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Targeted Endodontic Microsurgery and EMS: A surgical simulation comparison

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***Targeted Endodontic Microsurgery and EMS: A Surgical Simulation Comparison.***

**Abstract**:

**Aim**: Targeted Endodontic Microsurgery (TEMS) produces precise osteotomy site, angulation depth and diameter, in anatomically challenging scenarios. Trephine bur are targeted to resect bone and root ends to exacting 3DSG specifications predetermined within design software. A gap in knowledge exists in that the efficiency and capability of TEMS, as compared to endodontic microsurgery (EMS), for efficient and effective osteotomy and root resection (OR) has not been investigated. The purpose of this study is to compare surgical time, bevel angle and site volumetric profiles of OR accomplished by TEMS and traditional EMS in a surgical simulation model (SSM). **Methodology**: An 80x80 mm Cone Beam Computed Tomography (CBCT) file was imported into Mimics software where artificial periapical lesions were created encompassing twelve root apices. Maxillary and mandibular surgical simulation models (SSM) were printed. TEMS 3DSGs were designed and printed for each surgical site. Three board-certified endodontists used the original CBCT to plan and perform EMS on six maxillary and six mandibular teeth. Next, endodontists performed TEMS surgeries on duplicate SSM for the same teeth. All surgeries were timed. Post-operative CBCT images of SSMs were made and imported into Amira software for measurement of bevel angle and site volumetric profiles. Paired t-tests compared the mean differences between EMS and TEMS groups. A Bonferroni correction determined data to be significant at $p<0.004$. **Results**: TEMS reduced surgical time, had bevel angles more closely approaching zero degrees, and had significantly less volume and length of root resection. **Conclusions**: TEMS represents a viable alternative to EMS throughout the dentition, and particularly in anatomically challenging scenarios where damage to adjacent teeth can occur.

Keywords: Targeted Endodontic Microsurgery, 3D printing, trephine, stent, guide

## Introduction:

Endodontic microsurgery (EMS) is a safe and effective means of addressing persistent apical periodontitis. A bevel approaching zero degrees and a 3mm root-end resection removes apical ramifications by up to 98% resulting in better outcomes (Kim & Kratchman 2006, Gilheany et al. 1994). Osteotomy diameters less than five mm result in improved osseous healing compared to those in excess of five mm that can result in fibrous tissue formation and delayed healing (Wang *et al*. 2004). With EMS clinicians determine perforation site, angulation and depth based upon preoperative radiographic images. Further, freehand EMS relies upon the clinician's perceptual ability and hand-eye coordination, often in anatomically challenging locations, for safe and effective treatment. Thus, better clinical outcomes may be achieved by precise osteotomy and root end resection.

Historically 3D printed surgical guides have been used in endodontics with limited utility (Anderson *et al*. 2018, Buchgreitz *et al*. 2016, Byun *et al*. 2015, Connert et al. 2015, Pinksy *et al.* 2007, Strbac *et al*. 2017). Recently, Targeted Endodontic Microsurgery (TEMS) was introduced (Giacomino *et al.* 2018). TEMS produces precise osteotomy site, angulation depth and diameter, in anatomically challenging scenarios. Trephine burs traditionally used for removal of failed implants and for bone graft harvesting, are targeted to resect bone and root ends to exacting 3DSG specifications predetermined within design software (Figure 1). A gap in knowledge exists in that the efficiency and capability of TEMS, as compared to EMS, for efficient and effective osteotomy and root resection (OR) has not been investigated.

CBCT studies can be uploaded into sophisticated software where anatomic structures can be quantified volumetrically. Volumetric analysis has been used to determine changes in apical soft tissue lesions after EMS and retreatment and in CBCT-based differentiation of cyst versus granuloma (Curtis *et al*. 2018, Pritcher *et al*. 2017, Metzka *et al*. 2013, Crossen *et al*. 2019).

The purpose of this study is to compare surgical time, bevel angle and site volumetric profiles of OR accomplished by TEMS and traditional EMS in a surgical simulation model (SSM). The null hypothesis is that no statistically significant difference between TEMS and freehand osteotomy will be detected for: operating time, volume of bone removed, volume of root removed, volume of periapical lesion unremoved, resection angle, resection length and resection depth.

**Materials and Methods**

***Experimental model fabrication:***

An 80 x 80 mm CBCT file of a caries and restoration-free patient was imported into Geomagic Freeform Plus (*3D Systems, South Carolina, United States*) software (Figure 2A). The region of interest was established as the entire maxillary and mandibular dentition including at least 7 mm beyond the apices of simulated surgical sites. Artificial periapical lesions (APL) large enough to encompass the entire root end, but small enough to avoid perforation of facial or lingual cortical plates, were digitally superimposed over root apices of several teeth in both arches. A base was digitally affixed for mounting in a Dexter mannequin (*Columbia Dentoform Teaching Solutions, New York, United States*). The resultant stereolithography file was printed six times for each arch with an Objet260 *(Stratasys, Texas, United States)* using Verodent and Verowhite Resin (*Stratasys, Texas, United States*) producing teeth and bone. Soft gelatinous Sup705 (*Stratasys, Texas, United States*) simulated periodontal ligament and APL (Figure 2G). These identical models, six of each arch were set aside for use by clinicians during the simulated clinical intervention. One of the models of each arch was scanned with CBCT and files were imported into Amira (*Thermo Fisher Scientific, Massachusetts, United States*) which was labeled Virtual Model One (VM1). VM1 documented preoperative volumes of teeth, APL and bone prior to clinical simulation (Figure 2K).

Next, within Freeform Plus, the bone volume was removed from VM1 and the resultant file containing only the maxillary and mandibular dentition and APL (Figure 2E) was printed once for each arch. These printed models were scanned with CBCT to produce a Virtual Model Two (VM2) and files were imported into Amira to digitally establish tooth and APL contours and volumes for postoperative comparison (Figure 2I).

Next, within Freeform Plus, the APL was removed from VM2 and the resultant file containing only the maxillary and mandibular dentition (Figure 2D) was printed once for each arch. These printed models were scanned with CBCT to produce a Virtual Model Three (VM3) files were imported into Amira to digitally establish tooth contours and volumes for postoperative comparison (Figure 2H).

Finally, within Freeform Plus software, VM3 models were altered by designing 3 mm resections at a zero-degree bevel perpendicular to the long axis of the tooth in a facial lingual dimension and the resultant design was printed once for each arch. (Figure 2F). These printed models were scanned with CBCT to produce Virtual Model Four (VM4) and files were imported into Amira to digitally establish resected tooth volumes and contours after ideal root resection for postoperative comparison (Figure 2J).

Once VM1, VM2, VM3 and VM4 were produced, within Amira software they could be merged with, added to or subtracted from each other or from a Virtual Post-treatment Model (VPM), to quantify volume of bone removed, volume of root removed, volume of periapical lesion unremoved, resection angle, resection length and resection depth.

***TEMS stent fabrication***

A TEMS stent accommodating a trephine of 4.40 mm outer diameter and 20 mm length was created within Mimics (*Materialise, Leuven, Belgium*) software. The stent prescribed a trephine pathway that would resect the root end at a zero degree bevel 3 mm from the apex with no extension beyond the lingual periodontal ligament (Figure 2B and 2C). For all but two TEMS resections, the depth of trephine insertion was limited by a washer that was laser welded to the trephine cylinder (Figure 2O). For two TEMS resections, a trephine without a washer stop was utilized to allow for resection of a deep fused DF-P root. For these fused roots, depth of insertion was indicated when the trephine cylinder reached a prescribed point within the guide port (Figure 2P and 2Q). 3DSGs were printed with the Objet260 using MED610 (*Stratasys, Texas, United States*) resin (Figure 2M).

***Definition of dependent variables***

*Clinical measurement time:* the time required by the BCE to evaluate boney anatomy and select a perforation site (did not include CBCT interpretation). *Surgical time:* first depression of the rheostat until BCE stated the procedure was complete. *Total time:* Clinical measurement time plus surgical time. *Total volume removed:* everything BCE removed from the experimental model with a bur or a curette. *Volume of bone removed:* volume of bone removed independent of root or APL removed. *Total volume of root removed:* volume of root removed independent of bone or APL removed. *Volume of root over-resected:* volume of root removed beyond the ideal when compared to ideal VM4. *Volume of root under-resected:* volume of root unremoved when compared to ideal VM4. *Volume of root resection deviation from ideal*: volume of over-resected tooth structure plus the volume of under-resected tooth structure. *Volume of APL unremoved:* volume of APL unremoved independent of bone, root and APL that was removed. *Facial-lingual Resection (bevel) angle:* deviation from a zero degree bevel at the 3 mm root end resection level using VM4 as the frame of reference. *Resection length:* the length of root resected measured from the middle of the root at the level of resection to the apex using merged VM4 and VM3 as the frame of reference. *Resection depth:* over or under-resection measured from the lingual root surface which was the ideal resection depth, using VM4 as the frame of reference.

***Simulation protocol***

A standardized armamentarium included: ProErgo (*Zeiss Inc, New York, United States*) microscope, high speed handpiece, scalers, spoon excavator, surgical bur block, micromirrors and methylene blue dye. Three board certified endodontist (BCEs) received *free hand osteotomy and resection* instructions : 1) study preoperative CBCT scans with no time limitation (Figure 2A), 2) select osteotomy perforation site, 3) create osteotomy large enough to accommodate a 4 mm wide micro-mirror for visualization of the entire root end under the operating microscope, 4) resect root ends 3 mm from the apex at a zero degree bevel, 5) curette the gelatinous material simulating the periapical lesion using methylene blue as an aid (Figure 2N).

Next BCEs were given *TEMS osteotomy and resection* instructions to include: 1) study preoperative CBCT images with no time limitation, 2) verify full seating of the surgical guide, 3) irrigate with water while rotating the trephine at 1,000 rpm using a pecking motion until the trephine reached the indicated depth (Figure 2Q), 4) remove the resultant core, 5) curette the gelatinous material simulating the periapical lesion.

Next, experimental models were affixed to Dexter mannequin in a dental chair. Once they were satisfied with their study of CBCT scans, BCEs conducted six maxillary and six mandibular OR with traditional EMS first, then six maxillary and six mandibular OR with TEMS. After completion, tape sealed each surgical site. At completion the primary author verified that a 4x12mm micromirror could be inserted into the surgical site to verify that OR conformed to OR requirements. In two instances after freehand OR, sites required a modification to accommodate the micromirror, the BCE modified the OR and additional time was recorded (Figure 3). After OR with TEMS the 3DSG was removed. All TEMS OR accommodated the micromirrior without modification. A post-treatment CBCT was made of every experimental model to produce a Virtual Post-treatment Model (VPTM) which was imported into Amira.

***Data processing***

Amira automatically calculated the volumes of *virtual* models after importation. Within Amira, VM1, VM2, VM3, and VM4 were selectively merged with VPTMs (Figure 3A-D). Amira allowed desired portions of a *virtual* model to be isolated and stored as a separate data set to be merged with desired portions of a the VPTMs. *Volume of bone removed* was established within Amira in the following manner: VM1 minus VPTM minus VM2. *Volume of root removed* was established (VM1 minus VPTM minus VM3). *Volume of root under-resected and over-resected* was established by merging VM3 and VM4 establishing the volume of root resected under ideal design, with VPTM which rendered of volume deviation from ideal (Figure 3E-G). *Volume of periapical lesion unremoved* was established by merging VM1, VPTM and VM2. The volume where these three models overlapped comprised the volume of periapical lesion unremoved which was quantified by Amira. *Resection angle, length and depth* were established by merging VM3 and VM4 with VPTM rendering areas of over-resection, under-resection and all aspects of the entire resection in 3 dimensions (Figure 3J and 3K). Volumetric damage to adjacent teeth were established by combining VM3 with VPTM.

***Statistical analysis***

The mean of the 36 TEMS simulation group and the mean of the 36 EMS simulations was calculated for each dependent variable. Means for TEMS and EMS were compared using paired sample t-tests. A Bonferroni correction determined data to be significant at $p<0.004$.

## **Results**:

*Clinical measurement time:* TEMS significantly reduced clinical measurement time from an average of 85 seconds to 39 seconds ($p<0.00001$). TEMS significantly reduced *Surgical time* from an average of 859 seconds to 254 seconds which was a statistically significant difference ($p<0.00001$). TEMS significantly reduced *total time* from an average of 943 seconds to 293 seconds ($p<0.00001$). For t*otal volume removed* EMS *averaged* 145.4 mm compared to TEMS at 138.9 mm ($p=0.188$). For *volume of bone removed* EMS averaged 54.9 mm compared to TEMS at 58.2 mm ($p=0.358$). For v*olume of root removed* EMS averaged 38.3 mm while TEMS averaged 27.2 mm which was statistically significant ($p<0.001$). For *Volume of over-resection* EMS exceeded ideal resection by an average of 9.2 mm compared to TEMS at 1.7 mm which was a statistically significant difference ($p<0.001$). *Volume of under-resection* showed mean EMS under-resection at slightly less than TEMS (5.9 $mm^3$ and 8.4 $mm^3$ respectively) with $p=0.207$. TEMS had a lower *volume of root resection deviation from ideal* at 10.2 $mm^3$ than EMS at 14.3 $mm^3$ ($p=0.08$). For *volume of APL unremoved* EMS left an average of 13.2 mm compared to TEMS with 11.3 mm ($p=0.015$). *Facial lingual resection (bevel) angles* were on average larger for EMS (10.6 degrees) as compared to TEMS (6.0 degrees) which was a statistically significant difference ($p<0.01$). For *resection length* EMS averaged 3.4 mm compared to TEMS at 2.7 mm which was a statistically significant difference ($p<0.01$). For r*esection depth* EMS averaged 1.0 mm from the lingual root surface compared to TEMS at 0.6 mm ($p=0.016$). The null hypothesis was accepted for *total volume removed, volume of bone removed, volume of APL unremoved,* and *resection depth.* The null hypothesis was rejected for *clinical measurement time, surgical time, total time, volume of root removed, facial-lingual resection (bevel) angle and resection length*.

During EMS, each BCE damaged an adjacent root during EMS of a fused DF-P. Damaged root volumes were 1.6 mm  (#14 D surface of MF root), 1.6 mm  (#3 D surface of MF root) and 0.9 mm  (#14 D surface of MF root). TEMS did not produce damage to adjacent roots. For EMS, one BCE did not remove the APL and root end on two mandibular premolars and was required correct the error with additional surgical time added.

## Discussion

3D printed models mounted in mannequins do not fully replicate *in vivo* conditions, but do achieve excellent standardization. Printing materials do not exactly replicate bone, root end and granulation tissue, and alveolar and masticatory mucosa were not present so retraction was not necessary. Patient positioning challenges were absent, direct visualization under magnification was easily achieved, and there was no bleeding. In sum the simulation was simpler than an actual clinical scenario which may have imparted an greater outcomes advantage to EMS but not to TEMS. With TEMS, all parameters of OR are expressly defined and if the stent is properly seated, deviation from ideal under clinical conditions is minimized. *In vivo* comparisons of EMS and TEMS are warranted.

Maxillary molars showed the greatest standard deviation for all dependent variables for both TEMS and EMS likely due to the resection of a fused DF-P root which required deeper bur penetration with greater possibility for human error. For TEMS surgical guide ports were all 7mm or longer, except for maxillary molars where the guide port was reduced to 4 mm to allow for deeper trephine penetration necessary to resect the fused DF-P root. Indeed, TEMS had a smaller standard deviation for all relevant dependent variables except for where the guide port was 4 mm in the maxillary DF-P scenario. A guide port in excess of 4 mm may be necessary to adequately guide a trephine. Further research investigating guide port length is indicated.

## Conclusions

Sophisticated volume rendering software allowed accurate measurement of dependent variables. The methodology holds promise for future endodontic experimentation. TEMS allowed BCEs to start surgery with less clinical assessment time, and to complete osteotomy and resection more efficiently with a more appropriate root end resection volume and bevel angle. TEMS represents a viable alternative to EMS throughout the dentition, and particularly in anatomically challenging scenarios where damage to adjacent teeth can occur.


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