ORIGINAL ARTICLE

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

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

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, 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.

Corresponding aAuthor
Maria Luisa Garo | Dental School, University of Brescia, 1, Piazzale Spedali Civili, Brescia | Italy
Phone +39 030 383424 | E-mail: marilu.garo@gmail.com

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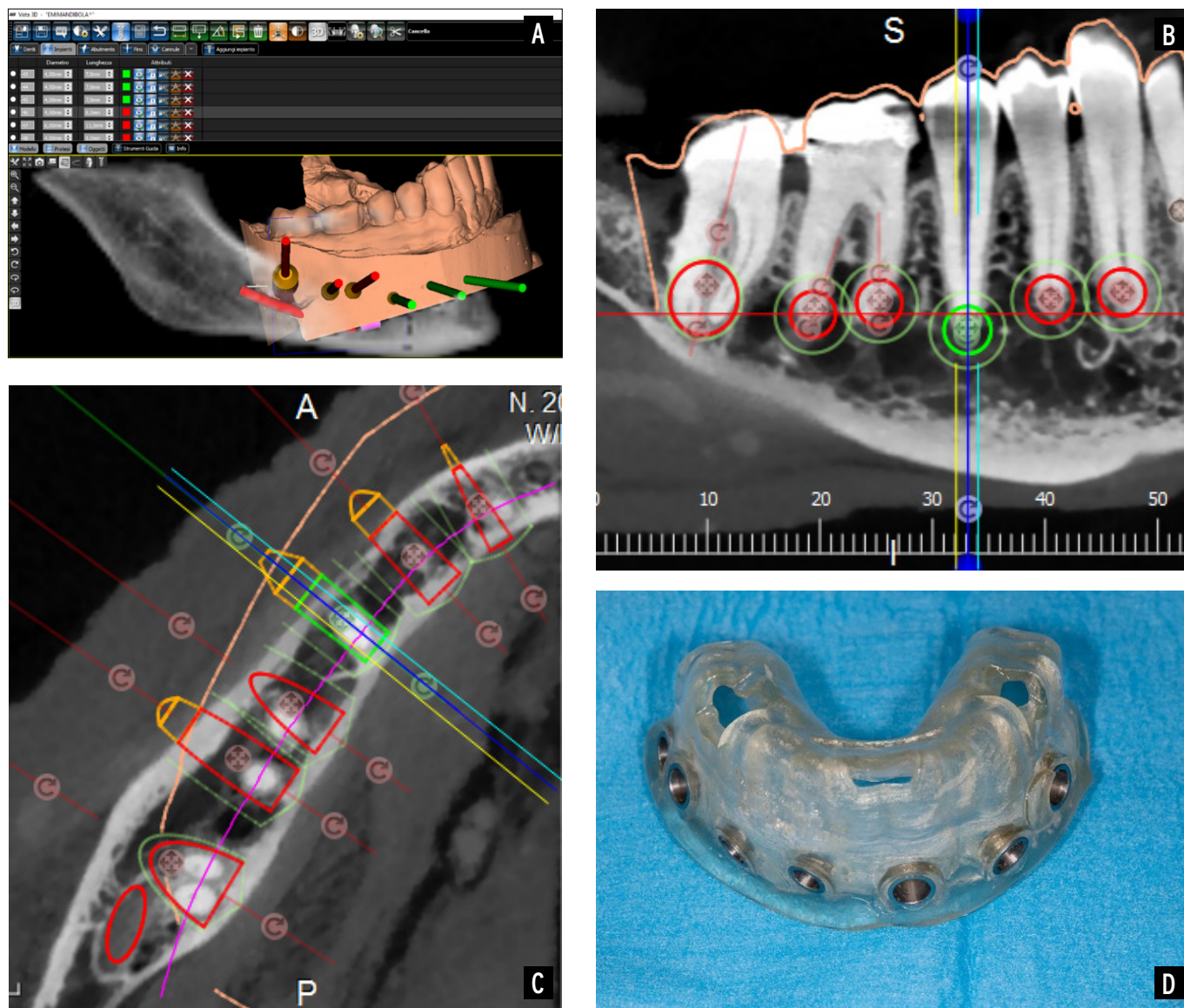
guide for osteotomy and root-end resection allows the inexperienced operator to accurately access a root to a pre-planned location with the same accuracy level as that of an experienced operator.

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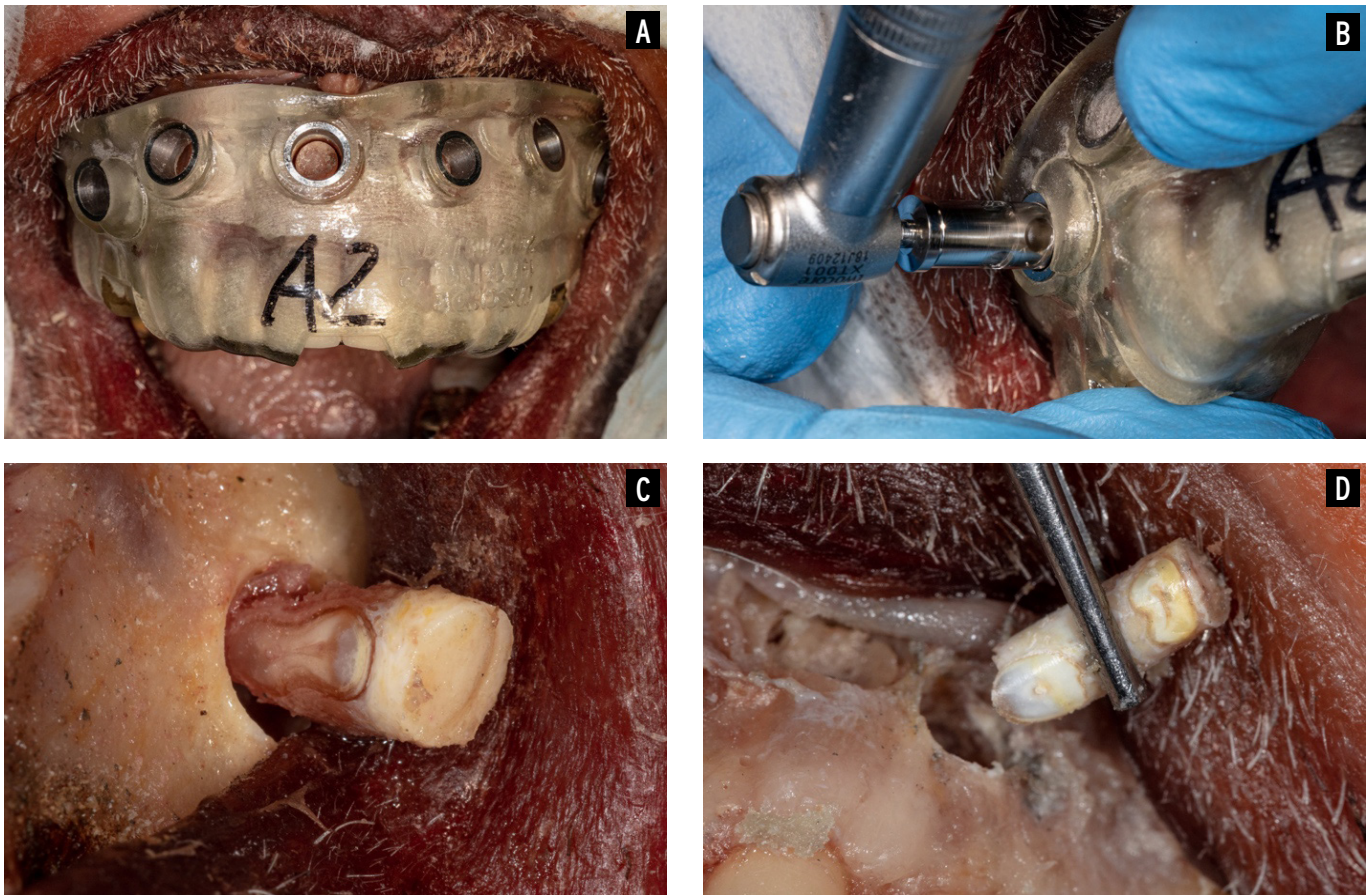
Figure 2
Surgical Access. **A)** Positioning of the guide on the arch, **B)** Cortical window and apical resection with only one milling operation, **C)** and **D)** Bone carrots extraction from the cortical table.

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 trepan bur (length 18 mm: n° 227.204.050 – external diameter 5 mm and internal diameter

4.1 mm – or n° 227.204.060 – external diameter 6 mm and internal diameter 5.1 mm; Komet Dental, Lemgo, Germany) (Figure 2B and 2C).

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$_{non-experienced}$ 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$_{non-experienced}$ 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 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).

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.*

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.

Conclusions

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.

Clinical Relevance

Guided endodontic microsurgery can help non-experienced surgeons to achieve higher success rates in their everyday endodontic clinical practice.

Conflict of Interest

None.

Acknowledgements

None.

References

1   Eliyas S, Vere J, Ali Z, Harris I. Micro-surgical endodontics. Brit Dent J. 2014; 216:169-77.
2   Kim S, Kratchman S. Modern endodontic surgery concepts and practice: A Review. J Endod 2006;32:601-23.
3   Nair PNR. On the causes of persistent apical periodontitis: a review. Int Endod J 2006;39:249-81.
4   Castellucci A. Microsurgical endodontics. (Edra Spa, ed.). Edra - Masson; 2019.
5   Gutmann JL, Pitt Ford TR. Management of the resected root end: a clinical review. Int Endod J 1993;26:273-83.
6   Sacco R, Greenstein A, Patel B. Endodontic microsurgery. In: Springer International Publishing, ed. Endodontic Treatment, Retreatment, and Surgery. Springer International Publishing; 2016:311-312.
7   Floratos S, Kim S. Modern endodontic microsurgery concepts: a clinical update. Dent Clin North Am 2017;61:81-91.

8   Rubinstein RA, Kim S. Long-term follow-up of cases considered healed one year after apical microsurgery. J Endod 2002;28:378-83.

9   Rubinstein RA, Kim S. Short-term observation of the results of endodontic surgery with the use of a surgical operation microscope and super-EBA as root-end filling material. J Endod 1999;25:43-8.

10 Huang S, Chen NN, Yu VSH et al. Long-term Success and Survival of Endodontic Microsurgery. J Endod 2020;46:149-57.

11 Kohli MR, Berenji H, Setzer FC et al. Outcome of Endodontic Surgery: A Meta-analysis of the Literature-Part 3: Comparison of Endodontic Microsurgical Techniques with 2 Different Root-end Filling Materials. J Endod 2018;44:923-31.

12 Pinto D, Marques A, Pereira JF et al. Long-Term Prognosis of Endodontic Microsurgery-A Systematic Review and Meta-Analysis. Medicina (Kaunas) 2020;56:447.

13 Blacher JD, Safavi KE, Aseltine RH, Kaufman BM. Defining endodontic residents' clinical experiences: a national survey. J Dent Educ 2019;83:504-9.

14 Creasy JE, Mines P, Sweet M. Surgical trends among endodontists: the results of a web-based survey. J Endod 2009;35:30-4.

15 Zhou W, Zheng Q, Tan X et al. Comparison of mineral trioxide aggregate and iRoot BP plus root repair material as root-end filling materials in endodontic microsurgery: a prospective randomized controlled study. J Endod 2017;43:1-6.

16 Song M, Jung IY, Lee SJ et al. Prognostic factors for clinical outcomes in endodontic microsurgery: A retrospective study. J Endod. 2011;37:927-33.

17 Giacomino CM, Ray JJ, Wealleans JA. Targeted endodontic microsurgery: a novel approach to anatomically challenging scenarios using 3-dimensional–printed guides and trephine burs - a report of 3 cases. J Endod 2018; 44:671-7.

18 Strbac GD, Schnappauf A, Giannis K et al. Guided modern endodontic surgery: a novel approach for guided osteotomy and root resection. J Endod 2017;43:496-501.

19 Kim J-E, Shim J-S, Shin Y. A new minimally invasive guided endodontic microsurgery by cone beam computed tomography and 3-dimensional printing technology. Rest Dent Endod 2019;44:e29.

20 Fan Y, Glickman GN, Umorin M et al. A novel prefabricated grid for guided endodontic microsurgery. J Endod 2019;45:606-10.

21 Liu Y, Liao W, Jin G et al. Additive manufacturing and digital design assisted precise apicoectomy: A case study. Rapid Prototyping J 2014;20:33-40.

22 Pinsky HM, Champleboux G, Sarment DP. Periapical surgery using CAD/CAM guidance: preclinical results. J Endod 2007;33:148-51.

23 Antal M, Nagy E, Braunitzer G et al. Accuracy and clinical safety of guided root end resection with a trephine: a case series. Head Face Med 2019;15:30.

24 Moreno-Rabié C, Torres A, Lambrechts P, Jacobs R. Clinical applications, accuracy and limitations of guided endodontics: a systematic review. Int Endod J;2020;53:214-31.

25 Benjamin G, Ather A, Bueno MR et al. Preserving the neurovascular bundle in targeted endodontic microsurgery: a case series. J Endod 2020;47:509-19.

26 Jonasson P, Ragnarsson M. Surgical retreatment. In: Springer International Publishing, ed. Apical Periodontitis in Root-Filled Teeth. Springer International Publishing; 2018:73-74.

27 van der Meer WJ, Vissink A, Ng YL, Gulabivala K. 3D Computer aided treatment planning in endodontics. J Dent2016;45:67-72.

28 Ahn SY, Kim NH, Kim S et al. Computer-aided design/computer-aided manufacturing–guided endodontic surgery: guided osteotomy and apex localization in a mandibular molar with a thick buccal bone plate. J Endod 2018;44:665-70.

29 Ackerman S, Aguilera FC, Buie JM et al. Accuracy of 3-dimensional–printed endodontic surgical guide: a human cadaver study. J Endod 2019;45:615-8.

30 Kim J-E, Shim J-S, Shin Y. A new minimally invasive guided endodontic microsurgery by cone beam computed tomography and 3-dimensional printing technology. Rest Dent Endod 2019;44:e29.

31 Ye S, Zhao S, Wang W et al. A novel method for periapical microsurgery with the aid of 3D technology: A case report. BMC Oral Health. 2018;28:1-7.

32 Popowicz W, Palatyńska-Ulatowska A, Kohli MR. Targeted endodontic microsurgery: computed tomography–based guided stent approach with platelet-rich fibrin graft: a report of 2 cases. J Endod 2019;45:1535-42.

33 Connert T, Zehnder MS, Weiger R et al. Microguided endodontics: accuracy of a miniaturized technique for apically extended access cavity preparation in anterior teeth. J Endod 2017;43:787-90.

34 Lara-Mendes STO, Barbosa C de FM, Machado VC, Santa-Rosa CC. A New approach for minimally invasive access to severely calcified anterior teeth using the guided endodontics technique. J Endod 2018;44:1578-82.

35 Torres A, Shaheen E, Lambrechts P et al. Microguided endodontics: a case report of a maxillary lateral incisor with pulp canal obliteration and apical periodontitis. Int Endod J 2019;52:540-9.