ORIGINAL PAPER

RJME
Romanian Journal of Morphology & Embryology
http://www.rjme.ro/

How accurate replicates the Thermafil System the morphology of the apical endodontic space? An *ex vivo* study

S. I. STRATUL[1)], ANDREEA DIDILESCU[2)], MIHAELA GRIGORIE[3)], EMILIA IANES[4)], D. RUSU[1)], LUMINIŢA NICA[5)]

[1)]Department of Periodontology, Faculty of Dental Medicine, "Victor Babeş" University of Medicine and Pharmacy, Timisoara

[2)]Department of Embryology

[3)]Department of Endodontics

Faculty of Dental Medicine, "Carol Davila" University of Medicine and Pharmacy, Bucharest

[4)]Department of Oral Surgery

[5)]Department of Endodontics

Faculty of Dental Medicine, "Victor Babeş" University of Medicine and Pharmacy, Timisoara

Abstract

Aim: To evaluate the morphology of the root canal in its apical third and the capacity of the Thermafil System to reproduce the entire morphology of the cleaned and shaped root canal. *Materials and Methods*: Thirty-two roots of periodontally compromised teeth were prepared using the ProTaper System to an apical size 30 and filled with the Thermafil obturation technique and sealer. The roots were surgically amputated and prepared for metallographic evaluation by incremental reductions of 0.5 mm each, starting with the apical foramen. Photomicrographs of each section were taken at a magnification of 500× and 100×. The images were analyzed and processed. The position of the apical foramen with respect to the anatomical apex was identified and marked. Additional morphological details as lateral canals and recesses were also recorded. The cross-sectioned area of the canal and gutta-percha, the total perimeter, the shaped perimeter and the filled perimeter were recorded for each sample and the results were expressed as percentages. Multiple images of successive sections were used to create a 3D reconstruction of the apical anatomy of the tooth. The ANOVA test was performed to assess mean differences between evaluations of perimeters/areas at different levels. *Results*: The anatomical apical foramen was found at the tip of the root in 50% of the evaluated samples. In the remaining samples, the foramen was located between 0.5 and 2.5 mm from the centre of the apex. Lateral canals, which opened in accessory foramens, were recorded in 25% of the evaluated samples. Statistical significant differences ($p<0.05$) were found between different levels of preparation and obturation. *Conclusions*: The complex morphology of the apical third of the root canal is satisfactory microstructurally replicated by the Thermafil System. Moreover, polarized light microscopy and the 3D reconstruction offered a discriminative vision of morphological details as lateral canals, recesses, the gutta-percha and debris.

***Keywords*:** root morphology, root canal preparation, root canal obturation, apical foramen, lateral canals.

Introduction

The complex anatomy of the root canal system presents a daunting challenge to the clinician who must debride and disinfect the "corridors of sepsis" [1] with absoluteness to achieve a successful treatment outcome.

Incomplete filling of the debrided and sculpted root canal space is one of the major causes of endodontic failure [1, 2]. Therefore, the complete obturation of the thorough cleaned and shaped pulp space with an inert filling material is the main and strongly anatomy-depending objective of the root canal therapy [3–5].

The apical third of the root canal system is known for its morphological complexity [1, 5]. According to the biological and mechanical principles of the endodontic therapy, this region has an overwhelming importance for the cleaning-shaping procedures and for the subsequent microstructural replication process [1, 3, 4].

The biological limit for the root canal preparation and filling is the apical foramen of the tooth. This limit does not always coincide with the tip of the root; in many cases, the apical foramen is situated more laterally and eccentric on the root surface. The literature suggests a distance between 0 and 3 mm from the center of the root apex, with predominance on the distal aspect of the root tip [5–13].

Because the apical foramen is the natural limit between the pulpal and periodontal tissue, its natural position on the root surface has to be conserved by the preparation technique employed, e.g. any transportation or excessive enlargement has to be avoided, and the canal orifice has to be sealed by the filling materials. Therefore, the accurate identification of the initial natural foramen is of outmost importance in the root canal therapy planning.

Other morphological features of the root canal system, often observed in the apical area and relevant for the success of the treatment are the accessory and/or lateral canals, apical deltas, fins, loops, apical ramifications, isthmi, areas of resorption and repaired resorption [5–13]. Lateral canals extend from the pulp to the periodontium and occur in 73.5% in the apical third of the root canal. They usually open on the external surface of the root at different levels, in orifices known as "accessory foramens" [5, 8]. Such areas usually harbor debris, biofilm and bacteria, which entails the carefully removal by the mechanical preparation, by the irrigation protocol and a proper filling technique with adequate root canal filling materials.

Since its introduction in endodontics, in 1867, by Bowman, as a root canal filling material, gutta-percha has proven to be the most commonly used root canal obturation material [1, 3]. Thermoplasticized gutta-percha is able to replicate the internal structure of the cleaned and shaped root canal, resulting in homogenous, voidless, root canal fillings. Introduced in the beginning of nineties, the Thermafil obturators derived from a technique developed in 1978 by Dr. W. B. Johnson, in which alpha-phase gutta-percha was placed on a metal carrier, heated and used to obturate the root canal [14]. Three types of Thermafil obturators were available, and their difference was based on the carrier material for gutta-percha, which was stainless steel, plastic or titanium. Today, plastic carriers are used, and Thermafil obturators are completely modified, in order to form a complete system for root canal obturation, which is documented to result in optimal root canal fillings, when correctly used [15, 16]. Radiographic evaluation and leakage evaluation studies [17–19] have shown that gutta-percha coating the core carrier has a good adaptation to the root canal walls, providing a better seal than with the lateral gutta-percha compaction technique.

The purpose of this study was to evaluate the micro-anatomical details involved in the microstructural replication process and the values of gutta-percha-related parameters (area and perimeter of the filling and debris, respectively), by using serial sections.

Materials and Methods

Thirty-two roots of periodontally compromised human teeth (three incisors, one canine, seven premolars and 21 molars) with indication of extraction with relatively straight canals (degree of curvature $<20^0$) and mature apices, as determined on the preoperative periapical X-rays, were cleaned and shaped *in vivo* with ProTaper® Universal System (Dentsply Maillefer, Baillagues, Switzerland) NiTi rotary files, under irrigation with 5.25% NaOCl and 17% EDTA, to a size 30.09 taper at the apex, creating a continuous taper preparation. All patients signed an informed consent. The study was approved by the Commission on Bioethics of the "Victor Babeş" University of Medicine and Pharmacy, Timişoara. All procedures were performed under the dental operating microscope OPMI Pico (Carl Zeiss AG, Oberkochen, Germany). A #30 Thermafil verifier was used to check the size of the canal and the choice of the adequate Thermafil obturator. Canals were obturated with AH Plus (Dentsply Maillefer, Baillagues, Switzerland) root canal sealer and the obturator, which fitted to the size of preparation (size 30). The Thermafil Plastic Obturator (Dentsply Maillefer, Baillagues, Switzerland) was heated in a Thermaprep Plus Oven (Dentsply Maillefer, Baillagues, Switzerland) according to manufacturer's instructions and inserted to the working length with firm apical pressure within 8–10 seconds. A round Thermacut bur (Dentsply Maillefer, Baillagues, Switzerland) at high speed was used to cut the plastic shaft at the desired level. The excess of gutta-percha was removed and the gutta-percha was vertically compacted with a plugger along the shaft, to ensure a better sealing at the coronal orifice of the canal. The access cavities were restored with fast setting glass ionomer restorative (ChemFil® Molar Caps, Dentsply DeTrey GmbH, Konstanz, Germany).

The single rooted teeth have been extracted and the pluriradicular teeth underwent amputation during flap surgeries, at intervals exceeding two weeks after the completion of the endodontic therapy, so as to ensure the setting of the filling materials. All roots were cleaned to remove debris, soaked for 5 minutes in 5.25% NaOCl and stored in distilled water containing thymol crystals.

The position of the apical foramen was identified and the distance between the centre of the root apex and the foramen was measured for each sample under the dental operating microscope. The location of the foramen was marked on the root surface as starting point for the reduction procedure. Afterwards, each sample was vertically embedded in an epoxy resin (Leica HistoResin, Leica Instruments GmbH, Heidelberg, Germany) and included in cylinders to facilitate manipulation and improve the metallographic-type preparation. Each sample was incrementally reduced by horizontal grinding in a WIRTZ Phoenix 4000 (Wirtz–Buehler GmbH, Düsseldorf, Germany) rotary grinding device for polishing metallographic samples, starting from the marked apical foramen, at six different levels of 0.5 mm each, using specific sandpaper discs for metallographic preparation, under copious water irrigation to avoid overheating.

The protocol for progressively reducing the examined samples was a development of the protocol described by Donath K and Breuer G, in 1982, for bone-implants samples [20], in which the sections were obtained by slicing in a hard-tissue microtome. The histological procedure was modified to result in perfectly clear sample surfaces, free of scratches and deformities. Fine sandpapering was used to eliminate deformities, and the specimens were polished and then degreased with alcohol and water and dried with filter paper to obtain highly reflective surfaces, which were examined under the microscope.

Each serial section was examined under a metallographic microscope (Olympus BX51, Olympus Europe Holding GmbH, Hamburg, Germany), in normal and in polarized light, at 100× magnification and photographed, and under the stereomicroscope (Leica MZ6, Leica Microsystems GmbH, Wetzlar, Germany). Morphological details as lateral canals, recesses and accessory foramina were especially observed and recorded under a 500× magnification. Images were captured by an Olympus CAMEDIA C–3040 digital compact camera (Olympus Imaging America Inc., Center Valley, PA, US) at each 0.5 mm, resulting six levels of observation, which were photographed and then digitally processed. Image analysis and processing were completed using Olympus DP – Soft 3.1® software (Olympus Europe Holding GmbH, Hamburg, Germany) and the AutoCAD 2002 Programme (Autodesk® US). The cross-sectioned area of the canal and the gutta-percha, the total perimeter of the canal, the shaped perimeter and the filled perimeter were recorded. Based on these primary data, the percentage of filled area (PFA), percentage of shaped perimeter (PSP), and the percentage of filled perimeter (PFP) were calculated. Sealer, gutta-percha and carrier were considered together as a homogenous mass of filling material, which was measured as "filled area". Only the voids of the filling mass in contact with the root canal walls were taken into consideration and were calculated as empty areas.

The three-dimensional anatomy of the root canal in the last apical third was digitally recomposed by processing the bi-dimensional images, using Solid Works 2005 Software (Dassault Systèmes SolidWorks Corp., Concord, MA, US).

Statistical analysis

Mean values and standard deviations (SD) of measurements were calculated. One-way ANOVA test (*post-hoc* Scheffe) was performed to assess mean differences between evaluations of perimeters/areas at different levels. Stata 11C statistical software (StataCorp LP, Texas, USA, version 2009) was used for data analysis. A p-value <0.05 was considered statistically significant.

Results

The apical foramen was located at the centre of the root apex in 50% of the evaluated samples. In 28.12% it started at 0.5 mm from apex, in 3.12 % at 1 mm, in 9.37% at 1.5 mm, in 6.25% at 2 mm and only in 3.12% at 2.5 mm.

Recesses and lateral canals were observed in 25% of the examined sections, reflecting the complexity of the root canal morphology in its apical third (Figure 1); all lateral canals were found in the amputated roots of the upper or lower molars included in this study. They usually appeared at the second level of observation and disappeared at level five. In two samples only, lateral canals were observed beyond this limit, up to the last observation level. The lateral canals were longer in the levels closer to the apex, but decreased in size and length as approaching to the last level of observation (Figure 2).

The mean value of the apparent perimeter on the sections of all observed lateral extensions of the canals was 617 μm. Seventy-five percent of the examined lateral canals were partially filled with gutta-percha and sealer up to the apparent half of the canal. The remaining space was either filled with debris and biofilm or empty, which emphasizes the efficacy of the irrigation.

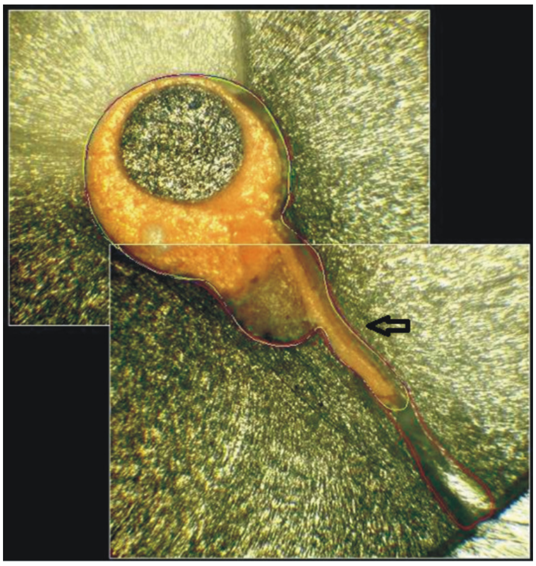

Figure 1 – ***Composed image of a section, polarized light, ×100 (arrow: lateral canal). The lateral canal is partially filled with gutta-percha and partially empty or filled with debris.***

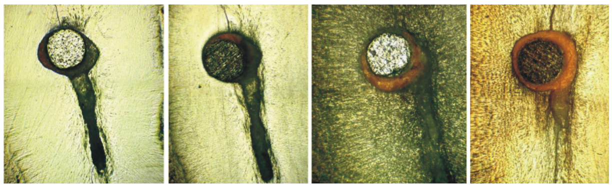

Figure 2 – ***Lateral canal in the apical third of the root, observed at four subsequent levels (2–5), normal light, ×100.***

Although the majority of the evaluated samples had a circular shape, oval canals flattened in bucco-lingual direction were observed (Figures 3 and 4) in 32% of the samples, predominantly in the lower molars and in the lower premolars (Figure 5).

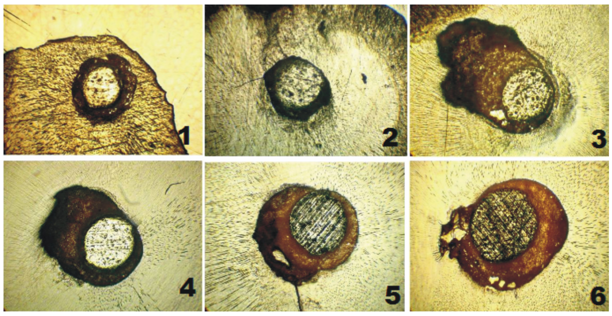

Figure 3 – ***Incremental series of cross-sections of a sample, normal light, ×100. 1–6, levels of observation.***

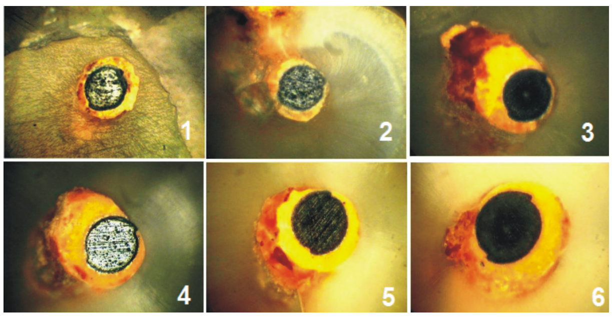

Figure 4 – ***The same sections, polarized light, ×100.***

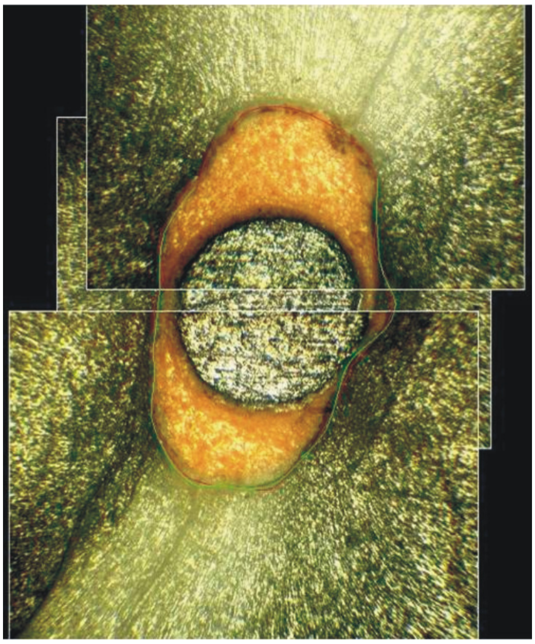

Figure 5 – ***Composed image of an ovoid root canal, polarized light, ×100. The morphology was fairly reproduced by the Thermafil System.***

The observed complicated root canal morphology was nevertheless satisfactory reproduced by the Thermafil system in the obturation process (Figures 5 and 6), as recorded data show.

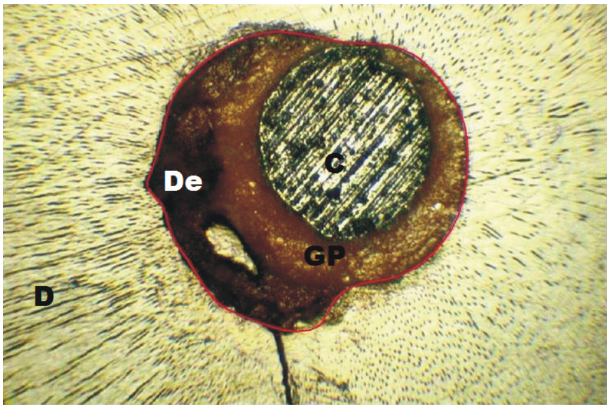

Figure 6 – ***A representative cross-section of a sample at 2.5 mm from the apical foramen (level 5), normal light, ×100. D – dentin, De – debris, GP – gutta-percha, C – carrier.***

The mean percentage of the shaped perimeter (PSP) compared to the total root canal perimeter (TP) varied from 21% at 0.5 mm from the apical foramen (level 1) to 66% at 2.5 mm back from the first reading level (level 6). A similar increasing was observed for the filling material. The mean percentage of gutta-percha filled area (PFA) varied from 45% to 92%, while the mean percentage of the filled perimeter (PFP) in contact with the root canal walls varied between 86% and 95%.

The mean shaped perimeter (SP) constantly increased from level 1 to level 5 of observation. An increasing trend was also observed for the mean filled perimeter (FP) and the mean total perimeter (TP) (Table 1). At level 6, the mean values fall abruptly in all these three parameters. The differences of mean values of these three parameters between each level are represented as a graph in Figure 7.

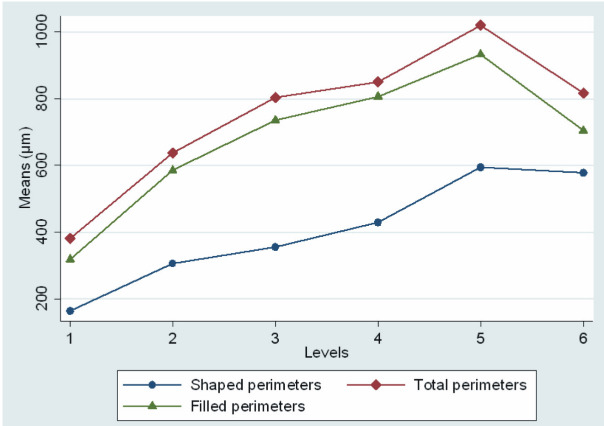

Figure 7 – ***Graph with the mean values of SP, FP and TP. Note the abrupt fall of the mean values between levels 5 and 6.***

Both the mean values of the gutta-percha filled areas (FA) and the total areas (TA) of the root canal increased from level 1 to level 4, where both areas had the highest values (Table 1).

The mean values of the FA decrease statistically significant to at level 5 and at level 6, respectively ($p<0.05$). The mean TA also decreased to level 5 and level 6. Figure 8 is a graphic representation of the mean differences and the standard deviations between subsequent levels for the filled area and the total area of the root canals.

Table 1 – ***Mean values of the shaped perimeter (SP), filled perimeter (FP), total perimeter (TP), filled area (FA) and total area (TA) of the samples at six subsequent levels (n=32)***

Section level	SP [µm]	FP [µm]	TP [µm]	FA [μm^2]	TA [μm^2]
1 (0.5 mm)	163.2	318.43	380.47	21703.13	25081.19
2 (1.0 mm)	306.24	585.34	637.66	40628.56	44302
3 (1.5 mm)	355.55	735.82	804.5	52697.59	55932.25
4 (2.0 mm)	428.77	806.76	850.56	288213.2	289501
5 (2.5 mm)	594.64	933.26	1019.90	80260.99	82704.28
6 (3.0 mm)	577.85	705.16	817.86	54654.91	57710.55

Discussion

The apical region of the root is known for its variability and unpredictability [5]. Knowledge of the morphological complexity of the canal system and the precise location of the apical foramen are basic requirements for endodontic success. One of the results of the present study showed that only half of the evaluated teeth had the apical foramen in a centered position at the tip of the root.

In all other samples, the foramen was situated more laterally and eccentric; the distance varied from 0.5 mm to 3 mm, as mentioned in literature [5, 8, 10–13].

In the present study, lateral canals in the evaluated apical third were predominantly found in the roots of maxillary or mandibular molars and in premolars. Their length was better represented closer to the apex, probably due to the intersection of the canal trajects with the sectioning direction. This finding has the significance of the membership of these canals in the apical delta group, rather than in the main root section, which is in accordance with the classical distribution as postulated by Vertucci FJ [5, 8].

Variations in canal geometry before cleaning and shaping procedures influence the changes that occur during preparation more than the instrumentation techniques themselves [21–24]. Peters OA *et al.* [21] found that more than 35% of the root canal area remained untouched by the endodontic instruments, because they are unable to contact all of the recesses present along canal walls. In fact, the apical region of the root canal was found with the least amount of preparation during instrumentation [22].

In our study, the endodontic instruments could not reach during the shaping process the total perimeter of the root canal as well, especially in ovoid canals and in canals with recesses, so the shaped perimeter was always shorter when compared to the total perimeter of the root canal, and its mean percentage varied from 21.04% at 0.5 mm from the apical foramina (level 1) to 65.75 % at 3 mm (level 6).

The finishing files of the ProTaper Universal system display a common taper in the last 4 mm of the file (9% taper – F3 file), which in the vast majority of situations corresponds to the length of the apical third of the root canal space. Yet, because of its complexity, the internal micro-morphology of the apical third cannot be entirely shaped by the working file [23].

In the present study, the mean values of the shaped perimeter, the filled perimeter and the total perimeter of the root canal are constantly increasing from level 1 (0.5 mm) to level 5 (2.5 mm) (Table 1). However, at level 6, the mean values recorded in our study fall abruptly in all three parameters. These apparently inexplicable findings are statistical significant more frequent between levels 5 and 6 ($p<0.05$), and they are present in 16 out of the 32 samples (50%).

As the calculated areas of the cross-sections follow the same decreasing pattern, the findings indicate a real morphological issue, which may be explained by the complexity of the anatomy of the canalar system, which, in many cases, displays an irregular shape, with recesses followed by narrow spaces, as shown by Vertucci FJ [5]. Thus, a relative discontinuity of the funnel-like natural canal taper should be taken into account when shaping the apical third of the canal. A possible discrepancy between the geometry of the Thermafil system and that of the ProTaper System may have intervened, suggesting that a hybrid shaping technique may be useful for the preparation of the last 2.5 mm of the root canal [24, 25]. On the other hand, the literature refers relatively frequently to the reverse tapering of the prepared root canal beyond moderate curvatures, due to extended shaping procedures which may entail transportation of the entire canal [26].

Although not all the portions of the root canal are reached by the endodontic instruments, the simultaneous use of different irrigation solutions will access and clean these areas, by removing the remaining debris, leaving regions of clean, although unprepared canal walls [27, 28]. Eventually, they will be microstructurally replicated by thermoplasticized gutta-percha, involving that even if the root canal is not 100% prepared by the endodontic instruments, it can be satisfactory obturated.

In the present study, gutta-percha of the Thermafil obturator reached the above mentioned regions as well, so the mean percentage of the filled perimeter when compared to the total perimeter of the root canal varied from 96.85% in its most apical part, to 85.97% at 3 mm. The differences between the mean values of the shaped perimeter, which were smaller when compared to the filled perimeter of the canal (Figure 7), could be explained in the same way.

When comparing the cross sectional area of the root canal filled with gutta-percha to the total area of the root canal at one level, the percentage varied from 45.05% to 91.65%.

The mean values of the gutta-percha filled areas (FA) and the total area (TA) of the root canal increased from level 1 to level 4, where the areas had the highest values. When compared to the sharp fall of the mean perimeters mainly between level 5 and 6, the total and obturated areas display a more scattered pattern of decrease, which includes level 5 and 6 (Figure 8).

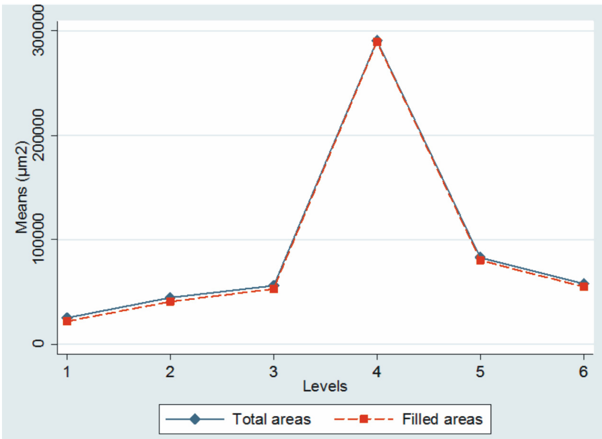

Figure 8 – ***Graph with the mean values of TA and FA. The transition between level 4 and level 5 marks a sharp decrease of the data.***

Usually, coated carrier systems are designed to optimally adapt to root canal preparations made with NiTi rotary instruments with the same size and taper (Thermafil + ProFile ISO, GT Obturators + GT Instruments, etc.). For the Thermafil System, the size of the obturator is determined in accordance with the “best fitting” verifier [29–32]. Although manufacturers are continuously developing new instrumentation/obturation systems, little published data exist regarding the adaptation of coated carriers in root canal preparations made with NiTi rotary instruments [16, 28–31] and on the impact of the primary anatomic features of the canal on the adaptation of the filling.

In our study, the Thermafil System was used to fill the cleaned and shaped root canal after using the NiTi rotary ProTaper System. Although a lack of congruence between this preparation system and the taper of the obturator (including possible collateral anatomic deviations of the canals) can occur, by using the heated gutta-percha and appropriate procedures the shaped space can be satisfactory filled. However, as our results showed, significant anatomic details of the un-processed apical canal walls may remain untouched by the instruments and un-filled. This is in accordance with several studies in the literature [24–26].

Moreover, the morphological deviant details may retain debris, which are commonly believed to impair the long-term results of the endodontic therapy. In our research, the debris accumulated in the un-processed spaces appears as dark-brownish-cloudy areas, better visible in polarized light (Figures 1 and 4).

The Thermafil System, which has been chosen in this research for filling the root canal space, as being less time consuming and more convenient as overall handling, acts by inserting a homogenous mass of gutta-percha in the root canal, up to the working length, with a better core/sealer ratio than achieved by the method of cold lateral compaction [18, 19, 33–37]. However, the literature is not consensual: comparative *in vitro* leakage studies between carrier systems and cold lateral compaction techniques showed that these systems might [33, 34] or may not offer [38, 39] a better seal of the root canal.

In fact, the purpose of the present study was not to compare the Thermafil technique with other filling techniques, but rather to evaluate the percentage in which the gutta-percha mass of the carrier is reaching, filling and microstructurally reproducing the entire internal complex anatomy of the apical third of the root. Furthermore, the research assesses the sealability of the apical foramen, of the lateral canals or accessory foramens. In oval and irregular canals, this technique proved to be efficient in the replication of the natural morphology of the root canals, as well.

In the present study, a method of computer-aided analysis of incremental cross-section digitalized images was supplementary employed to describe the morphology of the root canal and the quality of the obturation (Figure 9).

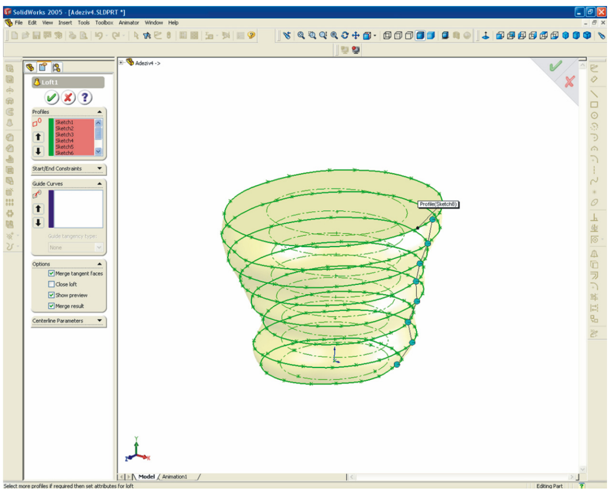

Figure 9 – *Recomposed 3D-image of the last apical 3 mm of the root canal.*

The method has the advantage of being highly descriptive in analyzing the anatomical details of the endodontic space and in the evaluation of the root canal filling. Future studies are necessary to compare the current data with data obtained from *in vitro* studies or with data regarding other systems or filling techniques. The results of endodontic procedures performed *in vivo* under the dental operating microscope, such as in the present study, seem to better reflect the reality than *in vitro* experimental studies, despite clinical difficulties and some ethical issues.

Conclusions

The findings of the study bring additional evidence to support the literature data, in which the apical foramen is most often located at a distance between 0.5 and 3 mm from the centre of the tooth apex, with major impact on endodontic procedures.

The *ex vivo* study revealed a relatively good ability of the Thermafil System to reproduce the otherwise complicated natural morphology of the root canal in the last apical 3 mm. Computer aided analysis of incremental cross sections proved to be a highly-descriptive method and a valuable tool to evaluate the morphology of the root canal and the quality of the obturation, especially when 3D data are obtained.

The irregular and oval canal shape, the lateral canals and recesses, as resulted from the study, seem to necessitate a closer morphological analysis, in order to become therapeutically relevant. The present study can be refined by diversifying and improving the standardization of the samples, according to the type of tooth, the degree of curvature, etc.

Acknowledgements

This study was funded by the Romanian National Centre for Research Programs Management (CNMP) within the Research Project No. 41–034.

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Corresponding author
Ştefan-Ioan Stratul, Senior Lecturer, DMD, PhD, MS, MDiv, *Medicus Primarius*, Department of Periodontology, Faculty of Dental Medicine, “Victor Babeş” University of Medicine and Pharmacy, 9 Revoluției Avenue, 300070 Timişoara, Romania; Phone +40744–521 470, e-mail: sbs@online.ro

Received: November 10th, 2010

Accepted: January 25th, 2011