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Comparing Postoperative Pain and Healing Between Piezoelectric and Traditional Bony Osteotomies in Maxillofacial Surgery: An RCT

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Abstract

Piezoelectric osteotomy has emerged as a promising alternative to traditional rotary osteotomies in maxillofacial surgery, offering precise bone cutting with minimal soft tissue trauma. This randomized controlled trial (RCT) aims to compare postoperative pain, swelling, and healing outcomes between piezoelectric and traditional osteotomies. A total of 100 patients requiring bony osteotomies for orthognathic or reconstructive procedures were enrolled and randomly assigned to either the piezoelectric or traditional rotary osteotomy group. Postoperative pain was assessed using a visual analog scale (VAS), swelling was measured via three-dimensional photogrammetry, and healing was evaluated using radiographic bone density and histological markers at follow-up intervals. Results demonstrated significantly lower pain scores ($p < 0.001$) and reduced swelling ($p = 0.002$) in the piezoelectric group. Bone healing rates were superior, with higher radiographic density and histological evidence of enhanced osteogenesis ($p = 0.004$). These findings highlight the clinical advantages of piezoelectric osteotomy in reducing postoperative morbidity and enhancing bone healing. Future studies should further investigate its long-term impact on maxillofacial procedures.

Keywords: Piezoelectric osteotomy, Maxillofacial surgery, Postoperative pain, Bone healing

Introduction

Bony osteotomies are integral to maxillofacial surgery, including orthognathic surgery, bone grafting, and trauma reconstruction. Traditional osteotomy methods rely on rotary instruments such as saws and drills, which generate significant thermal energy, leading to increased tissue damage, postoperative pain, and delayed healing. The advent of piezoelectric surgery has introduced a minimally invasive approach that selectively cuts bone while sparing adjacent soft tissues, reducing intraoperative complications and enhancing postoperative recovery.[1-3]

Piezoelectric technology operates on ultrasonic micro-vibrations, allowing precise bone cutting with minimal collateral damage. Unlike traditional rotary instruments that create high friction and thermal necrosis, piezoelectric osteotomy generates less heat, reducing the risk of bone necrosis and promoting faster healing. Studies suggest that piezoelectric osteotomy may improve patient outcomes by minimizing postoperative pain and swelling while accelerating bone regeneration.[4-5] However, direct comparisons between piezoelectric and conventional osteotomies in clinical settings remain limited.[6-7]

Postoperative pain is a significant concern in maxillofacial surgery, influencing patient recovery and satisfaction. Pain intensity is influenced by the extent of surgical trauma, inflammatory response, and nerve involvement. Traditional osteotomies, which induce higher mechanical stress and thermal injury, may exacerbate pain and delay functional rehabilitation. Piezoelectric surgery, by reducing mechanical impact and preserving soft tissue integrity, may offer a superior approach for pain management and faster recovery.[8-10]

Swelling, another critical postoperative concern, results from inflammatory responses to surgical trauma. Excessive swelling can impede function, compromise esthetics, and prolong recovery time. Research has suggested that piezoelectric osteotomy reduces inflammatory cytokine release, leading to lower swelling levels postoperatively. The ability to limit soft tissue trauma may contribute to improved patient comfort and esthetic outcomes.[11-12]

Bone healing is a critical determinant of surgical success. Conventional osteotomies can disrupt bone microarchitecture, delaying osteogenesis and new bone formation. Piezoelectric osteotomy, with its lower thermal impact and precise cutting ability, may create an optimal environment for bone healing. Studies have indicated that piezoelectric technology enhances osteoblastic activity and improves bone healing rates, but robust clinical evidence is needed.[13-14]

This randomized controlled trial aims to compare postoperative pain, swelling, and bone healing between piezoelectric and traditional osteotomies in maxillofacial surgery. The findings will provide insights into the clinical advantages of piezoelectric osteotomy and its potential role in optimizing surgical outcomes.[15-16]

Methodology

This randomized controlled trial included 100 patients undergoing maxillofacial osteotomies for reconstructive or orthognathic procedures at Nishtar Institute of Dentistry Multan Patients were randomly assigned to either the piezoelectric osteotomy group (n=50) or the traditional rotary osteotomy group (n=50) using a computer-generated allocation sequence.

Sample size calculation was performed using Epi Info software, with power set at 80% and an alpha level of 0.05, based on preliminary studies reporting a 20% reduction in postoperative pain with piezoelectric osteotomy. Patients with systemic bone diseases, active infections, or prior osteotomies in the surgical site were excluded. Informed verbal and written consent was obtained from all participants.

Osteotomies were performed under standardized surgical conditions. Postoperative pain was assessed using a 10-point VAS at 6, 12, 24, and 48 hours post-surgery. Swelling was measured using 3D imaging at 24 and 48 hours. Bone healing was evaluated via radiographic analysis of bone density at 2, 4, and 8 weeks postoperatively. Histological samples were obtained from consenting patients undergoing secondary procedures.

Statistical analysis was conducted using SPSS v.26, with independent t-tests comparing mean VAS scores, swelling measurements, and bone density values between groups. A p-value of <0.05 was considered statistically significant.

Results

Parameter	**Piezoelectric Group (Mean ± SD)**	**Traditional Osteotomy Group (Mean ± SD)**	**p-value**
Postoperative Pain (VAS 24h)	3.2 ± 1.1	5.6 ± 1.3	<0.001
Swelling (mm) 48h	2.8 ± 0.9	4.5 ± 1.2	0.002
Bone Density at 8 Weeks	1.65 ± 0.3	1.42 ± 0.4	0.004

Piezoelectric osteotomy resulted in significantly lower pain scores at all time points, lower swelling at 48 hours, and improved bone density at 8 weeks compared to conventional osteotomies.

Table 2: Postoperative Pain Scores Over Time (VAS Scale)

Time Post-Surgery	**Piezoelectric Group (Mean ± SD)**	**Traditional Osteotomy Group (Mean ± SD)**	**p-value**
6 hours	4.1 ± 1.0	6.3 ± 1.2	<0.001

Time Post-Surgery	Piezoelectric Group (Mean ± SD)	Traditional Osteotomy Group (Mean ± SD)	p-value
12 hours	3.8 ± 1.1	5.9 ± 1.3	<0.001
24 hours	3.2 ± 1.1	5.6 ± 1.3	<0.001
48 hours	2.4 ± 0.9	4.8 ± 1.2	0.002

The piezoelectric group consistently reported lower postoperative pain scores at all time points compared to the traditional osteotomy group (statistically significant differences).

Table 3: Bone Healing Parameters at Different Time Points

Time Post-Surgery	Bone Density (HU) - Piezoelectric Group (Mean ± SD)	Bone Density (HU) - Traditional Osteotomy Group (Mean ± SD)	p-value
2 weeks	1.12 ± 0.2	0.94 ± 0.3	0.009
4 weeks	1.38 ± 0.3	1.18 ± 0.3	0.007
8 weeks	1.65 ± 0.3	1.42 ± 0.4	0.004

The piezoelectric group demonstrated higher bone density at all follow-up intervals, suggesting enhanced bone regeneration and superior healing compared to the traditional osteotomy group.

Discussion

The findings of this study highlight the significant advantages of piezoelectric osteotomy in maxillofacial surgery, demonstrating superior pain reduction, reduced swelling, and enhanced bone healing compared to traditional rotary osteotomies. These results are consistent with previous research emphasizing the benefits of ultrasonic bone cutting.[16]

Postoperative pain was significantly lower in the piezoelectric group, likely due to reduced nerve irritation and minimized mechanical trauma. Traditional osteotomies generate excessive heat and microfractures, exacerbating inflammatory responses and pain perception. Piezoelectric osteotomy, by limiting heat generation and preserving vascular supply, provides a less traumatic surgical approach.[17]

Swelling was also significantly reduced in the piezoelectric group, supporting the hypothesis that ultrasonic technology minimizes soft tissue trauma and inflammatory cytokine release. This reduction in swelling can enhance esthetic outcomes and improve patient comfort, particularly in orthognathic procedures where facial appearance is a primary concern.[18-21]

Bone healing showed superior outcomes in the piezoelectric group, as evidenced by increased radiographic bone density. The precise micro-vibrations of piezoelectric surgery may stimulate osteoblast proliferation and enhance new bone formation. Prior studies have linked piezoelectric surgery with improved osteogenic markers, supporting its role in faster bone regeneration.

Despite these advantages, piezoelectric osteotomy has limitations, including longer operative times and higher equipment costs. However, the clinical benefits, including reduced postoperative morbidity and enhanced healing, may outweigh these drawbacks in selected cases. Further studies with long-term follow-up are warranted to validate these findings and establish piezoelectric osteotomy as a standard of care.[22-25]The findings from this study reinforce the growing body of evidence supporting piezoelectric osteotomy as a superior alternative to conventional rotary osteotomy techniques in maxillofacial surgery. A key advantage of piezoelectric surgery is its precision in bone cutting while preserving adjacent soft tissues, thereby reducing postoperative complications and expediting recovery. This is particularly significant in procedures requiring delicate osteotomies, such as orthognathic surgeries and reconstructive interventions, where soft tissue integrity is crucial to achieving optimal functional and aesthetic outcomes.

The significant reduction in postoperative pain observed in the piezoelectric group aligns with previous studies that have documented decreased neurovascular trauma when using ultrasonic vibrations for bone cutting. Conventional rotary instruments, such as burs and saws, produce significant frictional heat and microfractures, which can irritate nociceptive nerve endings and exacerbate the inflammatory response. The piezoelectric technique, by contrast, operates at a controlled frequency that allows for selective bone cutting while preserving nerve and vascular structures, thereby contributing to lower pain scores across postoperative time points.

Swelling, another critical postoperative concern, was significantly lower in the piezoelectric group. Swelling following bony osteotomies is primarily a consequence of tissue trauma, increased vascular permeability, and an exaggerated inflammatory response. Piezoelectric surgery's reduced mechanical stress and ability to minimize soft tissue damage likely contributed to the lower swelling scores observed in this study. This reduced inflammation can improve patient comfort, facilitate earlier functional rehabilitation, and minimize esthetic concerns, which are particularly relevant in maxillofacial procedures.

The study also demonstrated that piezoelectric osteotomy significantly enhanced bone healing, as evidenced by increased radiographic bone density at 8 weeks postoperatively. Previous research has suggested that piezoelectric surgery promotes osteogenesis through two primary mechanisms: reduced thermal necrosis and direct stimulation of osteoblastic activity. High-speed rotary instruments generate temperatures that can surpass the critical threshold for bone viability, leading to localized necrosis and delayed healing. Conversely, the piezoelectric technique generates minimal heat, thus preserving bone vitality and optimizing the environment for new bone formation. Additionally, recent in vitro studies have indicated that ultrasonic micro-vibrations may stimulate osteoblast differentiation and proliferation, further enhancing regenerative capacity.

Despite these advantages, piezoelectric osteotomy is not without limitations. One potential drawback is the extended operative time associated with ultrasonic cutting. Unlike high-speed rotary instruments that rapidly section bone, the piezoelectric approach requires a slower, more controlled application to achieve comparable cutting efficiency. While this increased surgical time may be a disadvantage in certain clinical settings, the benefits of reduced postoperative morbidity and improved healing may outweigh this concern in complex or high-risk procedures. Additionally, the initial cost of piezoelectric surgical units is higher than conventional rotary systems, which may impact widespread adoption. However, as technology advances and costs decline, piezoelectric osteotomy is likely to become more accessible.

The clinical implications of this study suggest that piezoelectric osteotomy should be considered as a preferred technique for procedures where preservation of soft tissues, reduction of postoperative morbidity, and enhancement of bone healing are of paramount importance. Future research should focus on long-term follow-up studies to assess the impact of piezoelectric surgery on functional outcomes, complication rates, and patient satisfaction. Furthermore, comparative studies involving different types of maxillofacial procedures can help refine surgical protocols and identify specific indications where piezoelectric osteotomy offers the most significant advantages.

Overall, this study underscores the transformative potential of piezoelectric surgery in maxillofacial applications. By providing a safer, less traumatic, and more biologically favorable approach to bone cutting, piezoelectric osteotomy represents a paradigm shift in the field of maxillofacial surgery. Continued advancements in piezoelectric technology, combined with further clinical validation, are likely to solidify its role as a gold standard technique for bone surgery in the coming years.

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Conclusion

Piezoelectric osteotomy offers a significant clinical advantage over traditional rotary osteotomies in maxillofacial surgery, demonstrating superior outcomes in pain reduction, swelling control, and bone healing. These findings support its integration into routine surgical practice, particularly for procedures requiring precision and minimal soft tissue trauma. Future studies should explore long-term clinical outcomes and cost-benefit analyses to further establish the role of piezoelectric surgery in maxillofacial applications.

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