Discover Applied Sciences

Perspective

New cross sonic piezosonic cutting blade geometry design: pilot study

Bianca Pulino[1,2,4] · Marcelo Pigatto D'Amado[1] · Guilherme Louzada[1] · Gustavo Câmara[1] · Geraldo Prestes de Camargo Filho[3] · Raphael Capelli Guerra[1,2,4]

Received: 10 January 2025 / Accepted: 25 May 2025
Published online: 16 June 2025

Abstract
The principle of piezosurgery is "pressure electrification". When electrical voltage is applied to certain materials such as quartz and Rochelle salts, it causes the materials to expand and contract, producing ultrasonic vibrations. This device uses ultrasonic vibration at 60–210 µm/s at 24–36 kHz to selectively remove bone with minimal damage to soft tissues such as blood vessels and nerves. In addition, it provides excellent visibility due to its cavitation effect. Piezoelectric surgery uses low-frequency ultrasonic vibration for osteotomy, which minimizes the risk of damage to soft tissue (nerves, vessels and mucosa). Micrometric vibration ensures precise cutting action and allows operative control, with consequent increased safety, in anatomical areas that are difficult to access. The aim of this study is to provide a device capable of providing a smaller contact area, less effort, lower temperature generation, faster cutting, shorter surgery time, shorter post-operative time and maxillofacial, orthopedic, neurosurgical and otorhinolaryngological procedures.

Article Highlights
The pilot study presented in this article is about the development of a new piezo tip design, which is not commercialized on the Brazilian market, due to the studies and laboratory analyses being carried out. For this reason, there are no preliminary studies published with results for comparison. Our aim is to publish this pilot study and more in-depth studies are in the development stage for future publication. A technical note on the development of the new design was published showing the difference between the cross sonic tip and conventional tips, showing its main property which is the angled and multidirectional teeth, reducing the contact area and thus bringing the benefits presented in this article with a pilot study.

Keywords Piezosurgery · Ultrasonic device · Osteotomy

1 Introduction

Piezosurgery was first used in oral and maxillofacial surgery by Vercellotti et al. [1], which sought to simplify maxillary sinus surgery by avoiding perforation of Schneider's membrane. Recently, ultrasonic bone cutting has been used in orthognathic procedures [2–10], extraction of impacted third molars [11], orthodontics facilitated by corticotomy [12], implant site preparation [13–15], treatment of temporomandibular disorders [15], cyst enucleation [16, 17] head

✉ Raphael Capelli Guerra, dr.raphael.guerra@gmail.com; Bianca Pulino, biancapulino@icloud.com | [1]Instituto de Ensino e Pesquisa, Hospital Sírio-Libanês, São Paulo, SP, Brazil. [2]Department of Oral and Maxillofacial Surgery, Hospital Israelita Albert Einstein, São Paulo, SP, Brazil. [3]College of Dental Medicine, Clearwater Campus, Nova Southeastern University-NSU Flórida, Clearwater, Flórida, USA. [4]Department of Oral and Maxillofacial Surgery, Hospital Leforte, Rede Américas , São Paulo, Brazil.

and neck oncology and reconstructive surgery [18]. Piezoelectric surgery uses low-frequency ultrasonic vibration for osteotomy, which minimizes the risk of damage to soft tissue (nerves, vessels and mucosa) [1, 5, 6]. Micrometric vibration ensures precise cutting action and allows operative control, with consequent increased safety, in anatomical areas that are difficult to access [1].

The principle of piezosurgery is "pressure electrification". When electrical voltage is applied to certain materials such as quartz and Rochelle salts, it causes the materials to expand and contract, producing ultrasonic vibrations. This device uses ultrasonic vibration at 60–210 µm/s at 24–36 kHz to selectively remove bone with minimal damage to soft tissues such as blood vessels and nerves. In addition, it provides excellent visibility due to its cavitation effect [5, 10, 19, 20].

The use of ultrasonic tips has brought great benefits to osteotomy procedures in oral and maxillofacial procedures compared to conventional reciprocating saws. One of the main advantages is that they generate little heat, reducing the possibility of bone necrosis and increasing the safety and predictability of the surgical procedure. However, ultrasonic tips with straight tooth geometry still present problems.

The aim of this study is to provide a device capable of providing a smaller contact area, less effort, lower temperature generation, faster cutting, shorter surgery time, shorter post-operative time and maxillofacial, orthopedic, neurosurgical and otorhinolaryngological procedures.

2 Geometry

BYPRO Medical of Brazil innovation proposes a new cutting geometry for ultrasonic tips, the development of the Crossonic ultrassonic tip, which consists of an angled multidirectional tooth geometry, alternating right and left angulation in the active part of the tip. The combined geometry described here has a circular shape at the tip combined with a flat geometry, a flat straight segment, a curved cylindrical shank, a truncated segment, a cylindrical segment with a flattening, and a cylindrical segment with an internal thread, as illustrated in Fig. 1A and B, which differs from the conventional piezo tip that has a conventional straight dentition, as illustrated in Fig. 1C and D.

The making of a new tip is the angular multidirectional tooth geometry present in a part that has at its end, a design consisting of a circular surface (Fig. 2) combined with a flat geometry (Fig. 3). The fact that the different dentition is on a piece that has this combination (straight and flat surface) is the main object of this development.

With the growing demand for efficiency in osteotomy procedures, the choice of the type of ultrasonic tip used is crucial to optimize productivity and reduce costs. This technical note aims to analyze the technical superiority of the ultrasonic tip with angular multidirectional notching compared to the ultrasonic tip with conventional parallel notching, based on a pilot test carried out.

The ultrasonic tip revealed here has a cutting geometry with multidirectional and angled teeth, where this configuration reduces the contact area between the ultrasonic tip and the bone, reducing the cutting effort and, consequently, the heat generated during osteotomies in Oral and Maxillofacial, Neurosurgical, Head and Neck and Orthopedic procedures. This is crucial to avoid bone necrosis. The multidirectional geometry makes the osteotomy more favorable, and thanks to the reduction in friction, it requires less mechanical force and time, which increases the surgeon's precision and dexterity.The advantages of the crosssonic® ultrasonic tip over conventional tips are:

1. smaller contact area: provides a reduced contact area with the bone during osteotomy, which results in less need for friction and pressure during osteotomy procedures.
2. Less effort: the distribution of the force used in the procedure is multidirectional, resulting in less effort. This can reduce surgeon fatigue and provide a more comfortable experience during surgery and less chance of blade breakage.
3. Less temperature generation: the smaller contact area and more efficient cutting of the multi-directional dentition result in less heat generation during the osteotomy.
4. Faster cutting: the multi-directional shape of the teeth allows for faster and more efficient cutting compared to traditional teeth.
5. Shorter surgery time: because of the increased cutting speed and efficiency, the total surgery time can be reduced, which is beneficial for both the patient and the surgical team, as it minimizes the time, they are exposed to the risks associated with surgery.

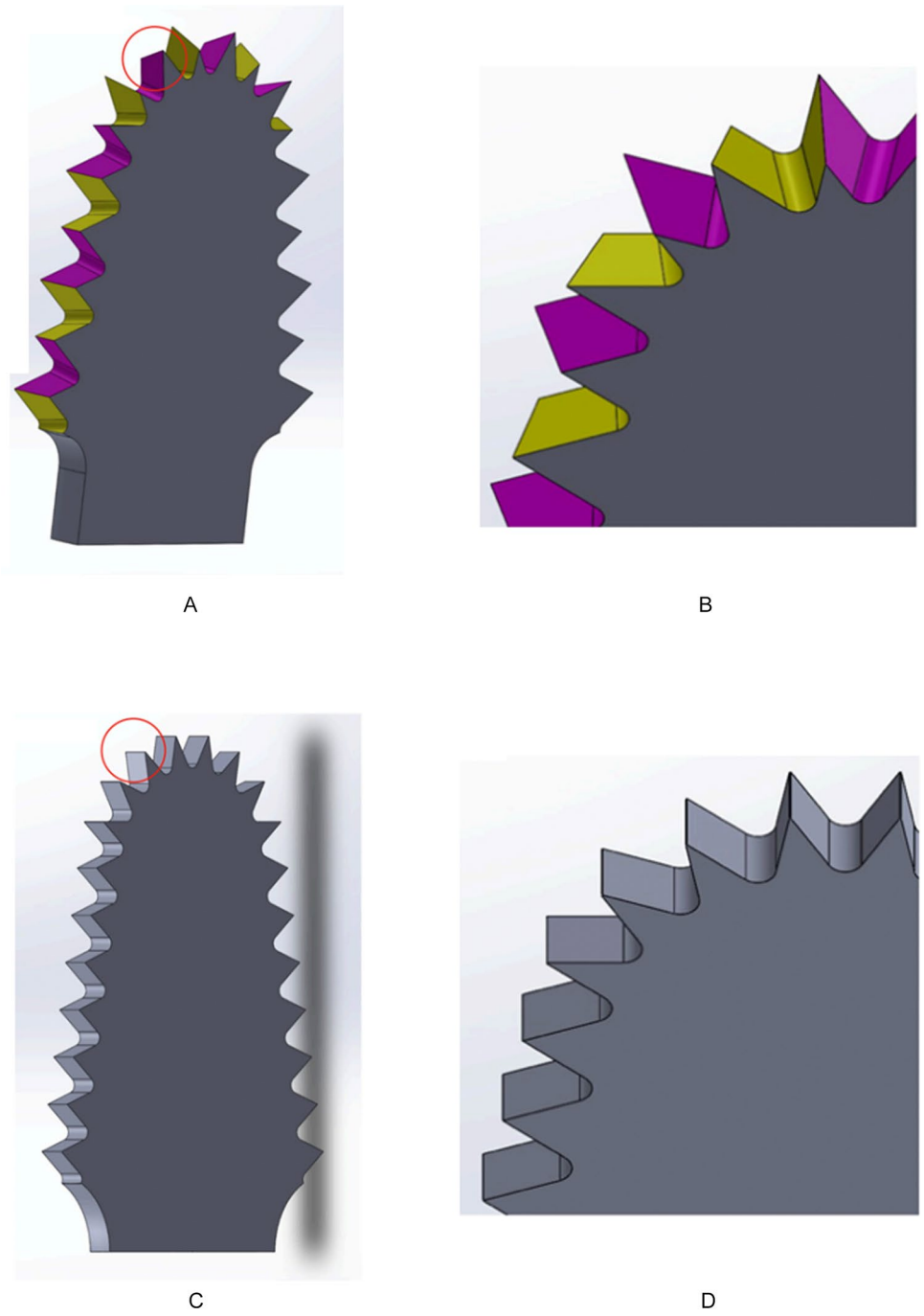

Fig. 1 **A** Angular multidirectional dentition—innovation. **B** At higher magnification the angular multidirectional dentition—innovation. **C** Conventional straight dentition. **D** Higher magnification of the conventional straight dentition

6. Elimination of bone debris: the angled multidirectional tooth geometry favors the elimination of bone debris resulting from the osteotomy, favoring a smoother cut, preserving bone tissue.
7. Reduced motor and handpiece problems: all these added benefits contribute to reduced wear and tear on the surgical unit's motor and handpiece, resulting in a longer service life for the equipment and less need for maintenance.

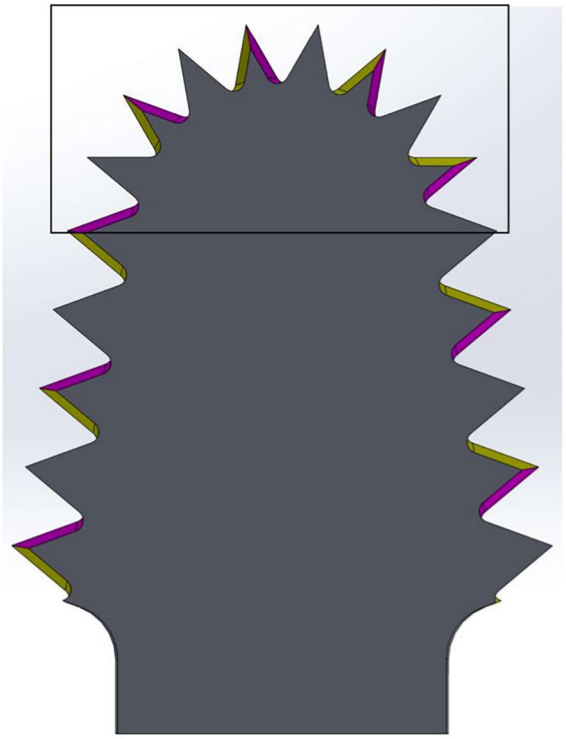

Fig. 2 Flat surface of the piezoelectric tip

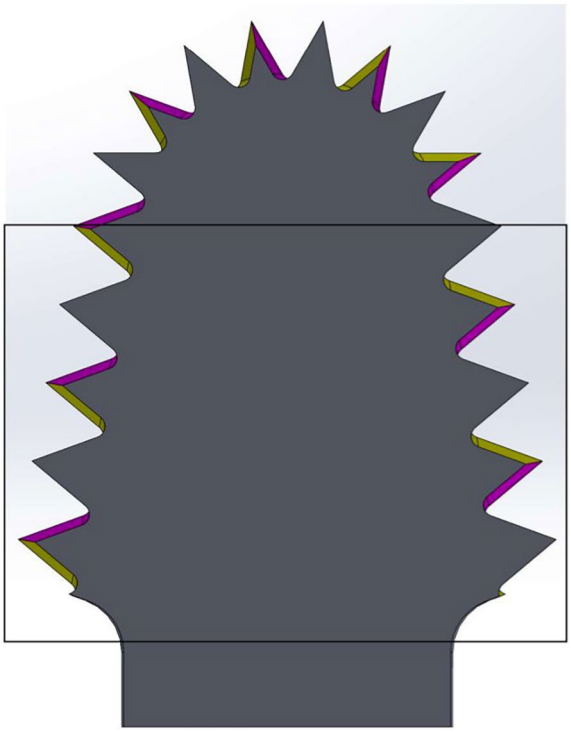

Fig. 3 Circular surface of the piezoelectric tip

3 Methodology

This study is a pilot test carried out at the Training Center of the Teaching and Research Institute of the Sírio Libanês Hospital. In this study, the methodology employed involves the use of synthetic biomechanical test bone blocks

"Proof Body 30 PCF with Bicortical 3 mm" (Empresa Nacional Ossos) to simulate precise bone conditions in a controlled environment. A total of 06 bone blocks and 06 piezoelectric saw samples were used, divided equally between the experimental (03 multidirectional cutting saws) and control (03 conventional saws) groups, with each sample being meticulously prepared and subjected to cutting procedures to assess variables such as cutting time, bone and blade temperature after cutting and loss of bone mass from the block.

The samples were cut using ultrasonic tips with the same shape and difference in dentition with multidirectional cutting geometry in the experimental group and traditional tips in the control group. Thermocouples were strategically positioned 5 mm away from the saw cut to measure temperatures during cutting to assess the thermal impact on the bone. In addition, cutting times were timed to the nearest second to analyze the efficiency of the blades. Bone residue analysis was carried out by weighing the samples before and after cutting using a precision scale (Sartorius BP 210 S) to quantify the loss of material. The methodology is detailed below.

3.1 Selection of bone blocks

The biomechanical test block called "Proof Body 30 PCF with Bicortical 3 mm", with the code 12214, offered by Empresa Nacional Ossos. This block is ideal for simulations in controlled environments due to its bicortical composition, which includes a top and bottom layer of 3 mm with a density of 40 PCF (0.96 g/cm^3), imitating cortical bone, and a core with a density of 30 PCF (0.16 g/cm^3), which simulates cancellous bone. With overall dimensions of 95/45/36 mm, this sample provides an efficient platform for testing the effectiveness of orthopedic devices, including the new cutting geometry of ultrasonic tips. This block is specifically designed to evaluate the anchorage of joint prostheses, implants, and other biomaterials, making it a choice for assessing precision and biomechanical impacts in simulated clinical testing conditions. A total of 20 test synthetic bone samples of the same size (5 × 5 × 2 cm) with a 3 mm hole were used to measure the temperature of the cut inside the bone with the thermocouple.

To ensure standardization in the direction and distance of the cut, a specific cutting guide was developed with dimensions of 1 × 5 cm on a 3D printer and attached to each bone block with two screws (Fig. 4). This ensures that the cutting direction and time are the same, since it is operator dependent.

3.2 Experimental groups

The samples were divided into two groups, a control group with conventional saws (N = 3) and a test group with multi-angle saws (N = 3).

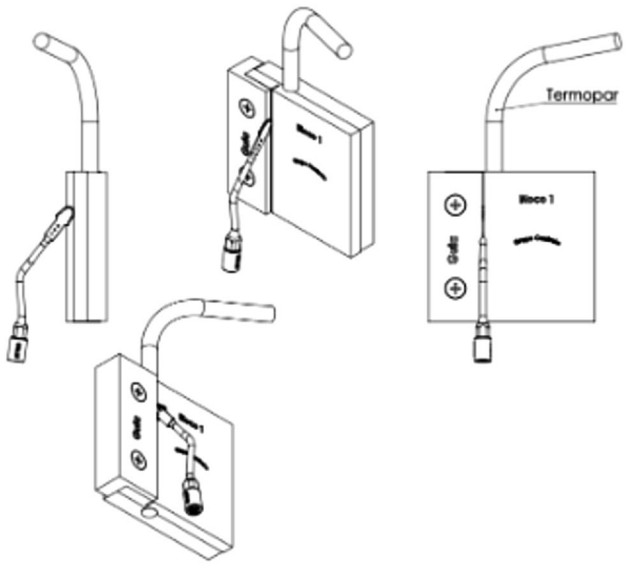

Fig. 4 Illustration of the study procedure: bone block with thermocouple

3.3 Traditional ultrasonic tips (Control)

These tips have a traditional blade configuration, known as a micro saw, which has a geometry characterized by linearly aligned teeth, which provides a consistent cut, but with a relatively large contact area between the tip and the bone.

3.4 Ultrasonic tip with angled multidirectional cutting geometry

This tip employs an angled multidirectional tooth geometry, alternating and interspersing the angulation of the teeth to the right and left along the active part of the tip. This design reduces the contact area between the tip and the bone, reducing the cutting effort required, and minimizes heat generation. The motor used in the study is the Mectron Piezosurgery Touch (Mectron) model operating in a frequency range of 24–29.5 kHz, in cortical bone cutting mode. The blade cooling system was used with 0.9% saline solution in the study at setting number 1.

3.5 Cutting time (seconds)

The cutting time was meticulously timed from the start of the cut to the complete insertion of the blade into its cutting area across the designated section of the sample. This measurement was made using digital stopwatches to ensure the exact duration of the cut was captured. The times recorded for each cut in both groups were compiled and statistically analyzed to determine whether the new tip geometry offers a significant advantage in terms of cutting speed compared to traditional tips.

3.6 Bone temperature (Degrees Celsius)

During the cutting tests in the study, bone temperature was monitored using thermocouples, which were strategically positioned 5 mm from the cutting area inside the bone and connected to a digital thermometer. This specific location allows a direct assessment of the heat transmitted to the bone tissue, which is crucial for understanding the thermal impact of ultrasonic tips in simulated surgical conditions. The thermocouples, due to their high precision and sensitivity, take exact temperature readings in real time, ensuring that any significant increase is immediately identified and documented. The initial temperature and the temperature at the end of the cut were counted and recorded in a table for each sample.

3.7 Blade temperature

A laser thermometer was used to measure and record the temperature generated in the cutting area immediately before and after each cutting procedure carried out with the ultrasonic tips. This approach allows for precise, non-contact evaluations, ensuring that measurements are made safely and non-intrusively, without altering the state of the equipment or the material being tested. The temperature of the blade was collected before cutting and immediately after the osteotomy was completed.

3.8 Osteotomy

3.8.1 Sample preparation

The synthetic bone block samples and their cutting guides were fixed in stable supports to ensure precision during the cuts. Each sample was cut using the tips assigned to the experimental and control groups. The procedure for each sample included initial preparation of the equipment and secure fixation of the sample at the cutting site and the use of a guide attached to the piece to ensure precision and safety (Fig. 4). All the parameters were tested for normality (Shapiro–Wilk test), the result of which showed no significant deviations from the normal distribution, so the other parametric tests used (t-test and ANOVA) were indicated. Minitab statistical software (version 19.1) was used to create the tables and graphs, as well as all the analyses used in this study, considering a significance level of $p \leq 0.05$.

4 Results

The data collected during the comparative tests showed significant differences between the two types of ultrasonic tips: The conventional tips reached temperatures above 50 °C while the multi-angle cutting tips-maintained temperatures between 35 and 40 °C during and after cutting with a reduction of approximately 30% in the temperature of the multi-angle blade. The bone block also reached higher temperatures with the conventional tips compared to the multi-angle cutting tips. All cuts were faster, with greater ease with the multi-directional cutting tip, with the 30-degree angulation being preferred by surgeons.

4.1 Cutting time

The cutting time in the Test group was 46.0 ± 3.4 s (mean ± standard deviation), ranging from 42 to 51 s; in the Control group it was 86.6 ± 17.3 s (mean ± standard deviation), ranging from 63 to 109 s. Note that the longest time observed in the test group (51 s) was even shorter than the shortest time observed in the Control group (63 s). The difference between the groups was statistically significant ($p < 0.001$), indicating that the Test group had a shorter cutting time than the Control group, an average of 46.0 and 86.6 s, respectively.

4.2 Bone temperature during cutting (maximum)

The maximum bone temperature during cutting in the Test group was 32.3 ± 2.2 °C (mean ± standard deviation), ranging from 29.0 to 36.0 °C; in the Control group, it was 39.5 ± 4.1 °C, ranging from 33.0 to 48.0 °C. It is worth noting that the highest value observed in the Test group (36.0 °C) was lower than the lowest value observed in the Control group (33.0 °C). The difference between the groups was statistically significant ($p < 0.001$), indicating that the Test group had a lower maximum bone temperature during cutting than the Control group, with averages of 32.3 °C and 39.5 °C, respectively.

5 Discussion

The results indicate a clear advantage of the ultrasonic tip with multidirectional angled teeth in several performance metrics. The superior cutting efficiency implies higher productivity, shorter surgical times, the possibility of cutting more robust bones and its use in other specialties such as orthopedics. In addition, the multi-angle tip showed lower wear resistance and better quality of the treated surface, which could result in faster, more effective and less invasive procedures for patients. In addition, the lower operating temperature of the angled multidirectional tip indicates better heat dissipation, which could also contribute to a longer service life for the ultrasonic equipment, generating less thermal necrosis of the bone tissue and less chance of the saw breaking during osteotomy. Despite the promising results, this was a pilot study carried out with only two bone blocks and one saw of each type. A new randomized laboratory study with 20 different saw samples will be carried out based on this pilot to obtain more data and a statistically significant result in the analysis of the parameters evaluated in the pilot trial.

The piezoelectric saw has been used in oral and maxillofacial surgery for more than 20 years and there are various types and shapes of saws supplied by different manufacturers on the market.

To date, the literature describes different saw shapes, but we are unaware of a change in the direction of the saw tooth. The multidirectional, angled geometry saw has already been tested by our group in the laboratory, comparing its cutting efficiency with that of the straight geometry saw, and showed superior performance. The results of this study are being prepared for publication.

One criticism many authors have leveled at the piezoelectric saw is that it can be technically difficult to learn how to use and has a slow learning curve [1, 3, 21, 22]. One study revealed that surgical times were reduced by approximately 20% with the regular use of ultrasonic surgery after a period of 2 years [3]. The multidirectional geometry also makes osteotomy technically easier, and thanks to reduced friction, requires less mechanical force and time, which increases the surgeon's precision and dexterity. This could consequently reduce surgeon fatigue, provide a faster learning curve and less chance of blade breakage.

Piezoelectric surgery is already considered slower compared to other osteotomy methods, especially when the surgeon is learning the technique [23]. A study comparing the procedure time for craniotomies showed an average time of

1 h and 10 min for the use of the piezoelectric saw compared to an average time of 43 min for the use of the craniotome [3]. A clinical study for hallux valgus correction showed an osteotomy time of 3 min with the osilatory saw and 10 min with the piezoelectric saw [23].

The blade of the piezoelectric saw is already irrigated with saline solution to control the temperature. Even so, cases of overheating and bone necrosis can occur due to the length of the procedure [22]. It is believed that the multidirectional shape of the dentition would allow for faster and more efficient cutting compared to the traditional dentition, which would cause less heat generation during the osteotomy [24]. Osteotomy speed and costs are the main limitations of piezoelectric surgery [23]. All the features and advantages of multidirectional and angled geometry can reduce problems with the motor and handpiece, resulting in longer equipment life and less need for maintenance, indirectly reducing costs.

Studies in the literature often compare oscillating saws and different osteotomy methods with piezoelectric saws [3, 10, 23, 25]. One study compared three piezoelectric saws from different manufacturers with each other, but with the same characteristics and tooth shape, finding better performance in one of the saws and a minimal temperature difference between them [26].

Another article, different piezoelectric saws were compared while maintaining the straight shape of the teeth to perform osteotomies and osteoplasties on porcine mandibles heated to 36 °C. The methodology used temperature sensors positioned 3 mm deep and 1 mm away from the work site, while the osteotomies were performed with the Piezosurgery 3 saw (Mectron) and cooled with ringer's solution. The variation in intraosseous temperature was significant between the different saws, with maximum peaks above 47 °C for short periods, not exceeding 29 s [27].

The results of preliminary tests comparing the new multi-angle geometry saw with straight-toothed saws indicate a clear advantage for the angled multi-directional toothed ultrasonic tip in several performance metrics when compared to the traditional piezoelectric saw. The superior cutting efficiency implies greater productivity, shorter surgical times, the possibility of cutting through more robust bones, new larger blade formats and their use in other specialties such as orthopedics. Despite the promising results, this is a technical note, and more elaborate studies need to be carried out. A new randomized laboratory study with 20 different saw samples was carried out based on this pilot and is being prepared for publication.

6 Conclusions

The use of ultrasonic tips with angled multidirectional dentition offers several advantages:

1. Reduced operating costs: greater cutting efficiency and lower resistance to wear result in faster and more effective procedures, reducing operating room time and the risk of infection.
2. Improved quality of procedures: better quality of the treated surface and lower operating temperature contribute to safer and less invasive procedures, resulting in faster recovery and fewer post-operative complications.
3. Patient satisfaction: faster and less invasive procedures increase patient satisfaction.
4. Efficient use of resources: greater cutting efficiency results in more efficient use of resources, in line with sustainable and economically responsible practices, and saws may soon be reused in more than one procedure and even new designs developed for use in orthopaedic procedures.

Acknowledgements BYPRO Medical, Brazil.

Author contributions B.P; RG; MA; GP; GL; GC: conception and design of the study, data collection, data analysis and interpretation, writing of the manuscript, critical review of the content and final writing. MA; GP; GL; GC: conception and design of the study, data collection, data analysis and interpretation, drafting of the manuscript, critical revision of the content and final writing. Figures: GP; GL; prepared figures. B.P; RG: conception and design of the study, critical revision of the content and final supervision. GP; GL; GC: final revisions and corrections. All the authors actively participated in the development of the work and agree with the final version of the manuscript submitted, taking collective responsibility for the content published.

Funding The research carried out in this article received funding from BYPRO Medical to supply the ultrasonic tips.

Data availability No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

References

1. Vercellotti T, De Paoli SNM. The piezoelectric bony window osteotomy and sinus membrane elevation: introduction of a new technique for simplification of the sinus augmentation procedure. Int J Periodontics Restorative Dent. 2001;21(6):561–7.
2. Gruber RM, Kramer FJ, Merten HASH. Ultrasonic surgery–an alternative way in orthognathic surgery of the mandible. A pilot study. Int J Oral Maxillofac Surg. 2005;34(6):590–3.
3. Beziat JL, Bera JC, Lavandier BGA. Ultrasonic osteotomy as a new technique in craniomaxillofacial surgery. Int J Oral Maxillofac Surg. 2007;36(6):493–500.
4. Robiony M, Polini F, Costa F, Sembronio S, Zerman NPM. Endoscopically assisted intraoral vertical ramus osteotomy and piezoelectric surgery in mandibular prognathism. J Oral Maxillofac Surg. 2007;65(10):2119–24.
5. Landes CA, Stübinger S, Ballon ASR. Piezoosteotomy in orthognathic surgery versus conventional saw and chisel osteotomy. Oral Maxillofac Surg. 2008;12:139–47.
6. Landes CA, Stübinger S, Rieger J, Williger B, Ha TKSR. Critical evaluation of piezoelectric osteotomy in orthognathic surgery: operative technique, blood loss, time requirement, nerve and vessel integrity. J Oral Maxillofac Surg. 2008;66(4):657–74.
7. Chung CU, Yu JW, Bastidas N, Bartlett SPTJ. Utility of the ultrasonic scalpel in mandibular distraction osteogenesis. J Craniofac Surg. 2012;23(5):1279–82.
8. Bertossi D, Lucchese A, Albanese M, Turra M, Faccioni F, Nocini PRYBR. Piezosurgery versus conventional osteotomy in orthognathic surgery: a paradigm shift in treatment. J Craniofac Surg. 2013;24(5):1763–6.
9. Gilles R, Couvreur TDS. Ultrasonic orthognathic surgery: enhancements to established osteotomies. Int J Oral Maxillofac Surg. 2013;42(8):981–7.
10. Spinelli G, Lazzeri D, Conti M, Agostini TMG. Comparison of piezo-surgery and traditional saw in bimaxillary orthognathic surgery. J Cranio-Maxillofac Surg. 2014;42:1211–20.
11. Jiang Q, Qiu J, Yang C, Yang J, Chen MZZ. Piezo-electric versus conventional rotary techniques for impacted third molar extraction. Medicine (Baltimore). 2015;94:1685.
12. Farid KA, Mostafa YA, Kaddah M, El-Sharaby FA. Corticotomy-facilitated orthodontics using piezosurgery versus rotary instruments: an experimental study. J Int Acad Periodontol. 2014;16(4):103–8.
13. Brugnami F, Caiazzo AMP. Piezo-surgery-assisted, flapless split crest surgery for implant site preparation. J Maxillofac Oral Surg. 2014;13:67–72.
14. Canullo L, Peñarrocha D, Peñarrocha M, Rocio AG, Penarrocha-Diago M. Piezoelectric vs. conventional drilling in implant site preparation: pilot controlled randomized clinical trial with crossover design. Clin Oral Implant Res. 2014;25:1336–43.
15. BoronatLópez A, BalaguerMartínez J, Lamas Pelayo J, Carrillo García C, Peñarrocha DM. Resonance frequency analysis of dental implant stability during the healing period. Med Oral Patol Oral Cir Bucal. 2008;13(4):E244–7.
16. Kocyigit ID, Atil F, Alp YE, Tekin UTH. Piezo-surgery versus conventional surgery in radicular cyst enucleation. J Craniofac Surg. 2012;23:1805–8.
17. Pappalardo SGR. Randomized clinical study comparing piezo-surgery and conventional rotatory surgery in mandibular cyst enucleation. J Craniomaxillofac Surg. 2014;42:e80–5.
18. Crosetti E, Battiston B, Succo G. Piezo-surgery in head and neck oncological and reconstructive surgery: personal experience on 127 cases. Acta Otorhinolaryngol Ital. 2009;29:1–9.
19. Agarwal E, Masamatti SS, Kumar A. Escalating role of piezosurgery in dental therapeutics. J Clin Diagn Res. 2014;8:ZE08-11.
20. Eggers G, Klein J, Blank JHS. Piezosurgery: an ultrasound device for cutting bone and its use and limitations in maxillofacial surgery. Br J Oral Maxillofac Surg. 2004;42:451–3.
21. Barrett AW, Sneddon KJ, Tighe JV, Gulati A, Newman L, Collyer J, et al. Dentigerous cyst and ameloblastoma of the jaws: correlating the histopathological and clinicoradiological features avoids a diagnostic pitfall. Int J Surg Pathol. 2017;25(2):141–7. https://doi.org/10.1177/1066896916666319.
22. Labanca M, Azzola F, Vinci RRL. Piezoelectric surgery: twenty years of use. Br J Oral Maxillofac Surg. 2008;46(4):265–9.

23. Russo A, Caravelli S, Mosca M, Girolami M, Ortolani A, Massimi S, et al. Piezosurgery in Hallux Valgus correction: distal linear osteotomy operative technique using piezoelectric tools. Joints. 2019;7(1):25–30.
24. Pulino B, D'Amado MP, Andrade JF, Camargo Filho GP, Guerra RC. Multi-directional geometry of the piezosonic cutting blade: technical note. J Braz Coll Oral Maxilofac Surg. 2025;11(1):94–104.
25. Liu J, Hua C, Pan J, Han BTX. Piezosurgery vs conventional rotary instrument in the third molar surgery: a systematic review and meta-analysis of randomized controlled trials. J Dent Sci. 2018;13(4):342–9.
26. Harder S, Wolfart S, Mehl CKM. Performance of ultrasonic devices for bone surgery and associated intraosseous temperature development. Int J Oral Maxillofac Implants. 2009;24(3):484–90.
27. Schütz S, Egger J, Kühl S, Filippi ALJ. Intraosseous temperature changes during the use of piezosurgical inserts in vitro. Int J Oral Maxillofac Surg. 2012;41(11):1338–43.