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Accuracy of 3-Dimensional Printed Surgical Guides with Varying Trephine Port Lengths in Simulated Endodontic Microsurgery

Abstract

Purpose: The aim of this study is to compare the accuracy of targeted endodontic microsurgery (TEMS) utilizing three different port lengths in a surgical simulation model.

Methodology: Thirty 3D-printed resin mandibular models were fabricated for simulated TEMS of the mesial root of a mandibular first molar. After preoperative planning, surgical guides were produced using a stereolithography printer with port lengths of 5mm, 7mm and 10mm. Two board-certified endodontists performed TEMS on the mesial root of #30 with associated surgical guides. Postoperative CBCT images of the experimental models were made and imported into Geomagic Studio software for comparison to the preoperative surgical plan. Linear deviations of the trephine bur at entry and at full depth were measured, and angular deviation was evaluated. One-way analysis of variance (ANOVA) was conducted to examine the effects of port length of the guides on the surgical outcomes. The level of significance was set at $P < .05$.

Results: There was no statistical difference between 5mm, 7mm, and 10mm port lengths with respect to linear deviation at full depth and point of entry as well as angulation of the trephine bur.

Conclusion: In this surgical simulation scenario, the use of a 5mm port length produced similar results in terms of linear deviation and angulation of the trephine bur when compared to surgical guides with 7mm and 10mm port lengths. The ability to use a smaller port length can aid in the ability to perform TEMS in cases with limited access.

Introduction

Endodontic microsurgery (EMS) is an effective way of treating persistent apical periodontitis, however it is a treatment modality that requires skill and experience.^{1,2} The various technical facets of EMS render this procedure challenging for a novice to perform freehand. EMS requires the clinician to estimate the site of perforation, angulation, and depth of osteotomy based on preoperative radiographs or cone beam computed tomography (CBCT) images.^{3,4} Maintaining a conservative, precise osteotomy, along with an accurate root-end resection may be challenging in areas of the mouth with limited access.⁵

TEMS facilitates EMS in challenging scenarios.⁶ TEMS utilizes CBCT and three-dimensional (3D) technology to print a surgical guide that directs a trephine bur to the apex, performing osteotomy and root resection simultaneously. Each TEMS guide is fabricated with a port, comparable to an implant guide sleeve, which accommodates the trephine bur and directs it to the precise location of the surgical target. Review of the endodontic literature found only three studies comparing the accuracy of 3D printed surgical guides (3DSGs) to freehand surgery. These three studies were conducted on cadaver jaws and 3D simulated models and found 3DSGs to be more accurate than freehand surgery.⁷⁻⁹ While 3DSGs have not been studied extensively for endodontics, their accuracy for implant placement has been thoroughly studied.¹⁰⁻¹³ The accuracy of guided surgery is frequently defined as the deviation between the position of the dental implant postoperatively and the planned position. This is commonly measured using postsurgical CBCT and comparing the deviation with the presurgical plan using 3D software.¹² Implant guide accuracy is altered by several parameters i.e. sleeve length, distance between the outer drill diameter and inner sleeve diameter, depth of osteotomy, and distance between the guide and initial osteotomy site. Accuracy is enhanced as the implant sleeve length increases.¹³⁻¹⁴ There are currently no studies showing the length needed of the port guide to ensure accurate osteotomy and root resection with a trephine bur using TEMS.

The purpose of this study is to compare the accuracy of TEMS guides utilizing 3 different port lengths in a simulated model and determine the minimum port length required to maintain accuracy. The null hypothesis is that all TEMS guides are equally accurate regardless of port length. Alternative hypothesis is that TEMS guide accuracy varies depending on port length.

Materials and methods

Experimental model

The study, modified from a previous investigation,⁹ was approved by the 59th Medical Wing Institutional Review Board. A deidentified 80x80mm CBCT file of a caries and restoration-free patient was imported into Geomagic Freeform Plus (3D Systems, Rock Hill, SC, USA) software. A base was digitally affixed for mounting in a Dexter mannequin (Columbia Dentoform Teaching Solutions, Long Island City, NY, USA). The resultant stereolithography file was printed thirty times for the mandibular arch with an Objet260 (Stratasys, Eden Prairie, MN, USA) using Verodent and Verowhite Resin (Stratasys, Austin, TX, USA) reproducing teeth and bone (Fig. 1). These identical models were set aside for use by operators during the simulated clinical intervention.

Thirty TEMS guides were designed with identical parameters excluding trephine port length within Geomagic Freeform Plus software (Fig. 1). Groups 1, 2 and 3 were designed with 5mm, 7mm, and 10mm port lengths respectively (Fig. 2). Due to location of the root apex with respect to external surface of simulated bone, the ports protrude outward from the models at an angle. The angulation and irregular topography of the simulated bone prevents the ports from being a uniform length. The port length was defined as the smallest internal linear measurement from the external surface of the model to the initial opening of the port.

TEMS Guides & Trephines

The guides were designed to accommodate a trephine (Osseodent, Inc., Charlotte, FL, USA) with a 4mm outer diameter. The guide would dictate a pathway that would resect the mesial root-end of tooth #30 at a zero-degree bevel 3mm from the apex (Fig. 3). The tolerance between the inner port diameter and the outer trephine diameter was 0.15mm; offset distance between the guide and simulated bone was 0.5mm. A stainless steel washer was fixated at the end of each trephine. A 3D printed cylindrical tube stop was fabricated for the 5mm and 7mm ports, 5mm and 3mm in length respectively (Fig. 2). The tube stop fits between the end of the guide and the trephine washer and creates a physical stop when the trephine reached the desired depth to resect the simulated root end. The fabrication of a cylindrical tube stop was not needed for the 10mm ports due to the total length of the trephine being 10mm. Surgical guides were printed with the Objet260 using MED610 resin (Stratasys, Austin, TX, USA).

Simulation Protocol

Each group (5mm, 7mm, and 10mm) had ten mandibular casts with ten corresponding surgical guides fabricated. The mesial root of tooth #30 was planned for TEMS. For each group, 10 simulated osteotomies were accomplished using the desired port length, combining for a total of 30 osteotomies. A new trephine was used for each new simulated osteotomy.

Two board-certified endodontists (operators) conducted the following protocol: (i) verified full seating of the surgical guide, (ii) performed osteotomy and root resection with trephines rotated at 1,000 rpm with water irrigation, (iii) utilized the corresponding 3D printed cylindrical tube on the trephines to provide a physical stopping point, ensuring the depth of penetration was adequate to reach the planned surgical depth.

Following the procedure, osteotomies were irrigated with water and air dried to remove loose debris. Post-operative CBCT scans of each cast were acquired using a 3D Accuitomo 80 (J. Morita Corp, Kyoto, JP) and the DICOM files were imported into Mimics Medical 19.0 (Materialise, Leuven, Belgium) software to generate a digital model. The post-treatment models were aligned and registered to the pre-treatment models with the surgical plan (Fig. 4). The pre-treatment models and the post-treatment models were then imported into Geomagic Studio (3D Systems, Rock Hill, SC, USA) software.

Data Processing

The Geomagic Studio software created a cylinder representing the presurgical plan and a best-fit cylinder in each post-surgical osteotomy site (Fig. 5). Central terminal points and central vectors of the pre-treatment and post-treatment cylinders were defined by the software. Angular deviation of the trephine bur, linear deviation of the trephine bur at full depth and entry measurements were calculated by the software using these points and vectors.

Statistical Analysis

The dependent variables of interest were the angular deviation, linear deviation at full depth and linear deviation at osseous entry. The independent variables were the port lengths: 5mm, 7mm and 10mm. One-way analysis of variance (ANOVA) was conducted to examine the effects of port guide length on the outcomes. Significance was set to $P < 0.05$. Statistical analyses were performed using SPSS v.24 (IMB SPSS Statistics software, Armonk, NY).

Results

The angular deviation (Chart 1) and linear deviation at entry (Chart 2) and depth (Chart 3) of a trephine bur using 3DSGs with 5mm, 7mm, and 10mm ports were measured. The mean angular deviation was $1.9^\circ \pm 1.0^\circ$, $1.7^\circ \pm 1.3^\circ$ and $1.4^\circ \pm 0.5^\circ$ for the 5mm, 7mm, and 10mm ports respectively. There was no significant difference between the 5mm, 7mm, 10mm groups.

The means for the linear deviation at osseous entry (Chart 2) was found to be $0.31\text{mm} \pm 0.17\text{mm}$, $0.26\text{mm} \pm 0.05\text{mm}$, and $0.29\text{mm} \pm 0.7\text{mm}$ for the 5mm, 7mm, and 10mm groups respectively. There was no significant difference between the 5mm, 7mm, 10mm groups.

The means for the linear deviation at depth (Chart 3) was $0.44\text{mm} \pm 0.19\text{mm}$, $0.51\text{mm} \pm 0.24\text{mm}$, and $0.56\text{mm} \pm 0.15\text{mm}$ for 5mm, 7mm, and 10mm port lengths respectively. There was no significant difference between the 5mm, 7mm, 10mm groups.

Discussion

TEMS guides facilitate EMS in challenging scenarios⁶ and may enable the clinician to decrease surgical time and increase precision when performing root end surgery, when compared to freehand EMS.⁹ A shorter port length may be necessary due to required depth of osteotomy as illustrated in a recent study where TEMS was performed on a maxillary molar with a fused distopalatal root.⁹ Limitations imposed by patient factors such as limited opening or limited access in the posterior quadrants may also necessitate a shorter port length.

Accuracy of surgical guides can be affected by several parameters including length of port, tolerance, distance between guide and bone, and depth of osteotomy.¹¹⁻¹³ The aim of this study was to determine if port length would be a factor affecting the deviation and accuracy of targeted endodontic microsurgery. Based on previous reports and systematic reviews of implant surgical guides, accuracy is increased with surgical guides when compared to free-hand. With that in mind, some deviation is still present when comparing the proposed surgical plan to actual implant placement. On average, guided implant surgery deviates 1.07mm at entry, 1.63mm at full depth, and has 5.26 degrees of angular

deviation.¹⁰ Furthermore, in 2012 the European Association for Osseointegration has recommended that when using a computer designed implant guide, plan for a mean deviation of 1.2mm at full depth.¹⁵

Currently three other studies analyzed accuracy of surgical guides used for EMS. The first study to compare guided EMS with freehand surgery yielded a mean deviation of $0.79\text{mm} \pm 0.33\text{mm}$ for guided osteotomy and freehand osteotomies resulted in a deviation of $2.27\text{mm} \pm 1.46\text{mm}$ from the pre-surgical plan.⁷ The second study, comparing guided EMS to freehand in a split mouth cadaver model, used guides which prescribed a pathway for Lindeman burs to locate the apical third of the desired root⁸ and reported a linear deviation of 1.47mm for guided surgery and 2.64mm for freehand surgery. It was also reported that none of the guided osteotomies in this study deviated more than 3mm. The third study concluded that the buccal-lingual resection angle were on average larger for EMS (10.6 degrees) as compared with TEMS (6.0 degrees).⁹

Most trephine burs are manufactured in a way that causes the teeth to flare out slightly compared to the rest of the bur. The selected trephine bur used in this study has no flare to the cutting edge and remains a constant 4.0mm diameter throughout the entire length of the trephine. A tolerance or empty space between the trephine bur and the port is required to allow for unrestricted progression of the trephine through the port during surgery. As the tolerance decreases, accuracy increases.¹⁶ Some implant studies use a tolerance as little as 0.10mm.¹⁶ Due to the amount of resistance encountered by the trephine while advancing through a port with 0.10mm tolerance, a tolerance of 0.15mm was chosen for this study.

A practitioner must keep in mind the attrition of trephine burs and its effect on accuracy. Attrition of surgical guides and drills occurs with every drilling procedure. Multiple uses of the trephine bur and sleeve on resin jaw models significantly reduces the osteotomy accuracy.¹⁷ In our study each port and trephine bur were single use in order to minimize deviation caused by attrition. Practitioners may be inclined to use trephine burs for multiple surgeries in vivo due to cost efficiency. Deviation due to attrition of the trephine bur is thought to be minimal, but could hinder desired accuracy in endodontic microsurgery.

TEMS has been suggested to be used in challenging areas in the mouth or in flapless surgeries like in the case for palatal roots of maxillary molars or the roots of mandibular second molars.⁶ Therefore, it is of utmost importance to know the maximum possible deviation of the surgical stent before guided surgery is performed. In this study the maximum deviation at depth was 0.63mm, 0.75mm and 0.71mm for the 5mm, 7mm, and 10mm ports respectively. The results clearly show that accuracy and deviation of the trephine does not significantly change when comparing the 5mm port length to the 7mm and 10mm port lengths. The ability to use shorter port lengths without hindering accuracy increases the ability to use TEMS in cases that were originally thought to be limited due to access. Nonetheless, this is an in vitro model and does not account for clinical variables. Deviations are expected to be greater in practice due to patient movement, obstructed access, and other patient-related factors.¹⁰

Conclusions

TEMS is proposed to be a viable alternative to EMS especially in anatomically challenging scenarios. It is crucial to ensure accuracy of TEMS guides and know the maximum possible deviation of the trephine bur from the planned surgical path to prevent surgical misadventures. This study exhibits that the use of 5mm port length shows no significant difference in linear deviation at entry or depth and angulation compared to 7mm and 10mm port lengths. Further testing should be performed using a cadaver or animal model to confirm that these findings are valid prior to moving to in vivo trials.

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Tables and Figures

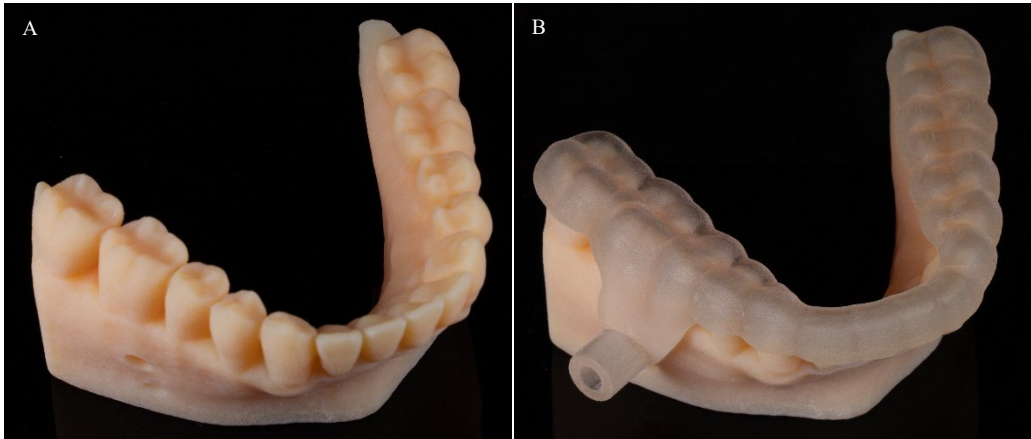


Figure 1. 3D surgical models and guides. (A) Mandibular arch model, (B) TEMS guide fully seated on 3D surgical model (10mm port length pictured).

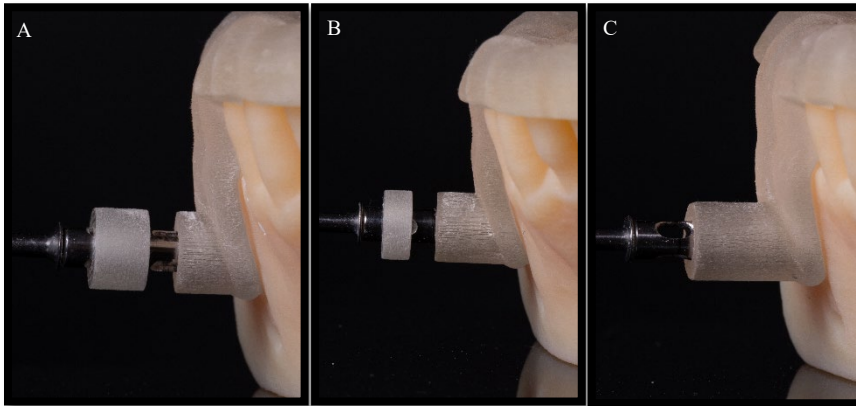


Figure 2. Port lengths and corresponding guide stops. (A) 5mm port length with 5mm guide stop, (B) 7mm port length with 3mm guide stop, (C) 10mm port length.

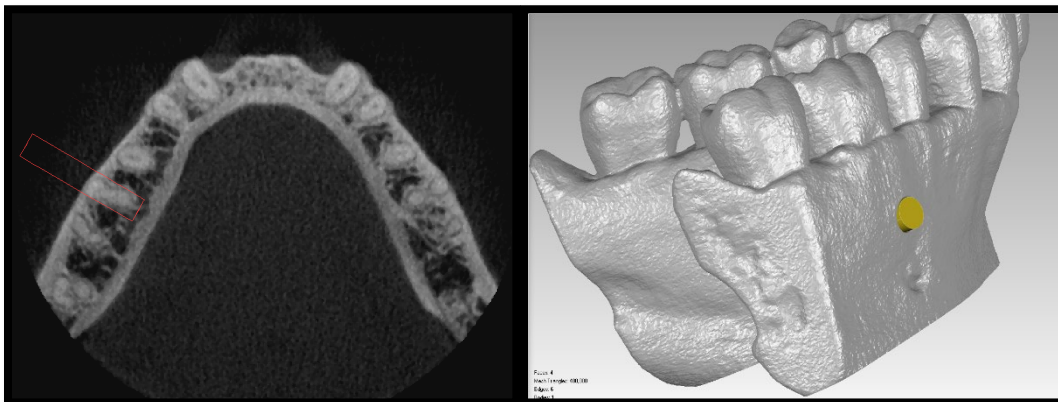


Figure 3. 3D surgical plan that would resect the mesial root-end of tooth #30 at a zero-degree bevel 3mm from the apex.

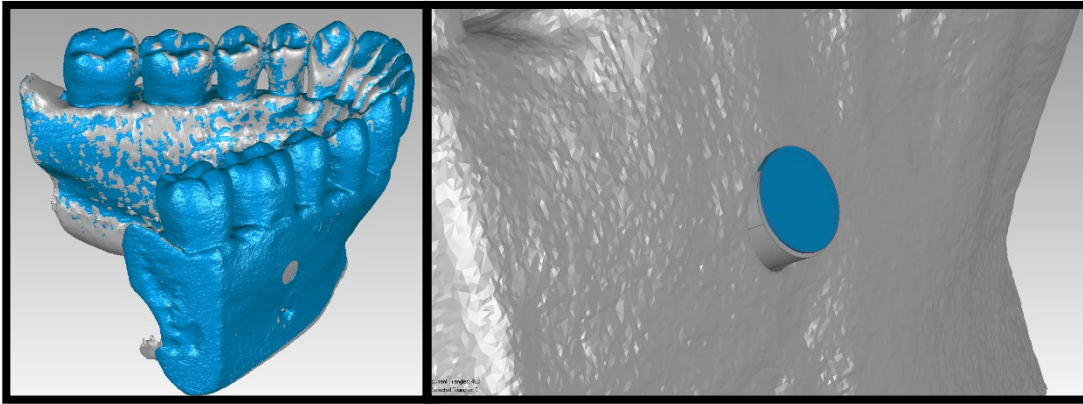


Figure 4. Post-treatment models (gray) aligned and registered to the pre-treatment models with the surgical plan (blue).

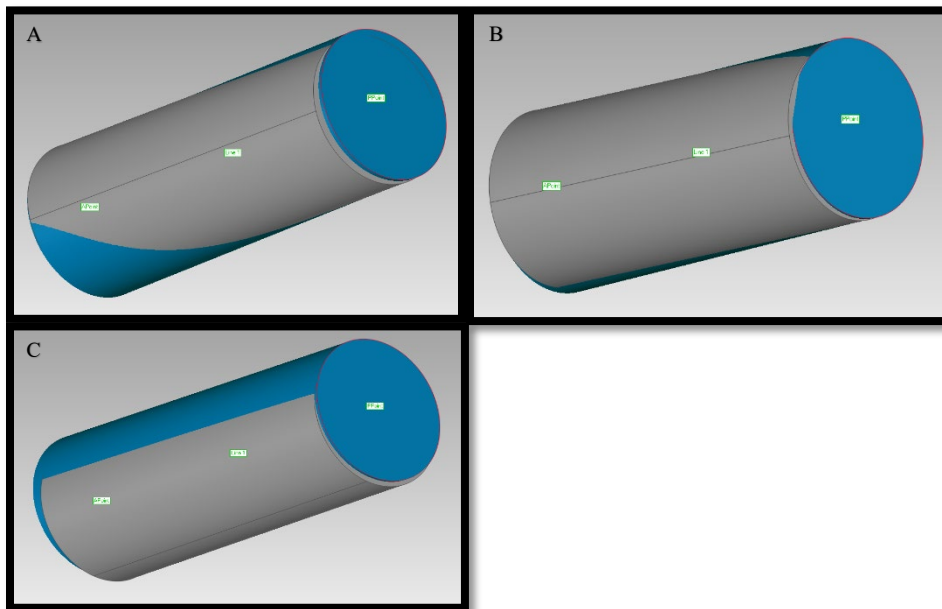


Figure 5. Geomagic Studio software created cylinder representing the presurgical plan (blue) and a post-surgical osteotomy best-fit cylinder (gray). (A) 5mm port length, (B) 7mm port length, (C) 10mm port length.

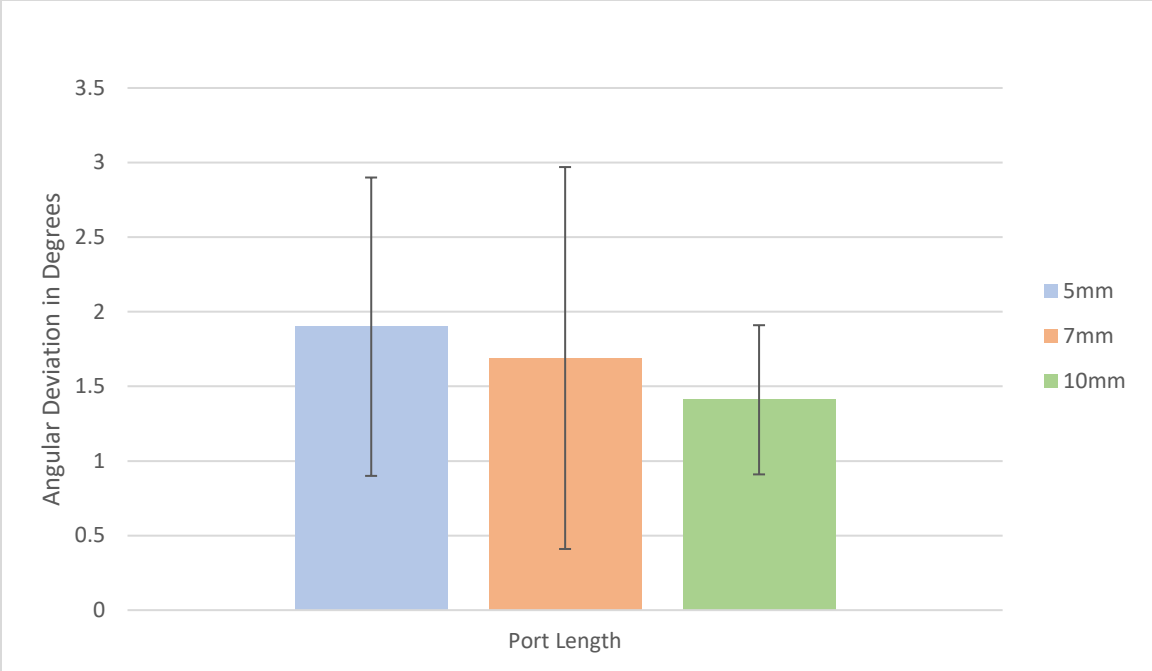


Chart 1: The means and standard deviations for angular deviation of the three different port length groups.

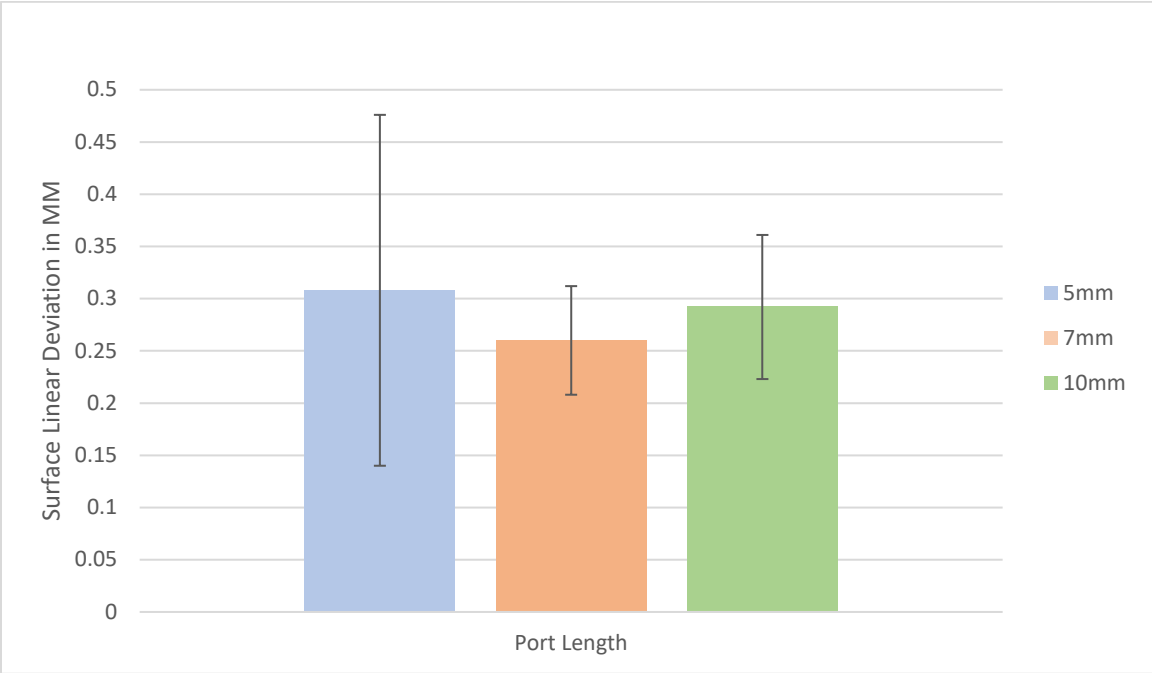


Chart 2: The means and standard deviations for linear deviation at entry of trephine of three different port length groups

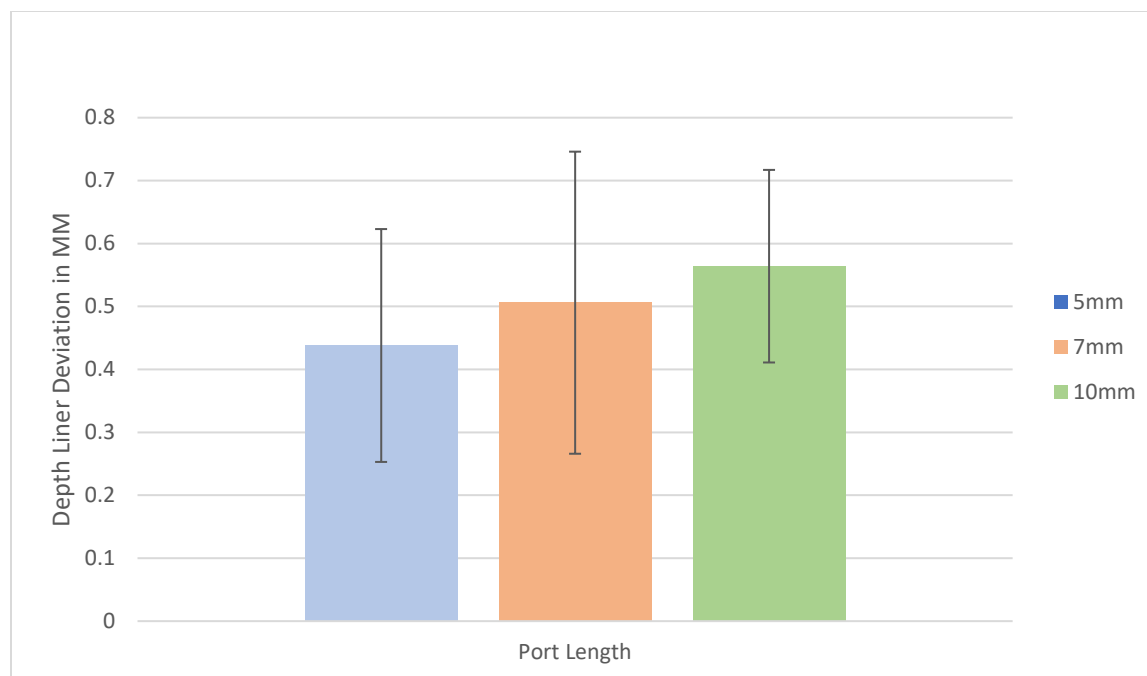


Chart 3: The means and standard deviations for linear deviation at depth of trephine of the three different port length groups.

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