-site preparation in selected maxillary sites. Larger studies with longer follow-up and broader anatomical and implant conditions are warranted to determine the reproducibility and long-term clinical significance of these findings.

FIGURES

Figure 1. Clinical steps: mucoperiosteal flap, implant insertion, torque-controlled placement, and cover-screw placement.

Figure 2. Postoperative clinical and radiographic follow-up, including soft-tissue healing, Osstell measurement, and digital periapical imaging.

Figure 3. Conventional drilling and implant placement.

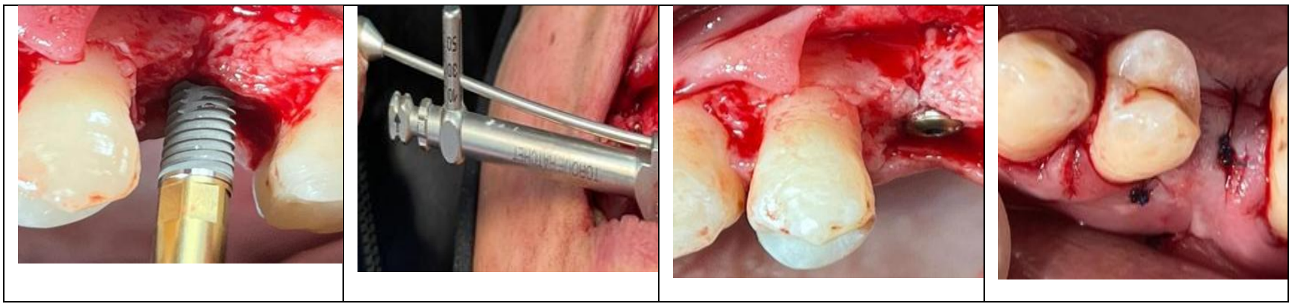

Figure 4. Piezoelectric osteotomy preparation using sequential dedicated inserts.

Figure 5. Comparison of radiographic bone density at the mesial and distal implant aspects during follow-up.

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