# Minimizing Invasiveness in Neurosurgical Osteotomies: A Comparative Histomorphometric Study of Piezoelectric Craniotomy versus High-Speed Drill

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BACKGROUND: **Piezoelectric bone cutting has gained popularity in neurosurgical osteotomies due to perceived lower trauma compared to rotary instruments. However, histological confirmation of its decreased aggressiveness is lacking, hindering conclusive proof. This study compares the bony and neuro-meningeal invasiveness of piezoelectric craniotomy with high-speed drill techniques.**

METHODS: **Histological data from 21 sheep undergoing piezoelectric craniotomy and 19 sheep subjected to high-speed electric drill craniotomy were compared. Piezoelectric craniotomy utilized a 0.35 mm micro saw titanium nitride coated. Outcome parameters included the detection of the "smear layer," average osteoblast count per high-power field, and residual bone matrix for bony invasiveness assessment. Parameters for meningeal and brain parenchymal invasiveness included pachymeningeal and leptomeningeal injury, gliosis, and histiocytic infiltration. Statistical significance was determined at $P < 0.05$.**

RESULTS: **Results showed the Piezo group had fewer frequent smear layers ($P < 0.001$), higher residual bone matrix ($P < 0.05$), and greater osteoblast counts per high-power field ($P < 0.05$). Additionally, the Piezo group exhibited lower rates of leptomeningeal injury, cerebral gliosis, and histiocytic infiltration ($P < 0.05$).**

CONCLUSIONS: **Piezoelectric craniotomy preserves residual osteoblast viability and leptomeningeal integrity while demonstrating lower rates of thermally induced gliosis and histiocytic infiltration compared to high-speed drills. This suggests the piezoelectric osteotome's minimal invasiveness in bone, meningeal, and brain tissue.**

## INTRODUCTION

Piezoelectric bone cutting is the result of the combination between the mechanical effect of ultrasound and the physical phenomenon of cavitation, the latter enhancing the former.[1,2] The phenomenon of cavitation leads to the formation of vapor-filled cavities as a result of abrupt and rapid pressure changes in a fluid.[3] These cavities collapse under the impact of a high-pressure change, creating a high-energy shock wave that propagates through the biological tissue, including the mineralized tissue.[1,3] As a result of the shock wave propagation, the biomechanical adhesion between the cell layer and the substrate is weakened, facilitating mechanical cutting of the tissue. In piezoelectric surgery, the source of pressure changes at the base of cavitation are the piezoelectric crystals, which can deform when exposed to an electric field that falls in the ultrasonic frequency spectrum.[4,5] These concepts constitute the physical basis of the so-called "indirect piezo effect."[6,7] The linear micrometric (60–210 μm) vibrations, when delivered at an oscillation frequency ranging between 25 and 30 kHz, are responsible for the selectivity of the piezoelectric cut on the

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- Bone healing
- Gliosis
- High-speed drills
- Histomorphometric study
- Neurosurgical osteotomies
- Piezoelectric craniotomy
- Thermal damage

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mineralized bone while sparing the underlying and neighboring soft tissues and neurovascular structures.[2,4]

In addition, the irrigation system coupled with the instrument leads to the avoidance of thermal injury. All these technical characteristics make the piezoelectric bone scalpel theoretically superior to the conventional rotary osteotomes used in neurosurgery, oto-neurosurgery, and maxillo-facial surgery. In confirmation of this, several studies have already been reported in the literature.[8-29] However, very few of them aimed at histologic confirmation of the presumed less aggressiveness of piezo surgery compared to rotary instruments. The same applies to the dynamics of bone healing in relation to the viability of residual osteoblasts.

The aim of the present study was to analyze the invasiveness of piezoelectric craniotomy from a histomorphometric point of view. A comparative evaluation with the high-speed drill was also performed.

## METHODS

The in vivo study was conducted at the Dipartimento di Medicina di Precisione e Rigenerativae Area Jonica facility, University of Bari, Italy, with Ministry of Health protocol approval (#654/2020).

Histological data of cranial vault, meningeal, and cerebral parenchymal samples from 21 sheep that underwent craniotomy with a piezoelectric bone scalpel (Mectron Piezosurgery Touch, Mectron Medical Technology, Genoa, Italy) (Figure 1) (Piezo group) were collected and compared with those from 19 sheep that underwent craniotomy with a high-speed electric drill (Osseoduo, Bien-Air Surgery, Biel, Switzerland) (speed range: 0–80.000 rpm, torque: 4.5 N/cm) (control group). A specially designed micro saw of 0.35 mm titanium nitride coated (OT12, Osteotomy Tips Kit, Mectron Medical Technology, Genoa, Italy) (Figure 1C) was mounted on the piezoelectric scalpel handpiece (Figure 1D). The micro saw has 3 landmarks (Figure 1C, black dots) indicating depths of 7, 8.50, and 10 mm. This characteristic, together with the elongated shape of the micro saw, allowed for deeper cuts. A preset power on the Piezosurgery touch screen of 16 W, designated for cortical bone, was applied with 25–30 KHz frequency modulation and 60–120 µm linear microvibrations. The irrigation rate was 30 mL/min. Figure 2 illustrates the key operative steps of a piezoelectric craniotomy.

In the control group, the handpiece was equipped with an irrigation nozzle connected to a peristaltic pump, and the saline flow was set at 80%. During surgery, the flow was increased to 100% on a case-by-case basis, depending on the need for greater cooling and/or clearer vision of the surgical field. Only 6.0 mm right fluted burrs were used.

Video 1 shows a comparison between piezoelectric and high-speed drill craniotomies.

Cranial vault and pachymeningal specimens were harvested en bloc, as were the leptomeninges and underlying cerebral parenchyma. Histological studies were performed by hematoxylin-eosin staining.

Video

*Video available at www.sciencedirect.com*

### Outcome Measures

The detection of "smear layer,"[30-33] mean number of osteoblasts/high-power field, and bone matrix were considered as outcome parameters of the invasiveness of the technique to the adjacent

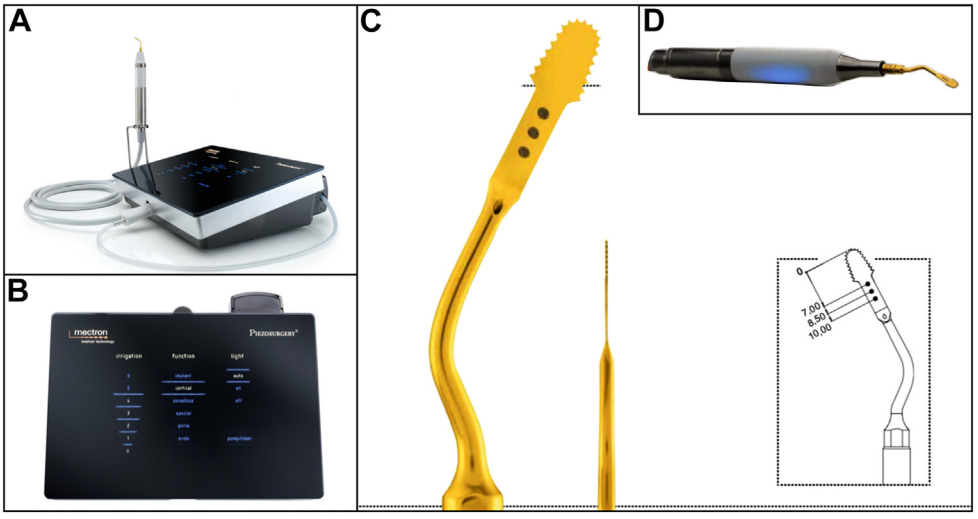


**Figure 1.** Piezoelectric bone scalpel (Mectron Piezosurgery Touch, Mectron Medical Technology, Genoa, Italy). (**A**) Power unit; (**B**) touch screen; (**C**) micro saw OT12 0.35 mm titanium nitride coated; (**D**) handpiece.

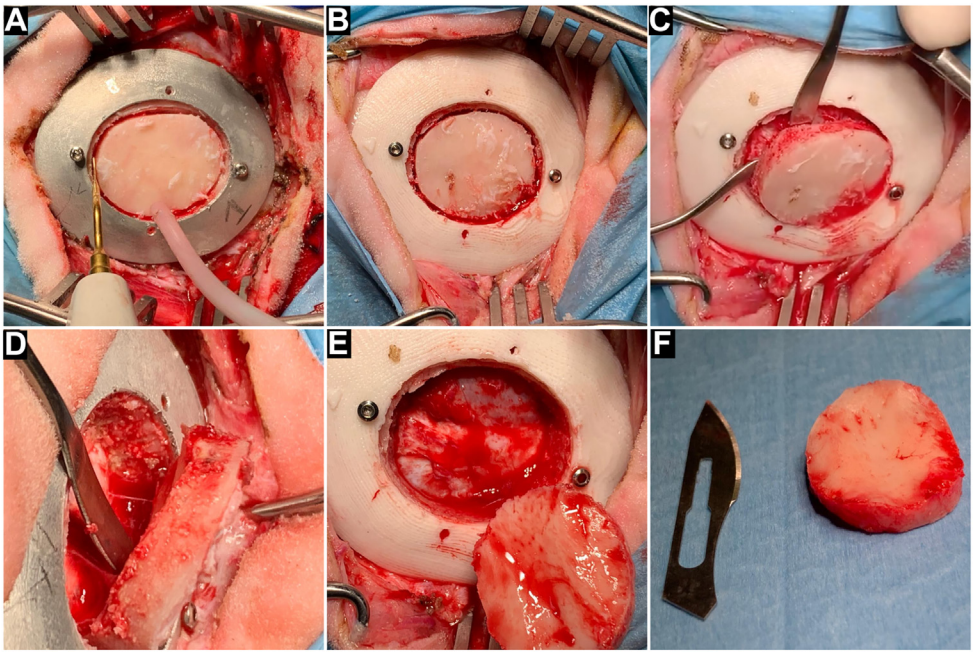


**Figure 2.** (**A**) Piezoelectric craniotomy performed with the aid of a fixed metallic frame. (**B**) Osteotomized calvaria after removal of the metallic frame. (**C**-**D**) Elevation of the bone flap. (**E**) Dura exposure. (**F**) Bone flap (with size reference to a No. 24 knife blade).

**Table 1.** Histological Data

| Variable | Data | | *P* Value |
|---|---|---|---|
| | Piezo Group | Control Group | |
| Total n° of Samples | 21 | 19 | |
| Site | | | |
| Cranial vault | | | |
| Smear layer evidence, n° (%) | 2 (9.5) | 16 (84.2) | <0.001* |
| Bone matrix evidence, n° (%) | 16 (76.1) | 6 (31.5) | 0.003* |
| Osteoblast/HPF, mean ± SD | 5.5 ± 3 | 3.1 ± 2 | 0.008* |
| Meninges | | | |
| Pachymeningeal injury, n° (%) | 3 (14.2) | 8 (42.1) | 0.050 |
| Leptomeningeal injury, n° (%) | 1 (4.7) | 8 (42.1) | 0.003* |
| Cerebral parenchyma | | | |
| Gliosis evidence, n° (%) | 2 (9.5) | 7 (33.3) | 0.039* |
| Histiocytic infiltration evidence, n° (%) | 2 (9.5) | 9 (47.3) | 0.006* |

HPF, high-power field; SD, standard deviation.
*Statistic.

cranial vault bone, while the dural sparing ability was determined by assessing the rate of pachymeningeal injury. Leptomeningeal injury, gliosis, and histiocytic infiltration were considered outcome measures of the aggressiveness of the instrument to the brain parenchyma.

### Statistical Analysis

Categorical variables were reported as values and percentages, whereas continuous variables with normal distribution were expressed as means (± standard deviation).

Unpaired and Welch's t-tests were used for numerical and continuous variables, respectively. Prism 9 software (GraphPad Software, Inc., La Jolla, California, USA) was used for statistical analysis. A P value $< 0.05$ was considered significant.

## RESULTS

In the Piezo group, the smear layer was less frequent ($P < 0.001$) and the residual amount of bone matrix was superior ($P < 0.05$). The mean number of live osteoblasts/high-power field was also greater ($P < 0.05$). The anatomical integrity of the pachymeninges was unaffected by either instrument type ($P > 0.05$), in contrast to the leptomeninges, which were more frequently injured in the control group ($P < 0.05$). The overall rate of cerebral gliosis and histiocytic infiltration was lower in the Piezo group ($P < 0.05$).

Table 1 summarizes the histologic data, and the bar graphs in Figures 3, 4, and 5 show the overall invasiveness of the

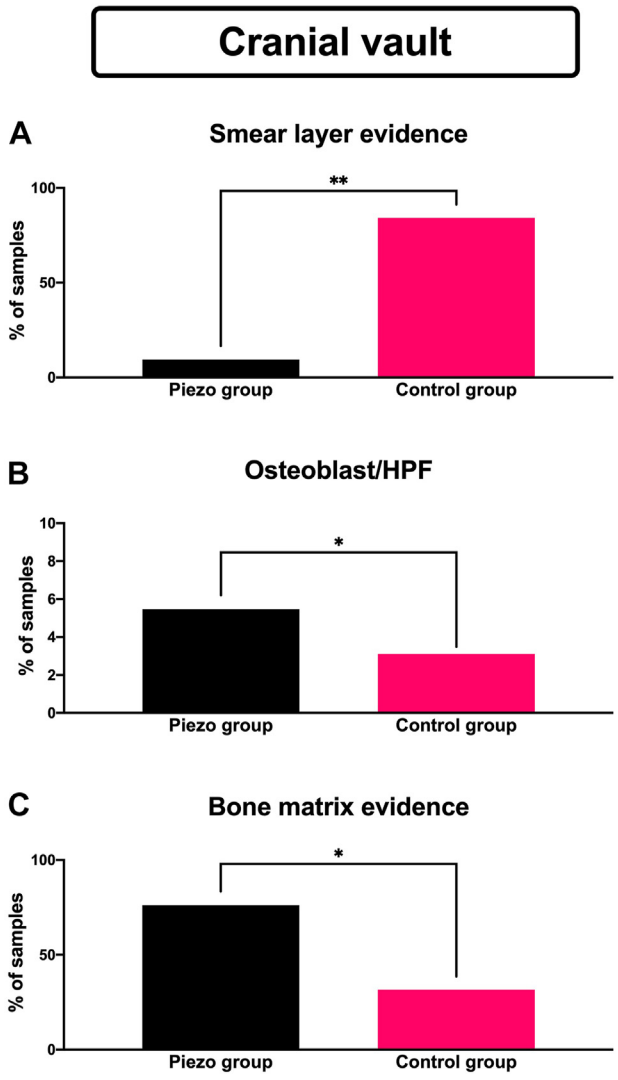


**Figure 3.** Bar graph showing the overall invasiveness of the piezoelectric bone scalpel versus the high-speed drill on the cranial vault bone in terms of smear layer evidence (**A**), live osteoblast/HPF (**B**), and residual bone matrix (**C**). $**P < 0.001$, $*P < 0.05$. HPF, high-power field.

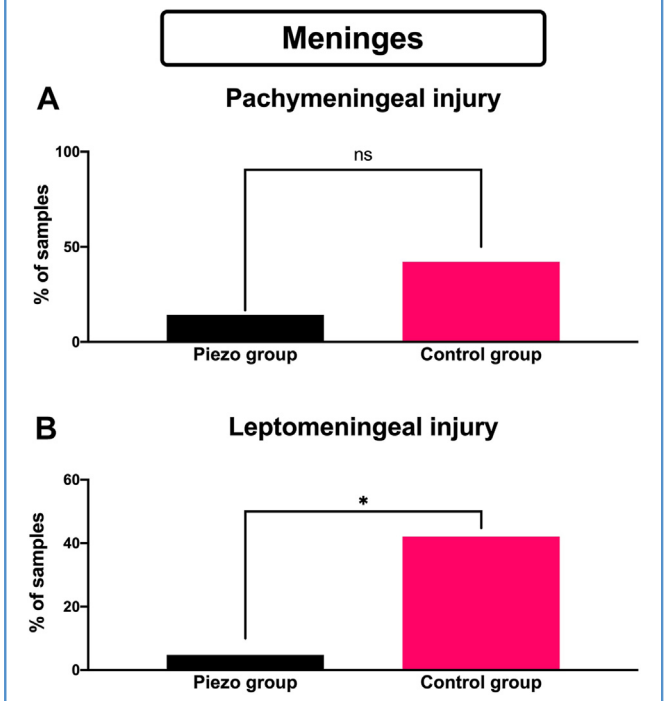


**Figure 4.** Bar graph demonstrating the rate of injury caused by both techniques on the pachymeninges (**A**) and leptomeninges (**B**). $*P < 0.05$.

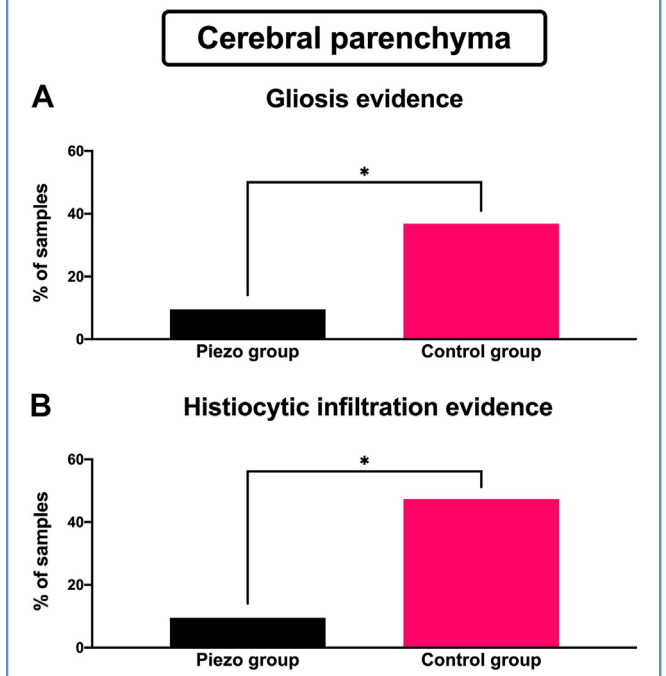


**Figure 5.** Bar graph depicting the invasiveness of the techniques on the brain parenchyma as demonstrated by the rate of gliosis (**A**) and histiocytic infiltration (**B**). $*P < 0.05$.

piezoelectric bone scalpel versus the high-speed drill on the cranial vault bone, meninges, and cerebral parenchyma, respectively.

Figures 6 and 7 show the major histologic patterns observed in the piezoelectric and control groups, respectively.

## DISCUSSION

The present study evaluated the invasiveness of piezoelectric craniotomy from a histo-morphometric point of view while performing a comparative analysis with the high-speed drill in terms of physical and thermal iatrogenic damage to the adjacent cranial vault bone, meninges, and underlying brain tissue.

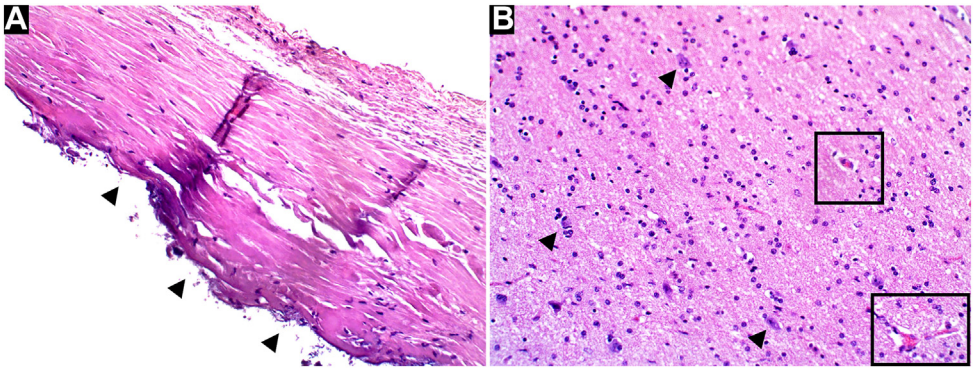


**Figure 6.** Main histologic patterns observed in the study group. (**A**) Anatomical integrity of the pachymeninges (black arrowhead) (Hematoxylin–Eosin stain, 200x). (**B**) Negligible reactive gliosis (black arrowhead) and evidence for osteoblasts (black squared areas) (HE stain, 200x).

The piezoelectric bone scalpel proved to be less invasive than the drill for all outcome parameters except dural injury, which did not differ between groups. The reasons for these results may be that the average manual dexterity of the surgeons was sufficient to respect the anatomical integrity of the pachymeninges in both groups, but the thermal damage transmitted by the drill was inherently higher. In support of this, the rate of thermally induced gliosis and histiocytic infiltration in the brain parenchyma was also significantly greater in the control group.

Piezosurgery has been reported to be less restrictive to bone healing than drills.[34-37] This is due to its ability to stimulate bone morphogenetic proteins and bone remodeling while better

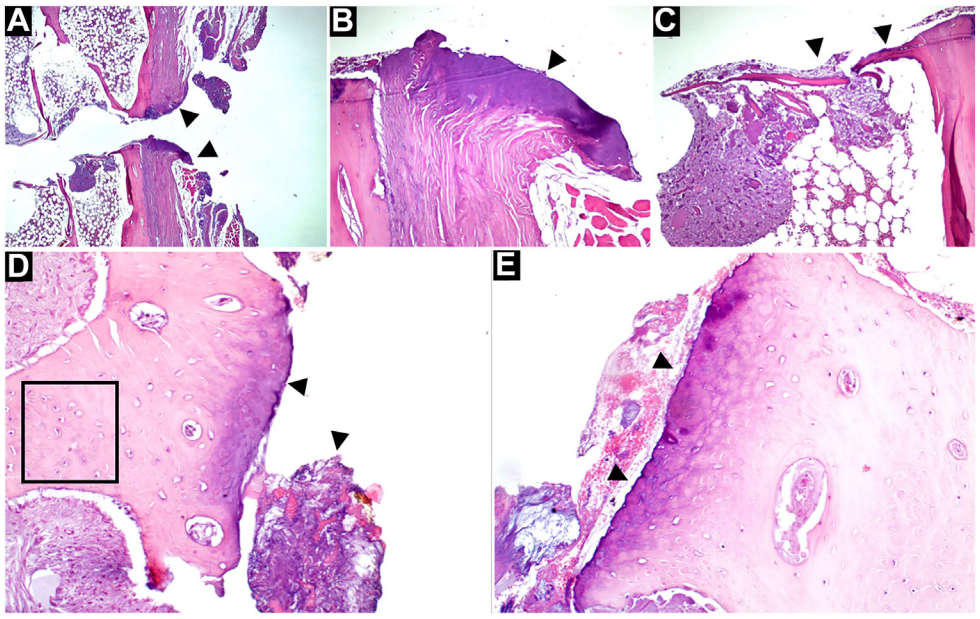


**Figure 7.** Main histologic patterns observed in the control group. (**A**) Thermal injury and formation of a "smear layer" (black arrowhead) (HE stain, 20x). (**B**) Coagulation of soft periosteal tissues due to thermal injury (black arrowhead) (HE stain, 100x). (**C**) Debris and smear layer formed due to the mechanical rotative effect (black arrowhead) (HE stain, 100x). (**D** and **E**) Thermal injury secondary to circular motion of the instrument (black arrowhead). The black squared area in Figure **D** indicates the histiocytic infiltration (HE stain, 200x).

controlling iatrogenic inflammatory processes. Thinner bone gaps are another advantage. Preti et al.[37] reported a combined histomorphometric and molecular study of osseointegration after piezosurgical osteotomy in which fewer inflammatory cells, more osteoblasts, increased expression of bone morphogenetic proteins, and decreased expression of pro-inflammatory cytokines were observed.

The first histological description of postoperative bone healing dynamics dates back to 1975 by Horton et al.[36] They conducted an in vivo study on dog alveolar bone and found accelerated bone formation in alveolar defects. Similar data confirming the preserved viability of residual osteoblasts have been reported in ex vivo and in vivo studies in the field of oral surgery and implantology.[37,35,38-40] However, there is still limited evidence on the histologic invasiveness of piezosurgery on the cranial vault.[41-44] Anesi et al.[41] found a higher number of tartrate-resistant acid phosphatase-positive osteoclasts per linear surface in the piezo group compared to the rotating instruments in rabbit cranial osteotomies, indicating greater bone remodeling with the former. The main limitation of the rabbit skull is its limited surface area, which often prevents the performance of near-real craniotomies. Therefore, in the present study, the authors decided to use a larger model, such as the sheep.

As with rotating instruments, the cavitation phenomenon is known to be associated with an increase in local temperature.[45-49] Two main factors affect the heat production of the piezoelectric scalpel, namely the load and the duration of the cut.

Stelzle et al. found that a harmful average temperature of 48.6 ± 3.4°C and a thermal effect of 200.7 ± 44.4 μm are both achieved with a load between 900 and 1000 g, suggesting a maximum load of 400 g as safe.[48] Tepedino et al. found that the thermal wave of the piezoelectric scalpel remains below levels of clinical concern when the cutting time does not exceed 20 minutes.[45] Bone compactness has also been reported to play a role, as reported by Delgado-Ruiz et al.[46]

The combination of these factors results in a site-specific probability of thermal damage that is higher in dense bone and lower in flat bones such as the skull, where the spongy component is also well represented. The less traumatic effect on adjacent and underlying tissues that were found in the Piezo group could be explained by this dynamic. Similar data were reported by Rashad et al,.[50] who noted less heat generation with ultrasonic and sonic osteotomy systems compared to conventional saw osteotomy. Pavlíková et al. also reported less depth and width of iatrogenic magnetic resonance imaging-detectable brain lesions in Wistar rats.[51]

### Limitations of the Study

The present study has limitations, mainly due to its retrospective design, the relatively limited number of specimens, and the operator-dependent interpretation of most histologic data. The pressure load of the instrument should be considered as a potential source of bias in both groups. The authors fully recognize the importance of increasing the number of animal studies to further validate the findings of this research.

## CONCLUSION

Piezoelectric craniotomy was shown to respect residual osteoblast viability and leptomeningeal integrity.

The lower rate of thermally induced gliosis and histiocytic infiltration demonstrated the minimal invasiveness of the piezoelectric osteotome to brain tissue compared to the high-speed drill.

Further evidence is needed to definitively validate these data before the use of the piezoelectric scalpel can be fully implemented in the neurosurgical scenario.

## CRediT AUTHORSHIP CONTRIBUTION STATEMENT

**Sabino Luzzi:** Conceptualization, Data curation, Investigation, Software, Validation, Writing — original draft, Writing — review & editing. **Antonio Crovace:** Conceptualization, Supervision, Validation. **Sergio Carnevale:** Data curation, Formal analysis, Investigation, Methodology. **Luca Lacitignola:** Investigation, Validation. **Francesco Staffieri:** Investigation, Validation. **Domenico Sfondrini:** Data curation, Investigation, Validation. **Edgar G. Ordóñez-Rubiano:** Data curation, Investigation, Validation. **Alberto Maria Crovace:** Conceptualization, Data curation, Investigation, Validation, Writing — original draft, Writing — review & editing.

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