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OTIGINAL ARTICLE

Accuracy of a minimally invasive surgical guide in microsurgical endodontics: a human cadaver study

ABSTRACT

Aim: *In the last decade, endodontic microsurgery has achieved high qualitative standards and excellent success rates. Technology and highly innovative materials have reduced pre- and intra-surgical complexity. To date, operator experience continues to be an important prognostic factor. This study aimed to evaluate the accuracy of root resections achieved by two operators with different experience in endodontic microsurgery using a surgical guide.*

Methodology: *A comparative study was conducted on 40 roots (20 roots/operator) in two defrosted cadaver heads. Preoperative CBCT and intraoral scans were used to plan and manufacture a bony-supported surgical guide equipped with oriented steel sleeves and buccal flanges. Two operators with different levels of endodontic skills and abilities executed osteotomies and root resections. Planned and postoperative CBCT images were superimposed to measure the linear deviation of the surgical access point from the planned target. A t-test was performed to compare linear deviations from the planned target between experienced and non-experienced operators. Statistical significance was set at 5% ($p<0.05$). Maximum length of resected apex, present and centred root canal, periodontal ligament, and sufficient osteotomy to complete the root-end preparation and filling were qualitatively evaluated by a third experienced surgeon.*

Results: *Overall, the mean linear deviation was 1.23 ± 0.38 mm. No statistically significant differences emerged between operators, even in posterior teeth. All root resections were considered clinically successful.*

Conclusions: *Guided endodontic microsurgery is an accurate and unbiased method to execute apical access, even in posterior teeth, and is not subject to the surgeon's experience.*

Stefano Gaffuri

Elisabetta Audino

Matteo Salvadori

Maria Luisa Garo*

Stefano Salgarello

University of Brescia, Dental School, Department of Medical and Surgery Specialties, Radiological Sciences and Public Health, Brescia

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Corresponding Author

Maria Luisa Garo | Dental School, University of Brescia, 1, Piazzale Spedali Civili, Brescia | Italy

Phone +39 030 383424 | E-mail: marilu.garo@gmail.com

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Introduction

Endodontic microsurgery is indicated for the treatment of periapical lesions of endodontic origin that do not respond to or cannot be treated with conventional therapy (1, 2). The primary goal of endodontic microsurgery is to eradicate the causes of persistent apical pathology and reduce postoperative discomfort. Persistence of bacteria within the anatomical complexity of the root canal, extra-radicular infection, foreign body reactions to gutta-percha root filling materials and radicular cysts may result in endodontic failures (3).

Small osteotomies and optimal root resections are two prerequisites to reduce the risk of endodontic failures. Given the correlation between small osteotomies and favourable postoperative healing outcomes, the osteotomy should be sufficiently large to allow instrumentation access to the root canal and small enough to reduce hard tissue trauma (4). An adequate osteotomy facilitates root-end canal preparation and subsequent removal of soft tissue lesion surrounding the apical access.

Moreover, an optimal root resection allows the operator to resect the root-end completely and detect multiple or aberrant canals with subsequent ease of retrograde preparation (5).

Therefore, root resection should be performed at 3 mm from the apex, with a bevel angle perpendicular to the long axis of the root and a cavity of at least 3 mm depth (2). The apical length of 3 mm is not an absolute value, but an ideal length to balance the need to remove apical ramifications and lateral canals and to maintain a favourable crown-root ratio (6). The length and angle of the root-end resection are critical prognostic factors for endodontic microsurgery success (2), because they impact the accessibility to the infection site, a crucial element for the success of the whole surgical procedure.

Proximity to the mandibular nerve or the maxillary sinus, the cortical bone thickness or a palatal root could represent significant hindrances in performing endodontic microsurgery. For this reason, accuracy and precision of osteotomy and root-end resection are fundamental to reduce the risk of damages to hard and soft tissues and neighbouring structures and perform an optimal root-end preparation (7-9).

New technologies, innovative materials and surgical expertise have been considered the main components to achieve a success rate greater than 90% in the medium-long period (10-12). In the last decades, technologies and innovative materials have increased the equipment needed for many practitioners, thus reducing many technological difficulties. Notwithstanding, the lack of surgical experience and specific endodontic skills continue to be an issue in preventing many endodontists from performing traditional endodontic surgery. Approximately 77% of residents in U.S. endodontic residency programs execute fewer than 20 apical resections during their training (13) and 25-30% do not perform surgery in the mandibular premolar-molar region (14).

To date, root access and visualization, tooth position, and lack of proper training have been considered the main challenges in the apical surgery procedure (14-16). Surgical guides, similar to those adopted in implantology, have been tested to reduce the operator's uncertainties and increase the precision and accuracy of the surgical approach. Many studies demonstrated how surgical guides could improve the precision of osteotomies and the accuracy of the root-end resection (17-24). Case reports also highlighted how the combination of Cone Beam Computed Tomographic (CBCT) imaging and guided endodontic microsurgery can potentially minimise the risk of intra- and post-operative complications (25).

In light of this, our study aimed to demonstrate how a surgical guide can increase the precision and accuracy of osteotomies and root-end resection for practitioners with a limited surgical endodontic experience. The accuracy level achieved respectively by an experienced surgeon and a sixth-year dental student was compared. The hypothesis was that using a surgical

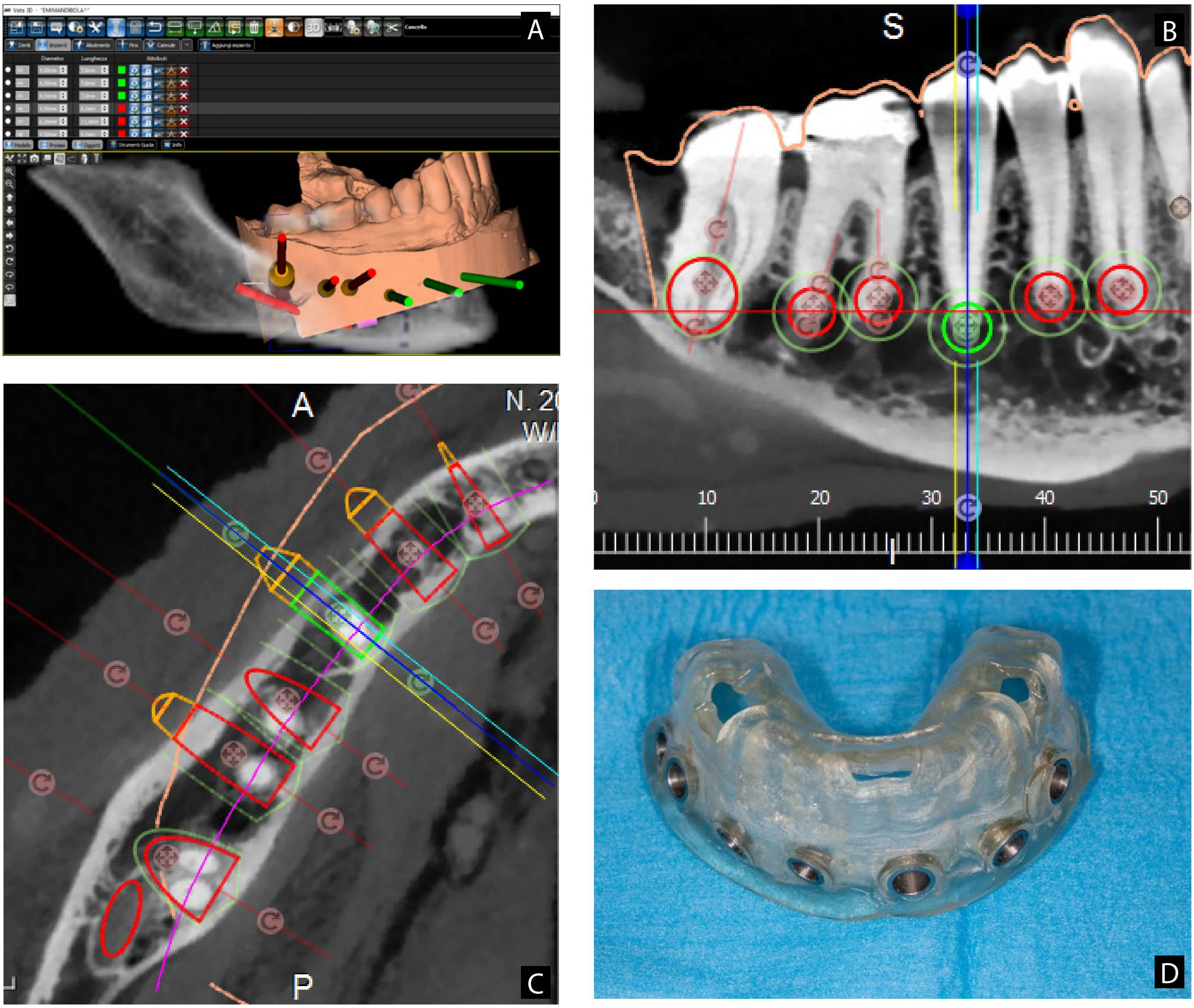

Figure 1
Planning and design of the surgical guide in the 3Diagnosis 4.1 software. **A)** Matching between STL and DICOM file; **B)** Identification of apexes; **C)** Positioning of virtual cylinders; **D)** Surgical guide.

guide for osteotomy and root-end resection allows the inexperienced operator to accurately access a root to a pre-planned location with the same accuracy level as that of an experienced operator.

Materials and Methods

A surgeon experienced in implants and endodontic microsurgery and a sixth-year dental student at the School of Dentistry of the University of Brescia participated in the study.
Two cadaver heads were obtained from ICLO (Teaching and Research Center, Verona, Italy). The use of anatomical parts derived from cadavers complies with the regulations of the National Bioethics Committee of the Italian Republic and the Helsinki Declaration. Ethics Committee Approval was not necessary.
Preoperative CBCT scans (5GXL, NewTom, Verona, Italy) and intraoral scans (Trios3, 3Shape A/S, Copenaghen, Denmark) of specimens were obtained. Scattering effect in CBCT was eliminated using a radio translucent bite (EvoBite, 3Diemme, Cantù, CO, Italy). A three-dimensional model of specimens was created using 3Diagnosis 4.1 software (3Diemme Bioimaging Technologies, Cantù, CO, Italy) (Figure 1A). Axial, panoramic and cross-sectional

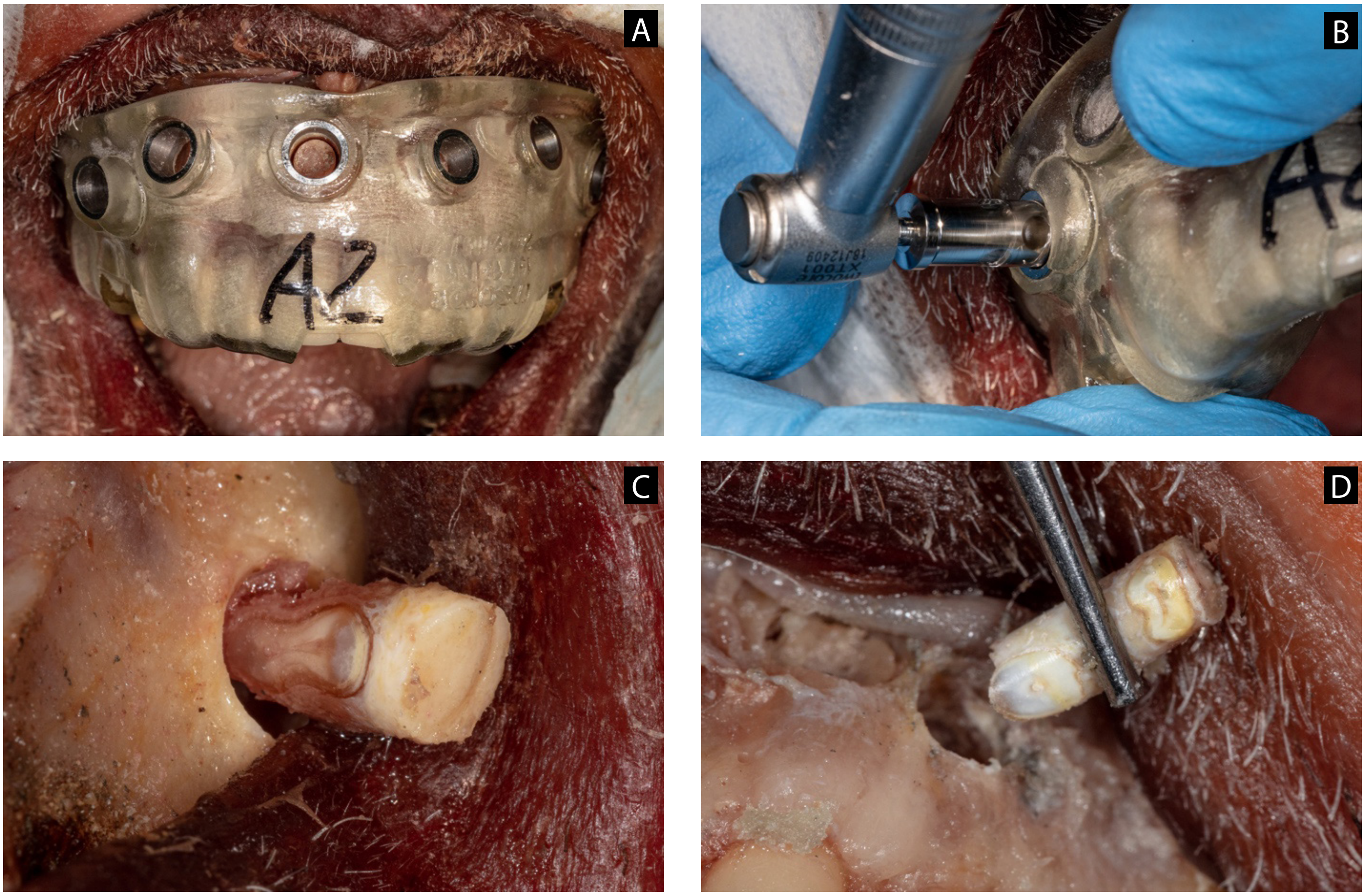

Figure 2
Surgical Access. **A)** Positioning of the guide on the arch, **B)** Cortical window and apical resection with only one milling operation, **C)** and **D)** Bone carrots extraction from the cortical table.

views were used to evaluate the functionality of dental structures and design the surgical guide. A software for guided implant surgery was used to position virtual cylinders (23) on the root's apical third (Figure 1B, 1C). The diameter of these cylinders varied between 4 and 5 mm, while their length ranged from 5 to 20 mm as per the specific clinical scenario. Each virtual cylinder was positioned at 3 mm from the apex in the coronal direction (panoramic view), perpendicular to the long axis of the root (cross view) and correctly oriented in the mesiodistal direction (axial view) according to physiologic and anatomic limits. In the cross-sectional view, the virtual cylinders were placed such that they overcame the root by at least 1 mm.
The experienced endodontist supervised the whole virtual planning designed by the student.
Surgical guides were also designed and produced in the 3Diagnosis 4.1 software and fabricated at Idi Evolution (Concorezzo, MB, Italy) (Figure 1D). Each surgical guide was equipped with oriented 5 mm-long rounded steel sleeves in order to control the path and depth of the trephine and with a diameter range of 4 to 6 mm depending on the characteristics of the apex. A buccal flange was designed following the profile of the bone table to improve guide adherence and protect soft tissues due to its role as passive retractor of the mucogingival flap.
During the surgical intervention, soft tissues were removed from the specimen mimicking flap reflection in a clinical scenario. The guide was positioned over the occlusal surface of the teeth (Figure 2A).
Osteotomy and root resection were performed on forty roots (20 roots/operator) with unique access using a trephine bur by Komet Dental, Lemgo, Germany (Figure 2B, 2C)

length 18 mm
n° 227.204.050
-external diameter 5 mm
-internal diameter 4,1 mm
or n° 227.204.060
-external diameter 6 mm
-internal diameter 5.1 mm

The resection of the root was made simultaneously to the bone using the same trepan bur. Given the different hardness of the tissues, we slightly increased the speed as well as the thrust in according to the tissue strength. No vibrations were noted during the whole process. Bone carrots and resected apices were removed from the cortical table (Figure 2D). Optimal tissue irrigation was maintained during the whole surgical procedure.

Postoperative CBCT scans were taken for each specimen using the same settings of the preoperative CBCT scans. Pre- and post-operative scans were superimposed using 3D GeoMagic Qualify 3D Systems® software (3Diemme Bioimaging Technologies, Cantù, CO, Italy). The deviation of the postoperative access point from the pre-planned point was measured. Then, the linear deviation was determined as the distance between the planned access point (value 0) and the executed surgical access point.

To quantify the clinical success of the procedure, roots and resected apices were examined using HS Moller-Wedel International Model V.M. 900® operating microscope (AT x10, x12 magnification*)* (Moeller Wedel Optical Rosengarten, Wedel, Germany). The root surfaces were then treated with methylene blue to stain the periodontal ligament and root canal selectively.

A third experienced surgeon assessed the success or failure of the endodontic microsurgery. Success was defined with respect to the following four parameters: (1) maximum length of resected apex 3 mm; (2) root canal present and centred; (3) periodontal ligament characterised by an unbroken circular line around the root surface; (4) sufficient osteotomy to complete the root-end preparation and root-end filling. Roots that did not conform to any one of the parameters mentioned were classified as failures.

Sample size calculation using G*Power 3.1 for Macintosh (Heinrich-Heine, Dusseldorf, Germany) estimated a minimum of 18 roots per group (alpha=0.05, power=0.8). However, because of the randomness of small samples, a minimum sample size of 20 per group was adopted for this study (20). Roots treated by the experienced endodontist were considered the control group. An external researcher randomly assigned the 40 roots to each operator. Linear deviation (mm) was reported as mean ± standard deviation. A T-test on independent samples was performed to evaluate the statistically significant differences between experienced and non-experienced operators. Statistical significance was set at 5% ($p<0.05$). All statistical analyses were performed using the STATA16 software (StataCorp., College Station, TX, USA).

Results

The sample comprised 40 roots (53% lower arch and 47% upper arch; 65% single-rooted teeth and 35% multi-rooted teeth). A total of 28% of teeth were molars or premolars.

Overall, mean linear deviation was 1.23 ± 0.38 mm (range: 0.48-2.17 mm). The mean distances achieved by the experienced and non-experienced operator was not statistically different ($deviation_{experienced}$=1.19 ± 0.37, 95% CI: 1.01-1.36; $deviation_{non\text{-}experienced}$ 1.27 ± 0.39, 95%CI: 1.08-1.45; $t=0.6638$, $p=0.5108$).

No statistically significant difference emerged between the two operators for posterior teeth ($deviation_{experienced}$=1.05 ± 0.31, 95% CI: 0.73-1.38; $deviation_{non\text{-}experienced}$ 1.42 ± 0.43, 95%CI: 0.89-1.96; $t=1.6596$, $p=0.1314$) and in lower or upper arch (Table 1).

Discussion

Endodontic microsurgery is a predictable surgical approach to explore and solve the cause of non-healing in root canal-treated teeth and eliminate persistent

Table 1

Descriptive statistics and t-test on independent samples between experienced and inexperienced operator

Group	Total sample (n=40)	Posterior teeth (n=11)	Anterior teeth (n=29)	Lower arch (n=21)	Upper arch (n=19)
Experienced operator	1.19 ± 0.37	1.05 ± 0.31	1.24 ± 0.39	1.03 ± 0.34	1.34 ± 0.35
Inexperienced operator	1.27 ± 0.39	1.42 ± 0.43	1.21 ± 0.38	1.12 ± 0.28	1.44 ± 0.45
p-value	0.5108*	0.1314*	0.8391*	0.5238*	0.5798*
Shapiro-Wilk test for normality of the variable "linear deviation" (p-value)				z=-1.835 (0.9667)	

Data are presented as mean ± standard deviation. Test t-statistics and Shapiro-Wilk test were reported.
*P-value of each test is reported into parenthesis. *Student's t-test.*

apical pathology effectively. The main goals of this procedure are the long-term survival of asymptomatic teeth and the healing of the periapical tissues (26).

Precise and accurate osteotomies and optimal root resections are considered prerequisites to achieve postoperative favourable healing outcomes in the medium-long period (10, 15, 24, 27, 28). Handling and controlling these intra-operative factors are, therefore, the main objectives of the surgical procedure.

To date, the lack of specific surgical endodontic skills and abilities continue to be considered a critical hindrance, preventing less experienced endodontists from using this predictable technique though technology and innovative materials have improved the effectiveness of endodontic microsurgery.

This study aimed to demonstrate how a surgical guide can increase the accuracy of osteotomies and root-end resections executed by practitioners with a limited surgical experience as well as improving existing capabilities. For this goal, the level of accuracy achieved by two operators with different levels of skills and abilities in executing respectively twenty osteotomies and root resections was compared.

Preoperative CBCT and intra-oral scans were used to plan the surgical approach and design the surgical guides. Mean linear deviation was used as a quantitative parameter to determine the deviation of the trephine by the planned path.

Overall, both operators reported a mean linear deviation equal to 1.23 ± 0.38 mm, thus confirming the excellent level of accuracy achieved by the guided endodontic microsurgery. This result is comparable with that achieved by Ackerman et al. (2019), who demonstrated that the accuracy level of the guided endodontic surgery (1.47 ± 0.75 mm) was statistically significant higher (p<0.01) than that registered using the "freehand" technique (2.64 ± 1.39 mm) (29).

From the comparison between the experienced and non-experienced operators, no statistically significant difference between the two operators in achieving an optimal level of accuracy emerged. The surgical guide reduced the less experienced operator's uncertainties, thus ensuring comparable results between operators with different endodontic skills (linear deviation experienced operator was 1.19 ± 0.37 mm; linear deviation non-experienced operator was 1.27 ± 0.39 mm).

Antal et al. (2019) suggested that the accuracy of the surgical approach without a guide is a direct effect of the surgeons' ability to keep in mind the three-dimensional image (23). In the "freehand" approach, the surgeon should balance the need to identify the point of execution of the cortical window, especially when a fistula is absent (30) with the need to limit tissue damages and keep a sufficient visual and operational space (31).

The presence of a surgical guide allows overcoming intra-operative difficulties. Thanks to the sleeves placed next to the root apices and oriented according to the root morphology, the guide becomes a tool for transferring preoperative information, as apex location and size, the thickness of the cortical bone, and orientation of the root in the surgical context, thus overcoming the surgical uncertainties due to limited experience (32).

Comparing linear deviation achieved by both operators in posterior teeth, no statistically significant difference emerged (p>0.05) between the two operators. Although the tooth and anatomical complexities can increase surgical difficulties (16), the surgical guide resulted in a fundamental tool to keep a high level of accuracy in more complex surgical conditions.

Both operators achieved 100% success. All resected roots were conformed to the four predefined parameters. During the planning phase, the non-experienced operator reported a certain level of difficulties in using planning software, especially for the first planning phases as CBCT and intra-oral scans superimposition. Therefore, although the surgical guide reduced the difficulties of the non-experienced operator in minimizing osteotomy and in executing the root resection correctly, some difficulties related to the use of technological devices remained. Some studies highlighted an extensive learning curve of microsurgical endodontics (27, 31). In this work, this extensive learning curve was transferred from the surgical phase to the preoperative one.

Guided endodontic microsurgery is an innovative approach to minimise intra-operative risks and improve postoperative healing outcomes. For a non-experienced operator, using a surgical guide reduces uncertainties because it allows reproducing easily all planned parameters. Moreover, in the most complex situations, the surgical guide can simulate the surgical intervention on 3D models, thus assuring an adequate training level.

Some problems related to the use of the surgical approach continue to remain. The surgical guide could not be readily applicable in patients with reduced mouth opening (33-35), dental elements with thin roots (24) or with some anatomical complexities. Trephines with small diameters could help to overcome some of these problems, but a particular caution should be exercised.

Despite the significant findings, some limitations also emerged. In a clinical scenario, the small retraction of the cheek, additional soft tissues or their consistency can increase the level of difficulty.

In conclusion, this study demonstrated that using a surgical guide equipped with a buccal flange and oriented sleeves allows accurate and precise identification of the lesion site, improving the execution of retrograde endodontic treatments by operators with less endodontic skills and even in contexts with a particular clinical complexity. In endodontic microsurgery, using a surgical guide assures total precision in achieving the target site and allows complete and simultaneous removal of the lesion.

Conclusions

Xxxxxxx

Clinical Relevance

xxxxx

Conflict od Interest

xxxxx

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