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Targeted Endodontic Microsurgery: A Clinically Oriented Evaluation of Three 3D printers

Julie A. Anderson, James A. Wealleans, Jarom J. Ray

Introduction: This study assessed the performance of 3-Dimentional printers (3DPs) in producing guides for Targeted Endodontic Microsurgery (TEMS).
Methods: A pilot study determined print-product nuances for the Objet260 Connex3 (Stratasys Ltd, Austin, TX), Form2 (FormLabs Inc, Somerville, MA) and Duplicator7v1.4 (Wanhao, Zhejiang, China). Part I: A template with five cylindrical holes was designed and printed thirty times by each 3DP. The mean differences between the printed diameters and the design were subjected to univariate ANOVA and post-hoc Tukey's test. Part II: A maxilla from a successful published clinical case was printed with a cylindrical TEMS trephine path reproducing the actual clinical osteotomy and root end resection path. The same STL file used to print the original clinical guide was used to produce thirty guides (3DSGs) from each printer. Guides were seated and a cylinder precisely replicating trephine bur dimensions was inserted through the guide and into the osteotomy. If the guide dictated a path that did not allow for insertion to full depth of the trephine path, the stent was considered unacceptable. Data was analyzed using Fisher's exact test.
Results: Part I: The Objet260 had the lowest mean deviation from the design (0.044mm-0.067mm) followed by the Form2 (0.099-0.166mm) and the Duplicator7 (0.222-0.321mm). The differences were statistically significant ($p<0.0001$). Part II: All 3DSGs from the Objet260 and Form2 guided the cylinder to full depth. Only 22/30 (73.3%) 3DSGs from the Duplicator7 guided the cylinder to full depth, which was a statistically significant difference ($p=.0046$).
Conclusions: The Form2 and the Objet260 consistently produced suitable TEMS 3DSGs.

Introduction

Applications of three-dimensional (3D) printing appear in the endodontic literature for guided access, autotransplantation, and endodontic surgery (1-6). The majority of endodontic publications utilized patented, jetting-type printers such as PolyJet, MultiJet, or ColorJet (7). Jetting-type printers have been shown to be highly accurate, but their size and cost may be prohibitive to use in individual endodontic practices (8). Alternative technologies such as stereolithography apparatus (SLA) and digital light processing (DLP) printers have price points and size profiles more amenable to wide-spread deployment throughout endodontics (9). The Form 2 is an SLA printer costing about $3,500. The Duplicator7 is a DLP printer costing about $500 (Table 1).

Targeted Endodontic Microsurgery (TEMS) uses 3D printing to produce surgical stents capable of guiding a trephine bur according to exacting design specifications (10). A trephine is rotated within the guide port of a stent producing osteotomy, root end resection and biopsy in a single step (Fig 1). TEMS allows surgical access to anatomically challenging areas such as the palatal root of maxillary first and second molars. The TEMS guides from the original introductory publication were printed with an Objet260 Connex 3 PolyJet printer costing in excess of $120,000 (10). During TEMS a cylindrical trephine bur rotates at up to 900-1,200 revolutions per minute (rpm) with circumferential contact with a guide port (Fig 1). Similarly, during guided endodontic access a bur's path is dictated by external surface contact with a stent. To date there

have been no evaluations of jetting-type, SLA, or DLP printers for TEMS or guided endodontic access.

Previous engineering studies have evaluated printer accuracy for endodontic and non-endodontic applications by using a 3D scanner and software to compare the dimensions and volume of a printed part to its virtual design (11-14). These studies provide quantification of the relative conformity of a printer's product with the original design, but clinical acceptability is not necessarily established, as such studies do not define how much dimensional and volumetric deviation from the digital design will produce a clinically acceptable stent (12). Further, if a printer deviates from design dimensions in a consistent manner, adjustments to design can be made to render print products clinically acceptable.

A gap in knowledge exists in that the clinical acceptability of individual 3DPs for TEMS applications is unknown. The purpose of this study is to quantify conformity between design dimensions and printed objects for the Objet260, Form2 and Duplicator7 3DPs (Part I), and then to conduct a clinically-oriented assessment of the acceptability of TEMS stents produced by each of these printers (Part II). For Part II, the null hypothesis is that all guides printed by the three printers will be clinically-acceptable in this simulation model.

MATERIALS & METHODS

A pilot study determined printer/print-product nuances based upon printer mechanical functionality, cure method and type of resin.

Part I: Preliminary Accuracy Assessment

A template with five cylindrical holes of varying diameter was designed using Solidworks 2018 software (Fig 2). Hole diameters were chosen based on the ISO diameters of a friction grip bur (1.6mm), a latch-type (2.35mm), and three trephine burs (4.0, 5.0 and 6.0 mm). The standard tessellation language (STL) file was used to print thirty templates from each of the three printers according to manufacturer's instructions. The Objet260 requires proprietary MED610 resin (Stratasys Ltd, Austin, TX). In contrast, the Form2 and the Duplicator7 cannot use MED610 and so templates were printed with NextDent SG Resin (3D Systems, Soesterberg, Netherlands). Templates were post-processed according to manufacturer's instructions and then scanned by a benchtop scanner (3Shape D1000; Whip Mix Corp, Louisville, KY). GeoMagic Studio 2014 software was used to measure the diameters of the printed templates as in previous accuracy studies (12-15). For all 150 cylindrical holes, the absolute difference between the printed diameter and the virtual diameter was measured and the data was subjected to a univariate analysis of variance (ANOVA) and post-hoc Tukey's test.

Part II: Clinically-oriented assessment of TEMS stents

Experimental printed cast: Anonymized CBCT and STL files from Case 1 of the original introductory TEMS article for palatal root surgery of tooth number 2 were used to print a maxillary model (10). Prior to printing, the trephine path utilized in the successful surgery was applied to the model design to produce a 6 mm diameter cylindrical osteotomy and root-end resection of tooth #2 replicating the path that occurred in the successful clinical case. In this way,

a single model with a clinically ideal osteotomy was derived (Fig 3a). Based upon accuracy data from Part I the Objet260 was used to print the experimental model utilized during Part II.

Calibration determination for each printer: Each 3DP employs different data integration methods and printing mechanics and some printers require specific resin. Printed products conform to design software specifications to varying degrees based upon these factors. In order to understand the performance profiles of each test printer, multiple stents were produced and guide port diameters were adjusted within design software until the same trephine bur of known diameter interacted with stents from each printer in a consistent and reproducible manner. This allowed examiners to adjust design software diameter settings, taking into consideration each individual printer's distinctive performance characteristics. Resultant calibration port diameter increases for the Objet260, Form2 and the Duplicator7 were 0.05mm, 0.15mm and 0.3mm respectively.

Stent fabrication: The same STL file used in the original introductory TEMS article for tooth number 2 was used to print 30 surgical guides (3DSGs) from each of the three printers, applying calibration adjustments previously described using FreeForm2018 software (Fig 3b). Group 1: 3DSGs were printed with the Objet260 using proprietary MED610 resin. Group 2: 3DSGs were printed with the Form2 using NextDent SG resin. Group 3: 3DSGs were printed with Duplicator7 using NextDent SG resin.

Stent assessment: In order to avoid abrasion of the resin model osteotomy path by the cutting tip of the trephine during repeated insertion into the model osteotomy site, the trephine was measured with digital calipers and a rod precisely replicating the bur diameter was utilized. The rod had a 1 mm wide groove at one extent, indicating the proper insertion depth for a clinically acceptable stent. The two board-certified endodontists who pioneered the TEMS procedure tested the 3DSGs in the following manner. Each guide was placed on the model and complete seating was verified by inspecting the disto-facial cusp of tooth number 2 and the incisal edge of tooth number 9 for intimate stent contact. Finger pressure was applied to the stent and the rod was inserted through the guide tube. If the rod could be inserted to the full depth of the osteotomy (to the depth indicator groove) with desirable internal fit, the 3DSG was considered clinically acceptable (Fig 3c). 3DSGs that did not allow for complete insertion of the rod to the depth indicator groove, indicating either an errant osteotomy path, or an anomaly in the guide tube diameter, were designated as unacceptable (Fig 3d). Following testing, the rod was measured with digital calipers to ensure its diameter had not been reduced due to multiple passes through the guides. The data was then analyzed using a Fisher's exact test.

RESULTS

Part I

For all diameters tested, the Objet260 had the lowest mean absolute deviation from the digital design (.044mm-.067mm) followed by the Form2 (.099-.166mm). The Duplicator7 had the highest mean absolute difference for all diameters (.222-.321mm). The results of Part I are summarized in Table 2. Post-Hoc Tukey's test determined the mean absolute differences were statistically significant between all three groups for all five diameters tested ($p<0.0001$). There

was no apparent correlation between diameter size and mean absolute difference for any of the printers.

Part II

All 30 TEMS guides printed by the Connex 3 and all 30 TEMS guides printed by the Form2 successfully guided the rod to ideal osteotomy depth. In contrast, 22/30 (73.3%) of surgical guides printed by the Duplicator7 did not allow insertion of the rod to the ideal osteotomy depth, which was a statistically significant difference (p=.0046).

DISCUSSION

To our knowledge, this is the first investigation into the accuracy of 3DPs for TEMS. Previous studies comparing 3DPs for other dental applications have defined outcomes in terms of exact numerical measurements. In one study, there was no significant difference in replica teeth printed from a Fused Deposition Modeling (FDM) printer and a PolyJet device (14). Another study found that orthodontic models made from an SLA device had a statistically significant deviation when compared to PolyJet models only when a specific base geometry was used (13). Endodontic accuracy assessments demonstrated the Form2's acceptability for replicating extracted teeth (11) and the Objet260's suitability for guided access (2), but no previous endodontic studies have directly compared printers. There is no gold standard for evaluating these devices (16). Our model sought to simulate an actual clinical scenario documented in the endodontic literature in testing clinically relevant capabilities of the three printers (10). Thus, rather than merely comparing printed product measurements to design measurements, Part II of this study assessed each printer's ability to *consistently* produce a clinically acceptable guide.

Based upon dozens of TEMS clinical cases, the authors knew all printed port lumens require a diameter increase over trephine dimensions within design software in order to accommodate the trephine. The decision to perform a pilot study was based on the authors' previous clinical experience using the Objet260 for TEMS surgeries. During post-printing inspection and before use, clinicians verify that a trephine is able to penetrate the guide tube without resistance. If excessive resistance is encountered and the trephine is "forced" to pass, it may create an "altered" path with undesirable clinical implications. If a guide tube is excessively larger than the trephine, the osteotomy could deviate from the desired path. The calibration assessment for each printer was utilized to account for differences in print product dimensions for individual printers. If all printers were adjusted with the same tolerance, for example a 0.15 mm diameter increase over design, one printer could be privileged toward success or doomed to failure more than another based upon its functionality and the specific resin it used. If all printers were adjusted to the absolute mean from Part 1, the interaction of the trephine with the guide port still might not produce adequate clinical performance because of deviations from the mean along a lengthy port lumen. In the pilot study we started with values suggested by Part I and adjusted guide ports until desirable interaction with trephines repeatedly occurred, such that the trephine was guided with axial stability for reproduction of a "true" path. After several successive prints from each printer, a clinically-oriented tolerance was established. Therefore, Part II assessed each printer's ability to *consistently* reproduce clinically acceptable stents utilizing tolerances established in the pilot study.

Like the costly Objet260, the affordable Form2 showed consistency in printing clinically-acceptable 3DSGs for use in TEMS. Although the Duplicator7 produced clinically acceptable stents in the majority of cases, 26.7% of stents were unacceptable, showing a lack of consistency in lumen diameter that would prohibit clinical use. The results of Part I align well with results in Part II; the standard deviation for the 6.0mm diameter hole was much higher for the Duplicator7 (.058mm) than it was for either the Connex 3 (.021mm) or the Form2 (.035mm). This data predicted the lack of consistency of the Duplicator7 seen in Part II and the null hypothesis was rejected.

Printer specifications such as XY axis and layer thickness cannot be used for side-by-side comparison of devices because they do not account for a multitude of factors that influence the accuracy of the final product. Potential inaccuracies during stent fabrication can be introduced during data acquisition, design and fabrication (16,17). Product geometry, orientation, and even resin color may impact the quality of the printed product (18). The study could not control for effects of use of different resins as manufacturer requirements precluded use of the same resin in each printer. Further, these results should not be generalized to various models of PolyJet, SLA and DLP technical-type printers because of differences in data integration capabilities, mechanical functionality and cure source among various brands.

CONCLUSIONS

All printed stents deviated from template design dimensions to some extent. The Objet260 costing in excess of $120,000 and the Form2 costing about $3500 were able to *consistently* produce clinically-acceptable TEMS stents and represent clinically-viable 3D printing options for the specialty.

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