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CASE SERIES

Endodontic Micro-Surgery by means of two different surgical templates performed with selective Piezosurgery® root resection: a report of two cases

ABSTRACT

Aim: *The aim of this case series is to introduce a new surgical template designed for static endodontic microsurgery using Piezosurgery®. The template, created with computer-aided design/computer-aided manufacturing (CAD-CAM) technologies, aims to enhance the precision of root-end resections by providing individualized guidance for the surgical procedure. This approach seeks to reduce invasiveness, minimize bone loss, and improve surgical outcomes in cases of persistent apical periodontitis or other post-treatment endodontic complications.*

Summary

Conventional endodontic treatments can fail in 14-16% of cases due to persistent infections within the root canal system or extraradicular factors. In such cases, endodontic microsurgery, especially when guided by advanced technologies, offers a high success rate of up to 89%. Recent innovations in piezoelectric devices and CAD-CAM-based surgical templates enable more precise, less invasive procedures. The new surgical template presented in this study allows for accurate root-end resections, ensuring optimal root sealing while minimizing damage to surrounding tissues. The template's design aims to improve accuracy and reduce the risk of surgical errors compared to freehand procedures, promoting better healing and fewer complications.

Key Learning Point

- *Persistent apical periodontitis after root canal treatment can often be resolved with microsurgical techniques.*
- *The integration of CAD-CAM technology with Piezosurgery® enhances surgical precision, reducing bone loss and tissue trauma.*
- *Surgical templates designed for static endodontic microsurgery provide individualized, accurate guidance, leading to improved surgical outcomes.*
- *The use of piezoelectric devices offers precise cutting with minimal damage to soft tissues, crucial for surgeries near sensitive structures.*
- *Advances in guided endodontic surgery are improving success rates and minimizing post-operative complications.*

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Received 2024, November 20

Accepted 2025, January 11

KEYWORDS *Endodontic surgery, piezosurgery, apical periodontitis.*

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Peer review under responsibility of Società Italiana di Endodonzia

10.32067/GIE.2025.39.01.02

Introduction

The primary goal of a conventional endodontic treatment is to prevent or resolve root canal infections through the processes of cleaning, shaping and three-dimensional sealing of the root canal system (1, 2).
Although shown to be a predictable procedure with a high degree of success, with initial root canal therapy there have been occurrences of failure after the treatment: data reports failure rates of 14-16% (3).
Lack of healing is attributed to persistent intraradicular infections residing in previously uninstrumented canals, dentinal tubules, in the complex irregularities of the root canal system or iatrogenesis (4).
Furthermore, there are extraradicular factors – located within the inflamed periapical tissue – that can interfere with post-treatment healing of apical periodontitis, i.e. extraradicular infection, generally in the form of periapical actinomycosis; extruded root canal filling or other exogenous materials, that can cause a foreign body reaction; accumulation of endogenous cholesterol crystals, that irritate periapical tissues; true cystic lesions (5, 6).
The prevalence of apical periodontitis and other post-treatment periradicular disease, reported in cross-sectional studies, exceed 30% of all root-filled teeth (7).
Endodontically failed cases with persistent apical periodontitis, reported as periapical radiolucent areas with or without symptoms, after nonsurgical root canal treatment can be managed by nonsurgical (orthograde) re-treatment through the access cavity, surgical (retrograde) procedure, or tooth extraction (8).
Lesions may persist even after orthograde re-treatment, sustained by bacteria established within the root canal system or at extraradicular sites. In these cases, apical microsurgery seems to be the only possible solution, with an excellent success rate, up to 89% (9).
Surgical treatment should be preferable in extremely compromised teeth and in those where endodontic therapy can be considered acceptable.
Sometimes, due to restoration-related (number and position of teeth involved, presence of metal or fiber post) or anatomical-related issues (apical delta, root canals with significant curves, calcifications, open apex, radicular resorption, etc.), even if re-treatment seems to be the first-choice option, surgical treatment must be considered. Root canal perforations, presence of broken instruments inside the root canal, ledges and false canal and other iatrogenic complications also require retrograde treatment.
On the other hand, in specific clinical situations it is, however, contraindicated to proceed with surgical treatment of the teeth: i.e., orthograde endodontic treatment clearly incongruous, in this case orthograde retreatment is advisable; independent lateral lesion, sign of the presence of an accessory anatomical system; presence of long endocanal posts, which means insufficient space to retain the retrograde filling once the apical part of the root has been resected; inadequate clinical crown-root relationship.
Endodontic surgery involves the raising of a mucoperiosteal flap, an ostectomy performed in the inflamed apex area, the resection of a certain amount of apex and root, and the placing of a root-end filling to guarantee the perfect sealing of the canal system. This allows to remove biofilm from unreachable infected areas, by placing a tight root-end filling following the root-end resection, allowing for the restoration of healthy periapical tissues (10, 11).
The success rate of endodontic microsurgery is higher than conventional apical surgery, due to magnification and illumination, ultrasonic tips for retropreparation, microsurgical instruments, and new root-end filling materials (9). Literature analyses report a success rate of modern endodontic microsurgery between 88.9% and 100% (12).
In order to reduce invasiveness and post-operative discomfort, in 1998 Tomaso Vercellotti introduced the first surgical piezoelectric device (13-15). Piezoelectric devices operate in a similar way to piezoelectric dental scaler devices but are capa-

ble of selective cutting through hard tissues, preserving soft tissues such as blood vessels, nerves and mucosa (15).
The tips of this devices work in a linear motion, which is ideal for endodontic surgery. The application of a slight pressure to bone tissue results in a cavitation phenomenon, a mechanical cutting effect that occurs only in mineralized tissues (8). The integrated saline coolant solution maintains a low temperature and allow clear visibility of the surgical site. The field is bloodless during bone cutting thanks to air-water cavitation (10).
The creation of dentinal cracks during root-end resection is a key concern, as these cracks can compromise treatment success by providing pathways for bacterial infiltration or weakening the tooth structure. Otterson S. et al. (16) found no significant differences between trephine and multipurpose burs in terms of crack formation, though the two burs have different cutting mechanisms. Piezoelectric cutting systems, known for their precision and minimal heat generation, could potentially reduce the risk of crack formation.
Cone-beam computed tomography (CBCT), typically employed for prosthetically guided implant surgery, is needed in order to determine the exact location and severity of endodontic lesions.
The novelty of this new surgical endodontic procedure starts with the use of computer-aided design/computer-aided manufacture (CAD-CAM) softwares, which obtain 3D imaging data employed in order to develop an individually specific surgical template. This makes it possible for the surgeon to perform a less invasive and less traumatic approach, minimizing bone loss compared to traditional osteotomy techniques. This approach lets the clinician plan with utmost accuracy the position and size of the ostectomy and of root-end section in accordance with the guidelines of modern microsurgical apicectomy, including the recommended 3-mm root-end resection approximately perpendicular to long axis of the root.
In the field of implant therapy, it can be pointed out that the accuracy of static computer-aided implant surgery is within the clinically acceptable range in the majority of clinical situations. Even if, taking into account the possible deviations between virtual and real, it is preferable to keep a safety marge from noble structures of at least 2 mm (17).
A systematic review showed that with the aid of digital template, implant surgery accuracy can be achieved with the distance deviation of <2 mm (most <1 mm) and angular deviation $<8°$ (most $<5°$). (18)
Compared to freehand surgery, it has been shown that using a surgical template significantly reduces the chance for a positional error at the time of implant placement (19). Arisan et al, reported a 6% probability of a positional error using a computer guided template, and an 88% probability of having a positional error with a freehand approach (20).
Similarly, accuracy in guided endodontic surgery has been investigated in both preclinical and clinical studies. The study by Fan et al. found that the deviation of apical resection guided by grid position was 0.66±0.54 mm, and the deviation of apical resection without template was 1.92±1.05 mm (21).
Zhao et al. compares the accuracy of endodontic microsurgeries performed with and without 3D-printed surgical guides. The deviation of the apical resection length of the experimental group (0.467±0.146 mm) was better than that of the control group (1.743±0.122 mm) ($P<0.0001$), and the deviation of the apical resection angle of the experimental group (9.711±3.593°) was significantly less than that of the control group (22.400±3.362°) ($P<0.0001$). Thus, showing that the section length and angle have been significantly improved (22).
Gaffuri et al. (23), on a human cadaver study, highlights the critical role of surgical guides in enabling non-expert operators to achieve accuracy levels comparable to experienced practitioners. Results showed no significant difference in performance between experienced and inexperienced operators. Both achieved clinically successful outcomes, demonstrating that surgical guides ensure precision and reduce operator-dependent variability, even in challenging conditions such as posteri-

or teeth. Previous reports have used guided endodontic surgery to identify an ideal ostectomy site, providing a significant improvement in bone removal, but none of them have used a specific template to perform a selective and accurate root-end resection in length and angle, critically important to minimize trauma and enhance surgical results.
Aim of this case series is to describe a new surgical template design, suitable to static endodontic microsurgery when performed by Piezosurgery®.

Case Report

Case 1: Maxillary central incisors with 2 surgical templates
A 24-year-old man was referred to the department of periodontology of IRCCS Agostino Gemelli Polyclinc foundation in Rome.
The patient's anamnesis indicated an absence of systemic diseases and no reactions to dental anesthetics or antibiotics.
The CBCT revealed periapical radiolucent lesions on each maxillary incisor (Figure 1). Both central incisors were endodontically treated 10 years ago and covered by fixed prosthodontics that the patient refused to replace. The decision to perform conventional endodontic treatments on lateral incisors and endodontic microsurgery on central incisors was made.
The CBCT images were imported to a dental CAD software (Implant 3D®, Media Lab s.p.a). According to the indications offered by the oral surgeon, two dental and bone supported surgical templates were made.
The first one was characterized by two circular slots with a diameter of 6mm. The centre of the circle was located 1mm coronally to the root end of each tooth. These slots were used to realize a minimally invasive ostectomy upon dental apex. The second one was characterized by two rectangular slots (6 mm x 1 mm) perpendicular to the y-axis of each tooth. According to guidelines of endodontic micro-surgery, each slot was located at 3mm coronally to the anatomical root apex (9, 24).
All surgical procedures were performed under 20x magnification (M320 D, Leica®). The fit of the 3D-printed surgical templates was verified intraorally before starting surgery by checking the position of the teeth through the occlusal holes of the template (Figure 2, Figure 3)
The patient was anaesthetised using 4% articaine with 1:100.000 epinephrine (Pierrel®). 3 cartridges of anaesthetics were used during the whole surgery.
A modified Widman flap with vertical bevelled incicions distally to both right and left canine teeth was performed, using a 15c blade, due to the presence of mild re-

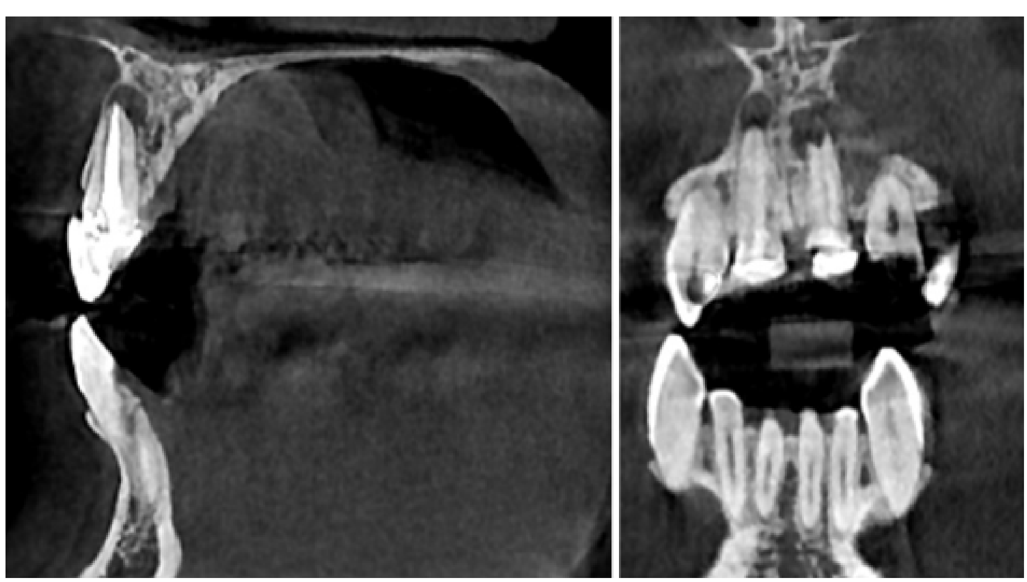


Figure 1
CBCT evaluation.

Figure 2
Surgical template #1 try-on.

Figure 3
Surgical template #2 try-on.

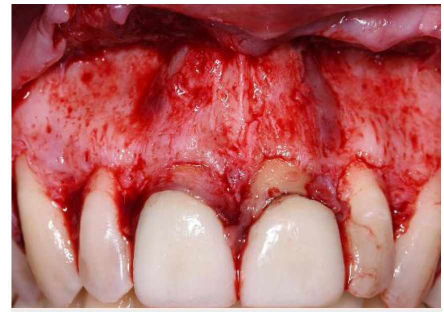


Figure 4
Full-thickness flap elevation.

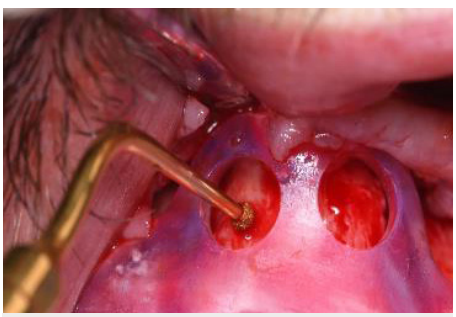


Figure 5
Ostectomy using OT13 tip and surgical guide #1.

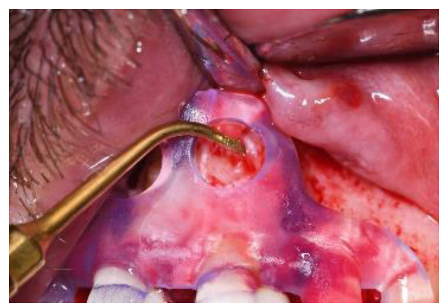


Figure 6
Ostectomy using OP7 tip and surgical guide #1.

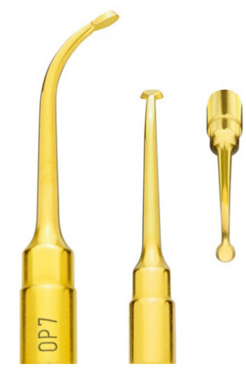


Figure 7
Root apexes exposed.

Figure 8
Root-end resection using OT7S-3 tip and surgical

sidual periodontal pockets, allowing for simultaneous treatment of both periodontal pockets and endodontic lesions. The use of this flap didn't affect the aesthetic outcome due to the presence of recessions and associate exposition of the metal frame of the prosthetic crowns, prior to the surgery.
A full-thickness flap was elevated using tissue elevators (Figure 4). The fit check of templates was repeated after flap elevations. Using the surgical template #1 and piezoelectric tips OT13 and OP7 (Piezosurgery®, Mectron), ostectomies were performed (Figure 5 and 6). Root apexes appeared clearly exposed after ostectomy (Figure 7). The template #1 was removed and replaced with template #2.
The surgical template #2, tailored to piezoelectric tip OT7S-3 (Piezosurgery®,Mectron) allowed to resect root-ends (Figure 8 and 9). Root apexes were carried off using root tip picks (Figure 10).
A root-end retrocavity of 3mm (9) was prepared with a piezosurgery diamond-coated retrotip EN3(Piezosurgery®, Mectron) (Figure 11) and filled using a

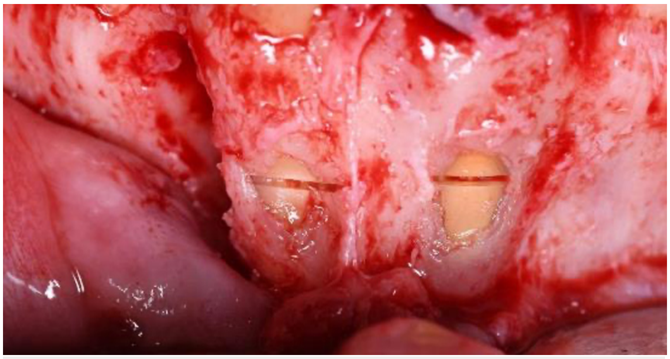


Figure 9
Root-ends resected.

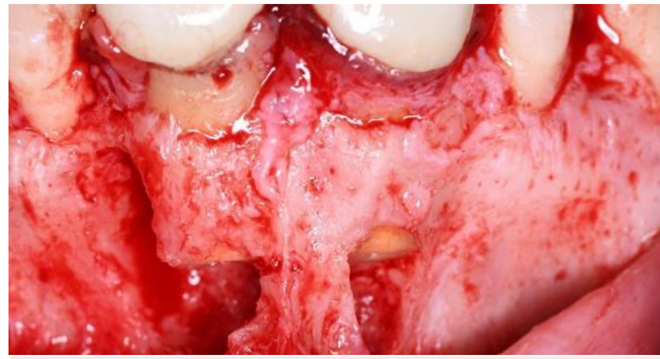


Figure 10
Root-ends carried off.

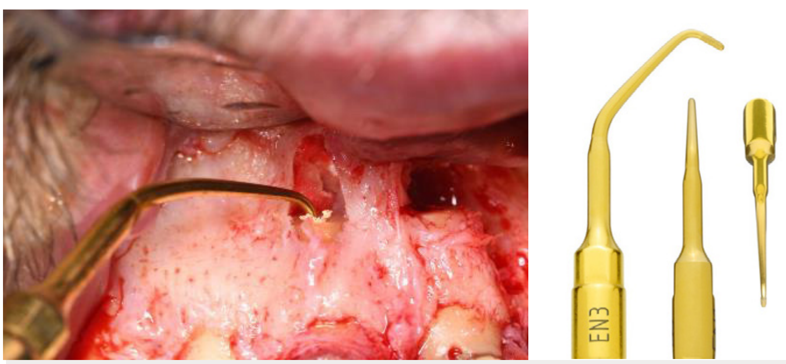


Figure 11
Root-end cavity preparation using EN3 tip.

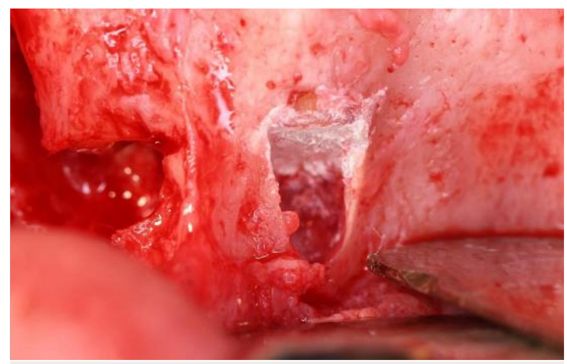


Figure 12
Root-ends filling using premixed bioceramic putty.

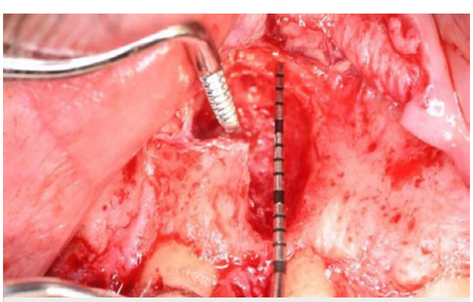


Figure 13
Residual bone defect.

Figure 14
Bone defect filled with bone graft.

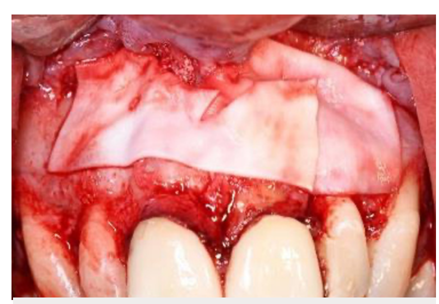


Figure 15
Collagen membrane positioned.

Figure 16
Flap suture.

Figure 17
Day of surgery, 6 and 12 months radiographic follow-up.

premixed bioceramic putty (Well-Root PT®, Vericom) (Figure 12).
The residual bone defect, (Figure 13) was filled with bovine bone graft (Bio-Oss®, Geistlich) (Figure 14) and covered with a resorbable bilayer collagen membrane (Bio-Gide®, Geistlich) (Figure 15), in order to prevent an incomplete healing owing to ingrowth of connective tissue (25). Considering the extension of the residual bone defect, a collagen membrane was used to obtain a barrier effect to ensure undisturbed and uninterrupted bone healing and a bone graft was placed in order to prevent a collapse of the collagen membrane into the defect.
The flap was sutured with single sutures using polyglycolic acid (PGA) 5.0 (Figure 16) and sutures were removed 7 days after surgery.
Radiographic and clinical evaluation was performed 6 and 12 months after surgery, showing the absence of neither symptoms nor radiolucent lesions on treated teeth thus proving the treatment's stability (Figure 17).

Case 2: Maxillary central and lateral incisors with a modular surgical template
A 33 years old woman was referred to the department of periodontology of IRCCS Agostino Gemelli Polyclinc foundation in Rome, with sporadic discomfort, swelling and tenderness to percussion in the premaxilla region.
The patient suffered from valvular heart disease which imposes the eradication of each possible infectious outbreak included the periapical lesions on each maxillary incisor confirmed by CBCT (Figure 18).
Due to the urgency of the treatment and the presence of a fixed prosthesis covering the endodontically treated teeth, the decision to perform a microsurgery approach was made.
DICOM files and STL data obtained from an extraoral cast scanning were imported to a dental CAD software (Implant 3D®, Media Lab s.p.a). According to indications offered by the oral surgeon, this time only one modular surgical template was made.
The surgical template was composed by a single dental and bone supported frame, non-removable during surgical procedures, to which two secondary removable templates (A and B) were connected through magnets (Figure 19):
-the first one (#A) was characterized by four circular slots 6mm in diameter. The centre of the circle was located 1mm coronally to the root end of each tooth. These slots were used to realize a minimally invasive ostectomy in the periapical hard tissues.
-the second one (#B) was characterized by four rectangular slots (6mm x 1mm) perpendicular to the long axis of each tooth. Each slot was located at 3mm to the root apex, defined on CBCT images, in order to perform root resection (9, 24).
All surgical procedures were performed under 20x magnification (M320 D, Leica®)
The fit of 3D-printed surgical templates was verified intraorally (Figure 20, 21).
The patient was anaesthetised using 4%

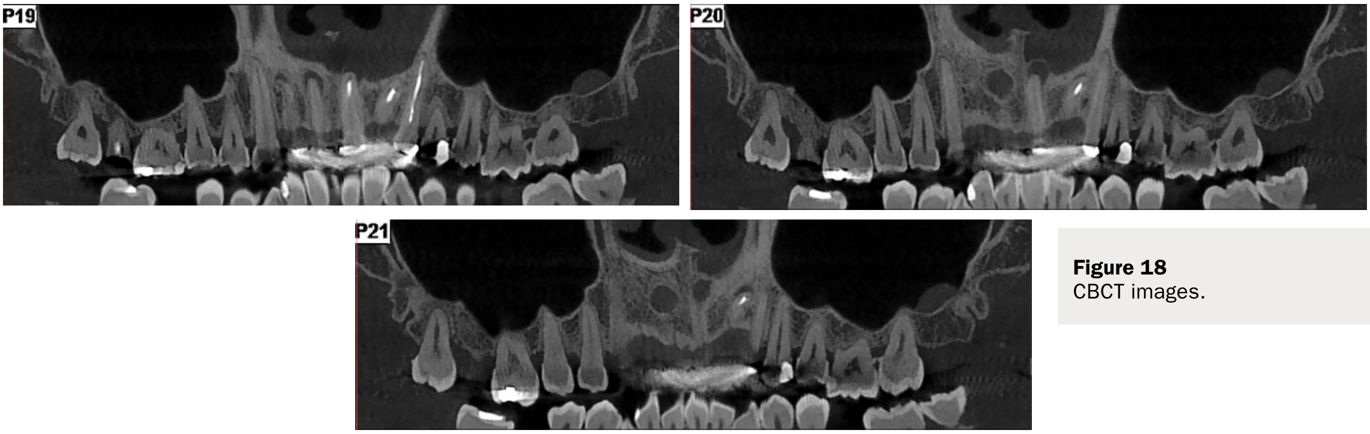


Figure 18
CBCT images.

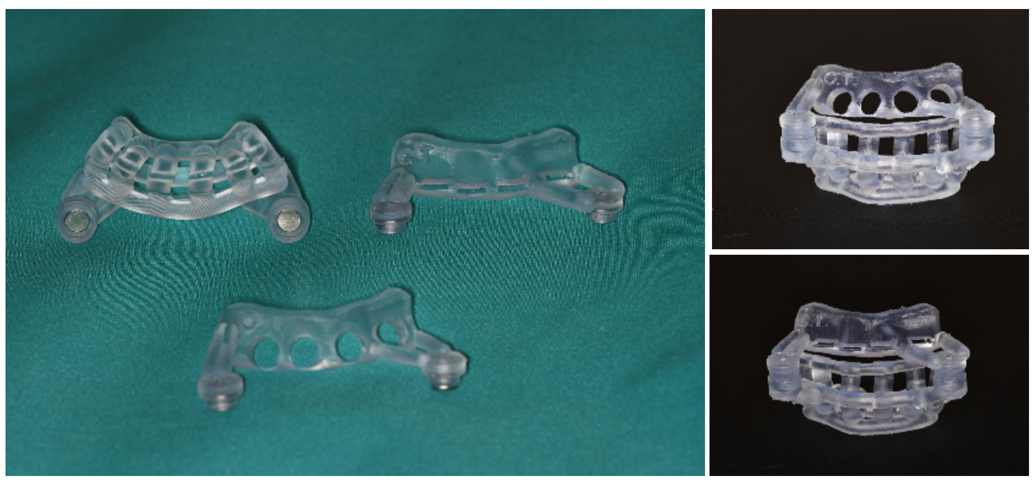
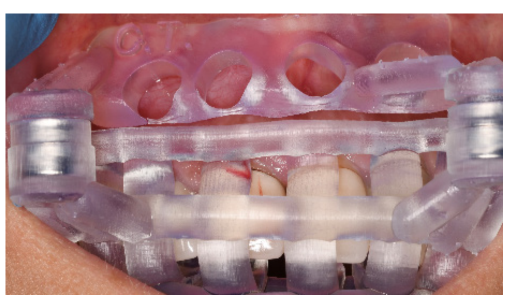


Figure 19
Surgical template #0, #A and #B.



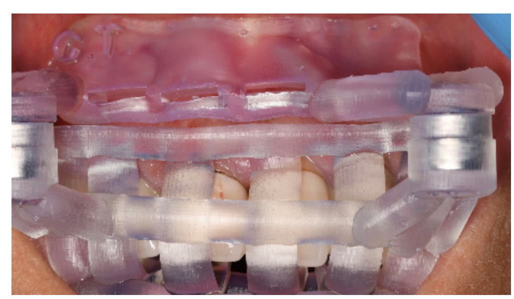


Figure 20
Surgical template #0 and #A try-on.

Figure 21
Surgical template #0 and #B try-on.

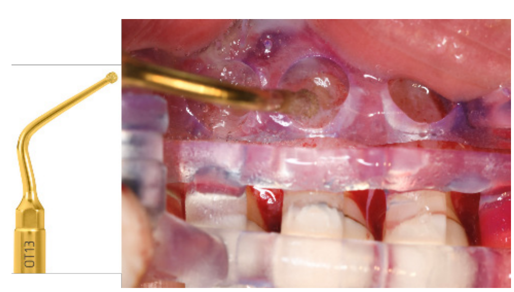


Figure 22
Full-thickness flap elevation.

Figure 23
Ostectomy using OT13 tip and surgical guide #A.

articaine with 1:100.000 epinephrine (Pierrel®). 5 cartridges of anaesthetics were used during the whole surgery. A modified Widman flap with vertical bevelled incisions distally to both right and left canine teeth was performed, using a 15c blade, due to the presence of mild residual periodontal pockets.

Figure 24
Root apexes exposed.

Figure 25
Root apexes exposed.

Figure 26
Root-end resection using OT7S-3 tip and surgical template #B.

Figure 27
Root-ends resected.

Figure 28
Root-ends resected at 3 mm from the apex.

Figure 29
Root-ends resected.

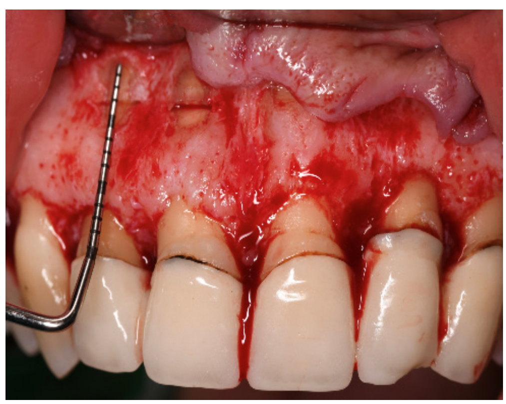
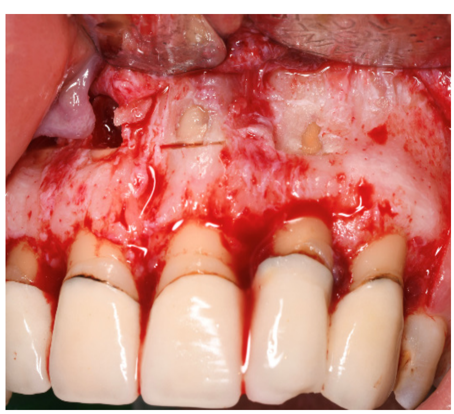
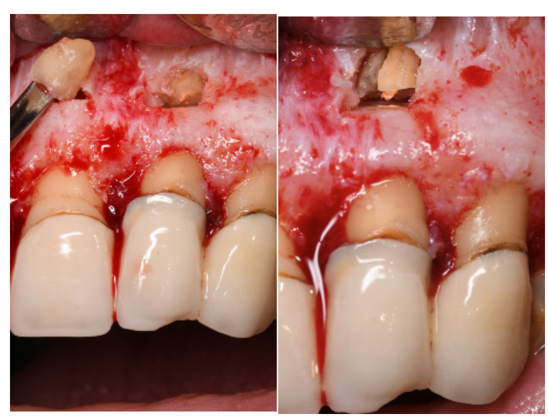


Figure 30
Root-ends carried off.

Figure 31
Roots-ends carried off.





A full-thickness flap was elevated using tissue elevators (Figure 22).
Template #0 was positioned intraorally, and the correct fit was checked.
The surgical template #A was connected to Template #0 and ostectomies were performed using piezoelectric tips OT13 and OP7 (Piezosurgery®, Mectron) (Figure 23). After ostectomies, root apexes are clearly exposed (Figure 24, 25).
The surgical template #A was then replaced by surgical template #B, and by means of a piezoelectric tip OT7S-3

Figure 32
Roots-ends carried off and apical lesions removal.

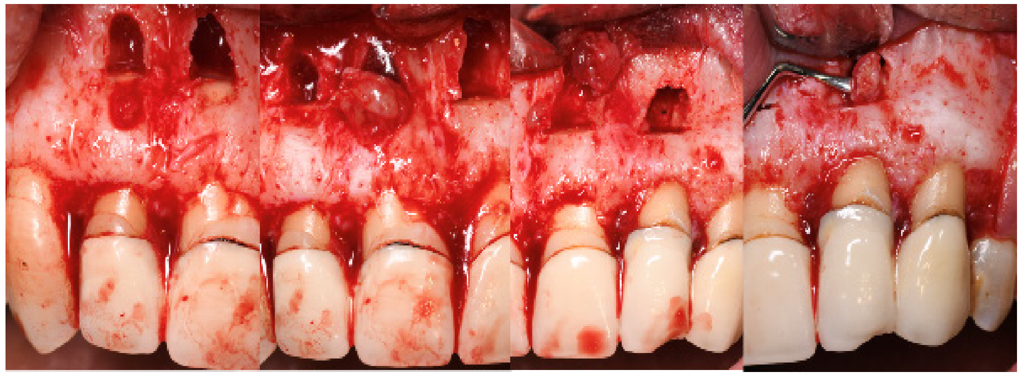
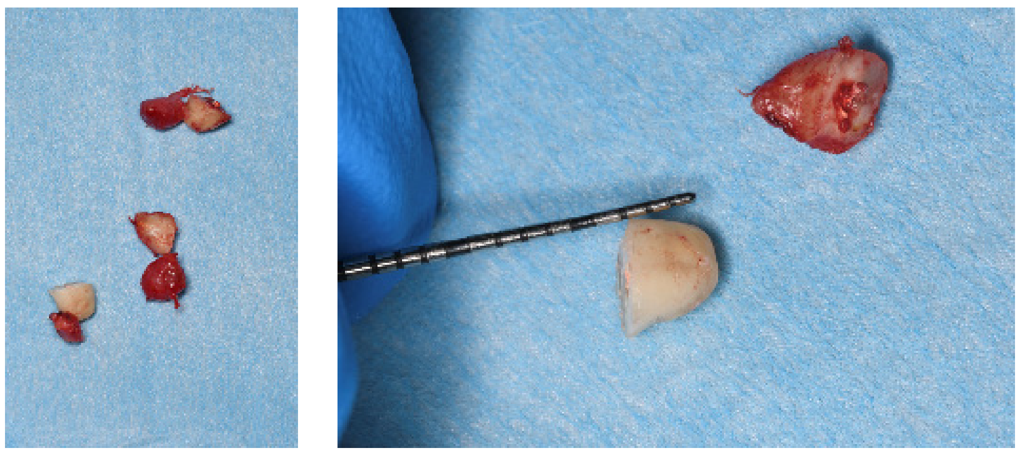


Figure 33
Apical lesions and root-ends resected.



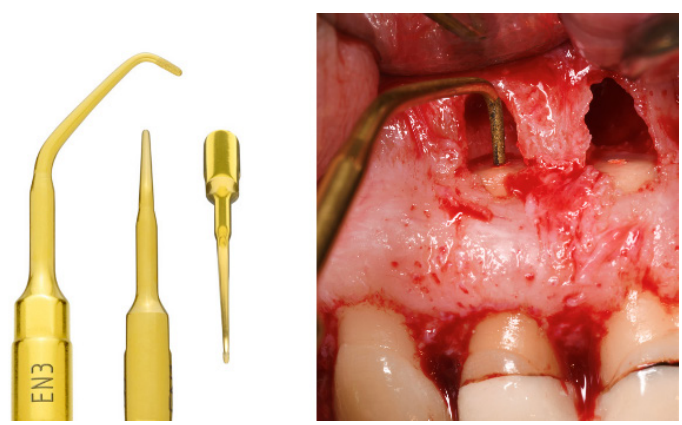


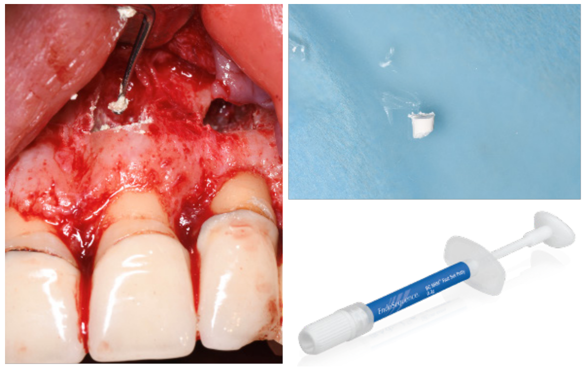
Figure 34
Roots-end carried off.

Figure 35
Root-end cavity preparation using EN3 tip.

(Piezosurgery®, Mectron) root-ends were resected (Figure 26, 27).
Root-ends were extracted using root tip picks (Figure 29, 30, 31). Piezosurgery diamond-coated retrotip EN3(Piezosurgery®, Mectron) was used to retroprepare the last 3mm of the root-end cavity (Figure 35).
The Root-end cavities were filled using a premixed bioceramic putty (EndoSequence BC Sealer®, Brasseler USA) (Figure 36).
As in the previous case, the residual bone defect (Figure 38) was filled with bovine bone graft (Bio-Oss®, Geistlich) (Figure 39) and covered with a layer of collagen (Condress®, Smith&nephew) (Figure 40) (25).
Flap was sutured with single sutures using Polyglycolic acid (PGA) 5.0 (Figure 41).
Sutures were removed 7 days after surgery.
Radiographical and clinical evaluations were performed 3, 6 and 12 months after surgery, showing the absence of radiolucent lesions on treated teeth thus proving the treatment's stability (Figure 43-46).

Figure 36
Root-end filling using premixed bioceramic putty.

Figure 37
Root-ends filling.



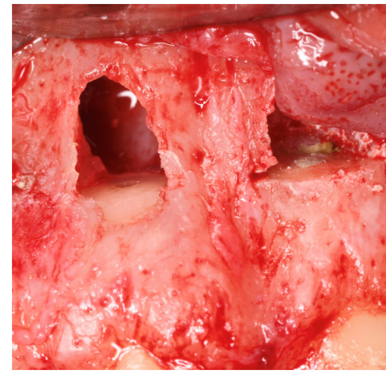
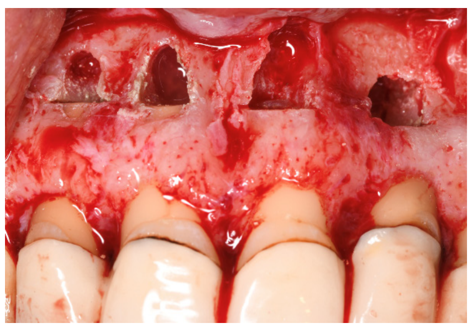


Figure 38
Residual bone defect.

Figure 39
Bone defects filled with bone graft.



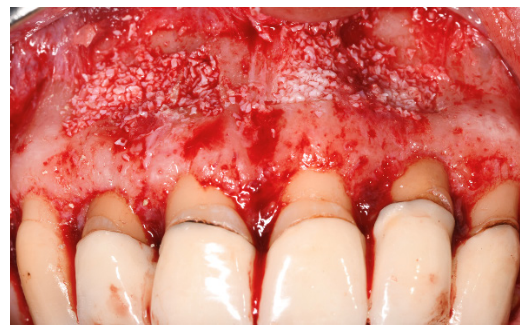


Figure 40
Bone defects covered with a layer of collagen.

Figure 41
Flap suture.

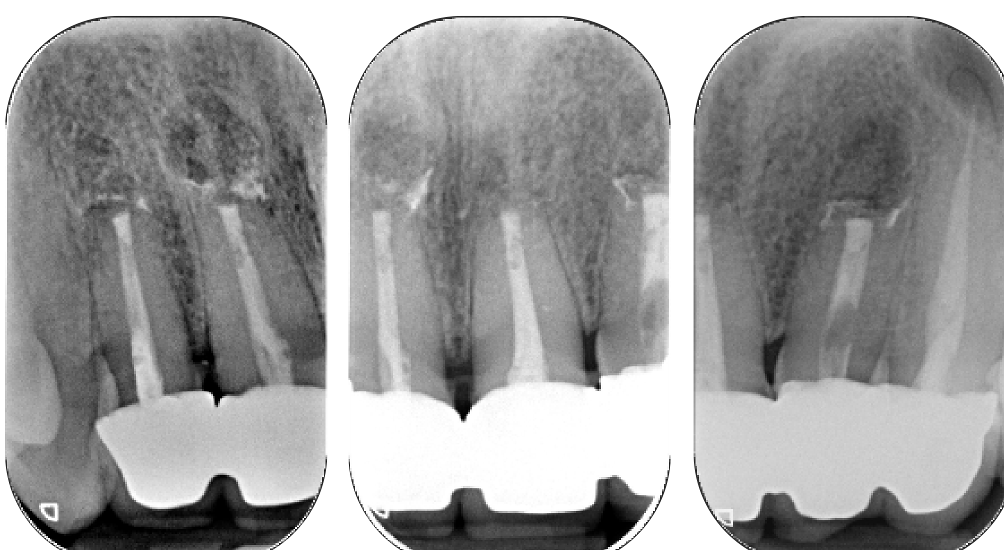
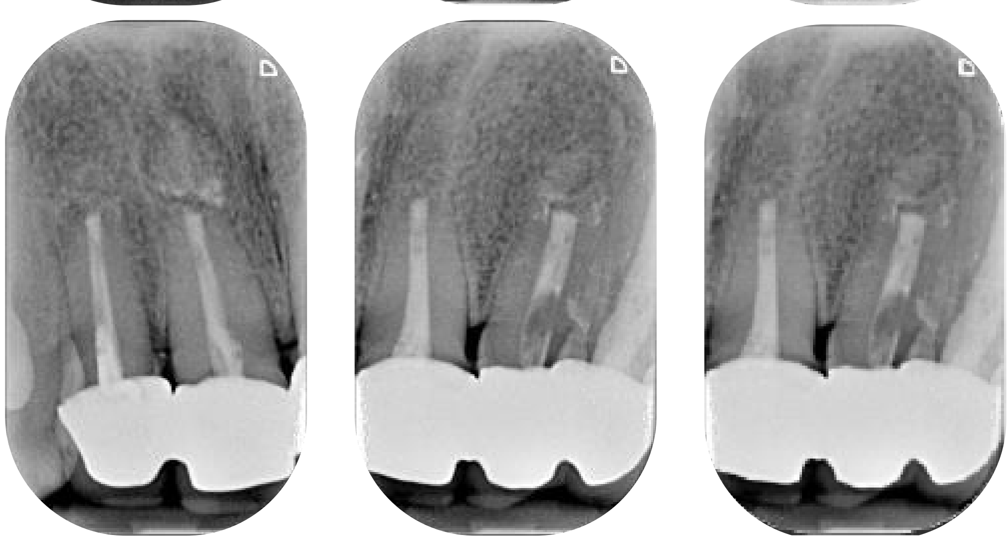


Figure 42
Rx performed at the end of the surgery.

Figure 43
Clinical evaluation 3 months after surgery.

Figure 44
Radiographical evaluation performed 3 months after surgery.

Figure 45
Radiographical evaluation performed 6 months after surgery.



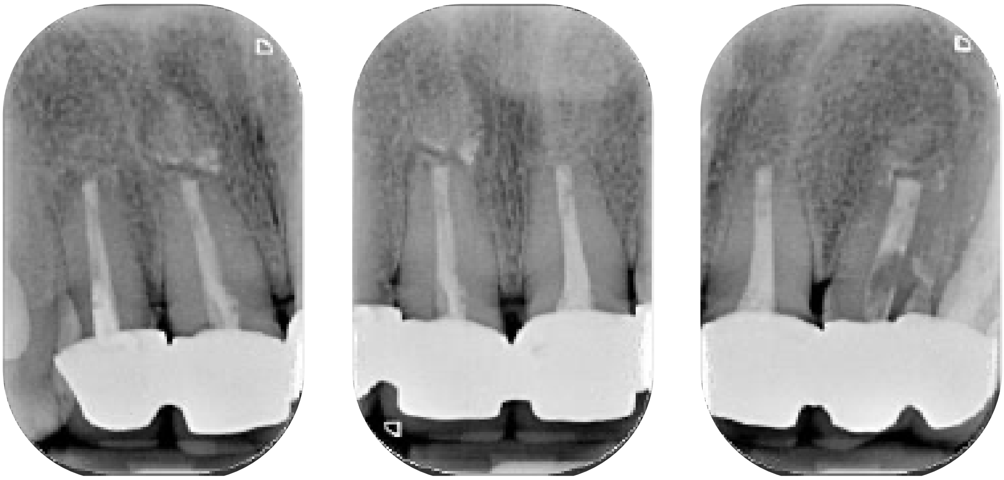


Figure 46
Radiographical evaluation performed 12 months after surgery.

Discussion

The development of surgical templates designed through a CAD software on the basis of patient CBCT provides precise apex and surgical site location, reducing surgical timing, avoiding access errors, damage to neighboring teeth, and injury to healthy tissue. The high precision guaranteed by the templates makes the procedure particularly suitable to the treatment of anatomically complex scenarios including lesions close to the nerve, the maxillary sinus, and arteries.
Guided endodontic microsurgery has the potential to be a more accurate and conservative apical surgery that can, in most of the cases, replace the more invasive traditional apicoectomy procedures.
Drawbacks need to be considered before using guided endodontic surgery, in fact, fracture template or poorly fitting template can occur. Moreover, the size of the surgical templates requires both a more extended flap design, which can be particularly tricky in the posterior areas, and a sufficient opening mouth, making it difficult to correctly fit the surgical template and the instrumentation during the surgery; dynamic navigation systems (3D-DNS) represent a viable alternative to static surgery, especially where spatial limitations makes template use challenging. It enables precise, real-time adjustments, ensuring accurate execution in tight spaces (26).
Even if, it is a more expensive approach, requiring advanced dental solutions such as CBCT imaging, specialized dental software for digital designs, and 3D printing capacity, the assistance provided by specialised 3D Studio Engineering, such as Media Lab S.p.A. help clinicians to overcome such adversity.
Piezoelectric surgery represents one of the most important evolution in bone surgery in the last decades. This technology provides maximum intraoperative control and cutting precision. The most important clinical feature of Piezoelectric surgery is selective cutting. Ultrasonic mechanical micro-vibrations are effective only when coming into contact with tissue that displays a high mechanical resistance, such as mineralized tissues. When in contact with soft tissues, which are typically elastic, the mechanical energy cannot be converted into cutting action, so it's immediately transformed into thermal energy. These advantages over rotary instruments configure piezoelectric surgery as a gold standard device to use in proximity of high-risk structures (27).
Guided surgery using prefabricated 3D printed templates has become a common treatment option in endodontic surgery because of its potential to reduce surgical intervention time and postoperative complications during treatment procedures, to perform guided osteotomy, apex localization, and root-end resection as planned and according to recommended guidelines for modern surgical endodontic treatment.
In the attempt of adapting the general principles of minimally invasive surgery to

surgical endodontics, over the past few decades, different surgical approach and template design have bene described.
In literature, the use of surgical guide is well described, both for the creation of the bone access to minimizes the removal of bone tissue without diminishing the possibility to correctly visualise the root-end and the lesion (28-30), and for executing safely the root-end resection, removing exactly the planned amount of structure (28). The so-called "targeted endodontic microsurgery" adopts a three-dimensional pre-printed surgical guide that allows the use of a trephine bur, that performed at a certain predetermined depth both ostectomy and root-end resection (31).
According to the authors, the use of specific templates to perform independently ostectomy and root-resection allows a less invasive surgical approach, considering that the diameter and the circular shape of a bur is not comparable to that of the root apex.
Moreover, templates developed for these cases were customized for the access of the piezoelectric tips employed during the stages of the surgery. For example, templates #2 and #B were both characterised by binaries, located 3mm coronally to roots apexes, and tailored to OT7S-3 tip. Those binaries allowed a precise cut of root apexes, enhancing the features of piezoelectric cutting precision, and reducing operative times and surgical stress.
In the case series described, the modular surgical template employed in case 2 represents an evolution of that used in case 1. The main advantage consists in the stabilization of the template #0, performed at the beginning of the surgery, without the need of template #2 and its fit check. Once the template #0 has been placed, the connection of templates #A and #B is easy and accurate, which further reduces surgical timing.
Guided endodontic approach seems to be very promising; it allowed to perform an endodontic surgery according to the study of the case and to recommended guidelines, minimizing invasiveness, reducing surgical timing and increasing accuracy. Digital guided surgery aimed at reducing the influence of operator's skill and the so-called "technique effect" during the surgery, minimizing the risk of errors during the procedure.

Conclusions

The development of surgical templates based on CAD software and patient-specific CBCT imaging represents a significant advancement in endodontic microsurgery. These templates provide precise localization of the apex and surgical site, minimizing surgical errors, reducing treatment time, and protecting adjacent healthy tissues. This approach is particularly advantageous in complex anatomical cases, such as those near the maxillary sinus, nerves, or arteries, where high precision is essential. Guided endodontic microsurgery offers a more conservative alternative to traditional apicoectomy, with the potential to improve accuracy and reduce invasiveness.
Piezoelectric surgery enhances the precision of bone resection by selectively cutting hard tissues without damaging soft tissues, making it especially useful near sensitive structures. Combined with 3D printed surgical templates, piezoelectric surgery improves the precision of osteotomy and root-end resections, reducing surgical time and postoperative complications.
In conclusion, guided endodontic microsurgery, with its use of digital templates and piezoelectric technology, holds great promise for enhancing the accuracy, efficiency, and safety of apical surgeries. It offers a minimally invasive, highly accurate approach that reduces operator-dependent variability and improves clinical outcomes.

Clinical Relevance

The study highlights the clinical relevance of a novel CAD-CAM-designed surgical template for static endodontic microsurgery combined with Piezosurgery®. This innovation enhances precision in root-end resections, minimizes bone loss and tissue trauma, and improves surgical outcomes compared to traditional freehand techniques. By reducing invasiveness and post-operative complications, it promotes faster recovery and higher success rates in treating persistent apical periodontitis and other endodontic complications. This advancement underscores the potential of guided technologies to refine microsurgical procedures and improve patient-centered care.

Conflict of interests

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

Acknowledgments

None.

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