SHORT THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY (PHD)

The effect of root canal morphology on the quality of root canal enlargement and root canal filling

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1. Introduction

The main goal of the root canal treatment is to prevent the propagation of the microorganisms from penetrating beyond the apex and to cure the periapical inflammatory processes caused by these microorganisms. The most important means of prevention is to reduce the number of bacteria inside the main root canal system including in the surrounding dentinal tubules by root canal cleaning and shaping procedures and then to create a proper seal between the root canal wall and the root canal filling material to prevent bacterial mikroleakage.

The tooth and root canal morphology is a complex description of the root curvatures and possible pulp anastomoses inside. There have been many classifications of root canal morphologies. One of the easiest and most relevant methods is the Schneider classification. In our fluid filtration and micro-CT studies we used this classification to clearly distinguish between the straight and curved human root canal experimental groups. In our other study where the apical transportation was measured, however, the fourth degree polynomial approximation computer graphic classification was relevant for classifying root canals (Nagy et al. 1995).

Root canal instrumentation is strongly affected by canal configuration with studies showing morphology to be highly influential on the efficacy of canal preparation. Frequency and magnitude of canal aberrations (e.g., zip, elbow, perforations, and asymmetric preparation) have been proven to be more prominent in curved root canals than straight ones. The convex wall of the apical portion of a curved root canal may be over-instrumented, removing excess dentine. The concave wall may be untouched (Zuolo et al. 1992), creating apical transportation (AT). More recently, Wu et al. (2000a) found a statistically significant negative effect of apical transportation (AT) on the seal of the root filling.

Leakage along root fillings may increase or decrease with time. Sealer dissolution may result in more leakage (Kontakiotis et al. 1997) whereas swelling of the gutta-percha may result in diminished leakage (Wu et al. 2000b). Sealer coverage of the root canal after lateral compaction of gutta-percha was approximately 50% (Wu et al. 2000c) with the result that its physical and chemical properties, such as the thickness of the sealer layer, may also play an important role in sealing the root canal (Wu et al. 1994). Sealapex (Kerr Manufacturing Co., Romulus, MI, USA) had significantly more leakage after being stored in water for one year than other sealers (Wu et al. 1995). After storage in water for two years there was no significant difference between Sealapex and Pulp Canal Sealer, but sealers containing zinc oxide had more leakage than Sealapex when applied in a thick layer (Kontakiotis et al. 1997).

X-ray microfocus computed tomography (micro-CT, MCT) has been extensively applied as a reliable methodology for the quantitative evaluation of root canal instrumentation. For the evaluations the following parameters have been used to characterise the quality of root canal instrumentation: surface area change (ΔA), volume change (ΔV), Structure Model Index change (ΔSMI). The ΔSMI parameter refects the cross-sectional change in the root canal after instrumentation, measured by three-dimensionally (3D). The natural root canal has concave and convex surface irregularities. For root canals one can expect that the SMI value change after instrumentation reflects both oval to round cross-sectional transformation and the smoothing of the root canal walls. The root surface area (A) and root volume (V) have been proven to be demonstrative of the canal shape, both pre- and post-instrumentation. However, when compared with experimental groups, contradictory results have been found in the changes of these parameters (ΔA and ΔV). A micro-CT study reported no significant differences regarding the three-dimensional parameters of root canal preparation while on the same teeth most of two-dimensional (2D) parameters delivered statistically significant differences between groups. These results raise a question about the usefulness of three-dimensional parameters describing canal changes during enlargement. The cross-sectional shape of a straight resin root canal is round but the enlargement shows that even in this simplified morphology the operator usually prepares one side of the root canal wall more effectively than the others. Consequently, the cross-sectional shape of prepared artificial root canals changed from regular to irregular, resulting in eccentricity. This finding was also reflected in the trend of the determined form factor and roundness values. These two-dimensional parameters should also be tested on simulated canals.

2. Objectives

1. In our thesis we would like to determine how the root canal form could influence root canal preparational errors (AT) in the case of step-back enlargement with Flexofile hand instrument
2. We would like to determine with fluid filtration method whether the root canal form or the root canal filling sealer property has a bigger impact on the long term sealing ability of the root canal filling material.
3. We want to determine if a multiple variable analyitical statistical test (π*) is suitable for the longitudinal (1 year) analysis of the root canal filling sealer degradation.
4. We will try modelling three-dimensionally how the SMI value changes during the applied enlargement sequences.
5. In our thesis we will try to prove that the ratio we used first for morphological comparative analysis in micro-CT measurement studies (delta A/deltaV) is a more useful parameter than the SMI values.

3. Materials and methods

3.1. Apical transportation (AT) measurements

3.1.1. Root canal enlargement and filling

Forty human teeth with a single canal and patent foramen were selected for the investigation. The teeth had been stored in buffered formaldehyde solution (pH 7.25) before they were used. Each tooth was embedded in a 15* 15* 20 mm resin block. Two stainless steel markers with different diameters were embedded at the corners of each resin block. After access preparation and extirpation of pulp remnants, a size 15 K-file (Dentsply Maillefer, Ballaigues, Switzerland) was inserted into each root canal and digital radiographs (RVG, Trophy, France) were taken from both a buccal and proximal view. On the basis of their radiographic images, the teeth were divided into two groups of 20 straight and 20 completely curved root canals according to a fourth degree polynomial approximation computer graphic classification (Nagy et al. 1995). Root canals were cleaned and shaped by one operator using Flexofiles (Dentsply Maillefer) and a stepback technique. The master apical file size was 30 and the canal was flared using a size 45 file. Copious irrigation was provided with 2.6% sodium hypochlorite solution (Hystolith, Lege Artis, Dettenhausen, Germany). To achieve patency a size 10 K-file was inserted into each root canal 1 mm through the apex. A final flush of 5 mL sterile saline solution was used.

The groups containing 20 roots were divided in two subgroups (n = 10) to test the two different types of sealer. The sealers were the calcium hydroxide containing Sealapex (Kerr Manufacturing Co., Romulus, MI) and the zinc oxide–eugenol (ZOE) containing Pulp Canal Sealer (Kerr Manufacturing Co.). The root canals were filled with one or the other of the sealers and lateral compaction of gutta-percha. The apical part of the master gutta-percha cone size 30 was coated in sealer and placed into the canal. Lateral compaction was commenced using a size A finger spreader (Dentsply Maillefer) and auxiliary gutta-percha points of identical sizes (Dentsply Maillefer). Excess gutta-percha was removed with a hot instrument. All of the roots were kept at 20 C (100% humidity). The cleaning and shaping procedures and root canal fillings were performed by one operator. The created groups are:

1. group: straight canal with Sealapex

2. group: curved canal with Sealapex

3. group: straight canal with Pulp Canal Sealer

4. group: curved canal with Pulp Canal Sealer

3.1.2. Radiological assessment of preparational error (AT)

Two-positional postoperative digital radiographs were taken as before. Transportation created during canal preparation was identified by the superimposition of pre- and postoperative radiographs. Superimposed, standardized 1:10 projections of the original canal path and the filled canal in m-d and b-l views were used to evaluate the difference in shape between the filled and the original canal. Accurate location and superimposition of the radiographs in both views was facilitated by the presence of two markers at the corners of each block. The radiographic assessments included measurements of the prevalence and the determination of apical transportation (AT). The determination of AT was expressed by the maximum asymmetry of preparation using the method described by Nagy et al. (1997b). Briefly, the measurements were carried out perpendicular to the axis of the original canal, using the method described by Briseno et al. (1993). The original canal width was divided into two halves, thus defining a point of the canal axis, which served as a reference point for the measurement of asymmetry. Asymmetry (expressed as an absolute value) was calculated by the subtraction of the left from the right canal width on either side of the reference point. The canal width changes were measured at 10· magnification to the nearest 0.1 mm using a ruler.

3.2. Fluid transport measurements

After complete setting of the root canal sealers (the setting time of Pulp Canal Sealer is 6 h and for the Sealapex is 40 min) the teeth were decoronated to obtain a 10 mm root length. The outer surface of the roots was modified for the fluid transport investigation in the following way: a highspeed water-cooled handpiece with a diamond fissure bur was used to create a more circular outline of the roots. The method used to measure fluid transport was as described by Wu et al. (1993). The set-up was placed in a water bath (20 º C) and the air bubble was adjusted with a syringe to a zero position within the microcapillary tube. A headspace pressure of 1 atm. from the inlet side was applied to force the water through the voids along the filling, thus displacing the air bubble in the capillary tube. The volume of the fluid transport was measured by the movement of the air bubble, the results were recorded in µL day) . The measurements were taken immediately after the setting of the sealer and repeated at 1, 3, 9, and 12-month intervals. The seals of the root fillings were categorised according to Wu et al. (1993).

1. 0–0.4 µL day) (score 1)

2. 0.4–20 µL day) (score 2)

3. more than 20 µL day) (score 3)

One-way anova and Duncan's multiple range tests were used for a statistical analysis of the AT values. The power of the sample was determined as described by Schuurs et al. (1993). The microleakage results in relation to the two different materials and root canal forms during the 1-year experimental period were analysed with the help of the π* index (Rudas et al. 1994). This method is an alternative to a classical loglinear analysis and is also useful for small samples.

3.3. Micro-CT investigations

3.3.1. Sample selection and pretreatment

Ten each straight and curved root canals with mature apices were selected from forty-three extracted human upper incisors and canine teeth due to severe bone loss for the study. Schneider's classifcation was used as the grouping criterion, where root canals with 25∘ curvature were designated as straight and curved, respectively. Teeth with mature apices having one main root canal without obliteration were included. Teeth having between 11∘ and 24∘ curvature were excluded. Pulp remnants were removed from each root canal using barbed broaches without any canal preparation. The teeth were then stored in 0.1% thymol solution.

3.3.2. Root canal preparation of natural human teeth

All of the twenty chosen root canals were prepared using the ProTaper Universal (Dentsply-Maillefer, Switzerland) protocol with a torque-controlled, constant speed endomotor (Technika, Dentsply-Maillefer, Switzerland). SX shaping file was used frst to provide an initial flare to the orifces. An ISO 10 K-reamer (Dentsply-Maillefer, Switzerland) was used with light downwards "watch winding" motion to determine the overall working length, which was calculated by subtracting 0.5 mm from the length reading when the tip was just visible at the main apical foramina of a root. ProTaper Universal rotary files (both shaping and finishing) were then used in "pecking" motion in the following sequences: S1 and S2 were advanced to resistance but no more than two thirds of the canal depth; SX was then introduced into the canal in “brushing” motion to 3-5 mm short of the working length followed by the use of S1 and S2 at the working length; and finally F1 and F2 finishing files were used at the working length. Histolith 2.5% NaOCl solution (Lege Artis, Germany) was used for irrigation with a 31-gauge needle after each file use and 30 ml in total was used for each root canal. Glyde (Dentsply-Maillefer, Switzerland) was used as lubricant, with the amount enough to cover all the flute area of each file. Canal recapitulation was also performed after the use of each fle. Files were regularly wiped using wet gauze to remove debris. A final flush was carried out using 5 ml sterile saline solution before drying with F2 ProTaper paper points (Dentsply-Maillefer, Switzerland). All instrumentation was performed according to the manufacturer’s instructions. In order to reduce interoperational variability all preparation was conducted by the same operator. In order to reduce contamination, only one set of instruments was used for the preparation of one canal.

3.3.3. Preparation of simulated canals

Twenty transparent resin simulated root canal blocks were used to assess the ProTaper instrumentation, amongst which ten were straight (A-ETK-0 endotrainer, Frasaco, Tettnang, Germany) and ten were curved with a curvature of 30∘ (A-ETK-30 endotrainer, Frasaco, Tettnang, Germany). Root canal preparation was carried out in the same way as was described for natural human teeth except that Glycerine was used as lubricant instead of Glyde.

3.4. Micro-CT scanning of the samples

All samples, both natural human teeth and resin simulated root canal blocks, were scanned before and after instrumentation with a desktop X-ray microfocus computed tomography scanner (SkyScan 1172, Bruker, Kontich, Belgium) at 10 W, 100 kV, and 98 μA, with a 0.5 mm aluminium flter, resulting in an isometric voxel size of 9 μm. During data acquisition, 2D projections through 180∘ of rotation were stored in digital format on an electronic medium. The 3D images were obtained by fltered back-projection of a series of 2D images of adjacent crosssections.

3.4.1. Volumetric Analysis

CTAn sofware (Bruker, Kontich, Belgium) was used to measure surface area (A) and volume (V) after manual threshold segmentation of the root canal systems. Surface area change (ΔA) and volume change (ΔV) were then calculated by subtracting the measured values of the untreated canals from those of the treated ones. The ratio of the surface area change to volume change ΔA/ΔV was then calculated accordingly. Triangulated data were also used to determine the Structure Model Index (SMI) of the canals. This index characterises the cross-sectional geometry of the root canal as having a plate-like shape when SMI = 0, and a rod-like shape when SMI > 3. For statistical analysis of results Mann-Whitney U test was used in the case of natural human roots and in the case of plastic blocks Kruskal-Wallis and Tukey-HSD post hoc tests.

3.4.2. Cross-sectional analysis

In order to track the eccentric movements of the files, the cross-sectional shape at 14 mm coronal from the apex of the straight resin simulated ten canals (A-ETK-0 endotrainer, Frasaco, Tettnang, Germany) was analysed with the CTAn sofware (Bruker, Kontich, Belgium). Form Factor, Roundness, and Eccentricity values were used to describe the canal cross-sectional shape changes caused by canal instrumentation. Statistical analysis was performed with one-way ANOVA and two-sample t-test.

4. Results

4.1. Assessment of canal preparation

The prevalence of apical transportation (AT) was 80% in the straight and 85% in the curved group. The mean AT value was 0.095 mm (SD 0.063) in straight canals in the buccal view. This value was 0.074 mm (SD 0.077) in the proximal view. In curved canals this value was 0.112 mm (SD 0.063) in the buccal view. In the proximal view the value was 0.087 mm (SD 0.074) in the curved group. The difference in mean AT values was not statistically significant ($P > 0.05$), the power of the sample was $F > 0.80$.

4.2. Fluid transport measurements

In the straight root canals of the Sealapex group, results obtained at 1-month were the same as the baseline. At 3 months the seal decreased considerably and similar results were obtained at 12 months. In curved canals of the Sealapex group the number of specimens with a score of 1 decreased continuously with time beginning with the first month. At 12 months in straight and curved canals the seal created by Sealapex showed similar results. In the Pulp Canal Sealer groups straight root canals had minimal leakage at 9 and 12 months, while in curved root canals leakage appeared at 1 month with additional leakage observed at 12 months. Analysis of the results according to canal shape revealed that the seal in straight canals became compromised after the first month, while in curved canals leakage appeared within the first month. Analysis of results according to the type of sealer revealed that at the end of 1 year there was more leakage with Sealapex than with Pulp Canal Sealer. The parameter estimates imply that the root canal form affects the sealing ability at 1-month, while after 1 year the quality of the seal is determined by the choice of the sealer material. The p* index was 0.04.

4.3. Micro-CT three-dimensional results

4.3.1 Human teeth

The mean values (standard deviation) of the ratio of surface area change to volume change and SMI change after the ProTaper instrumentation in straight and curved natural canals show the following results. The $\Delta SA/\Delta V$ values are statistically different between the straight and curved groups ($p=0.01$) (power=1.00). On the contrary, ΔSMI values are not significantly different between the groups ($p=0.74$) (power=0.89). Unlike $\Delta A/\Delta V$, the SMI did not change significantly after canal instrumentation in straight nor curved human canals.

4.3.2. Micro-CT three-dimensional results (acrilyc blocks)

The mean values (standard deviation) of the ratio of surface area change to volume change (ΔA/ΔV) and SMI change after the ProTaper Universal instrumentation in straight and curved resin simulated root canals are the following. The ΔSA/ΔV values are statistically different between the two groups. ($p<0,001$).

The ΔSMI value was statistically not significant between the straight and curved groups.

4.3.3. Micro-CT two-dimensional results (acrylic blocks)

In straight acrylic blocks 14 mm coronally from the apex the values measured before and after Pro Taper Universal preparation shows that the canal morphology changes caused by the excentric preparation significantly appear in the case of form factor: before 0, 898 (0,039), after (0,833 (0,027), the level between ($p<0,05$). In the case of roundness there can not be significant changes. The values of excentricity show that between the nature values 0,08 (0,091) and the postinstrumentational values 0,24 (0,044) there is a strong statistically significant difference.

5. Summary

Bacterial invasion through the intact tooth surfaces can be prevented or stopped by several methods. It is beyond the scope of this thesis to discuss the prevention of bacterial propagation towards the pulp canal space. Some initial values have, however, been researched for impact on a successful root canal treatment, such as the impact of root canal morphology on the root canal enlargement modality, the impact of the root canal sealer and the morphological aspect on the long term sealing ability of root canal fillings. These two-dimensional measurements do not appear to give enough information according to the micron-level appearance of the structural incidence. The micro-CT measurements can solve this problem. The information at this micron level seems to be enough to characterise precisely the root canal enlargement modalities in the case of human teeth and even in the artificial acrylic blocks as well.

(AT)

In the present investigation the prevalence of AT in curved canals was similar to that reported by Wu et al. (2000a), but a comparison with that work showed significant differences in the prevalence of AT in straight canals. In our study 80% of straight canals had AT. This surprising result can be accounted for both by the selected morphology of human root canals and the sensitivity of the methodology. Roots grouped as ‘straight’ may have slightly curved canals (Nagy et al. 1995). This relatively high prevalence of apical transportation in straight canals has been discussed previously

(Nagy et al. 1997a). Wu et al. (2000a) in their study could identify AT only when 0.2 mm or more. The preparation asymmetry measurement (Nagy et al. 1997a,b) is a more sensitive (0.1 mm) quantitative method for determining AT values. In the present study all the AT mean values were smaller than 0.2 mm both in the straight and curved canals. These different AT values between the straight and curved canals were not statistically significant.

(Fluid filtration)

The solubility of sealers can negatively influence their long-term seal (Ørstavik 1983). In many longitudinal studies (1–2 years) filling techniques or different sealers were compared (Georgopoulou et al. 1995, Wu et al. 1995, Kontakiotis et al. 1997, Wu et al. 2000a,b,c). In the present study Sealapex allowed more leakage than Pulp Canal Sealer. The observed fluctuation in values of score 1 both in straight canals of the Sealapex group and in the curved canals of the Pulp Canal Sealer group could be the result of several factors. A similar fluctuation was observed in score 3 values in the groups of straight and curved canals with Sealapex and in curved canals of the Pulp Canal Sealer groups. These fluctuations may be associated with the different characteristics of the materials, namely, the expansion of gutta-percha when moist and sealer dissolution altering with time. Wu et al. (1995) reported that ZOE containing Tubliseal had significantly less leakage than Sealapex after 1 year. This observation is in agreement with the result of the present study. Others found less leakage with Sealapex than with Pulp Canal Sealer following 1 year

(Georgopoulou et al. 1995) and 2 years (Kontakiotis et al. 1997). The inconsistency among the studies may be explained by the difference in sample storage. In other studies the specimens were stored in water whereas in the present study 100% humidity was used. Storage in water may predispose the dissolution of sealer but this may not be the case in 100% humidity.

(3-D Micro-CT/ human delta A/V)

The present work focused on the quantitative characterisation of the difference in root canal morphology after Pro Taper Universal preparation using available parameters. The mean values of the ratio of surface area change to volume change after the ProTaper Universal instrumentation in straight and curved natural canals predict that $\Delta A/\Delta V$ values are statistically different between the two groups.

(3-D Micro-CT/ human delta SMI)

The limitation of SMI in describing root canal morphological change after instrumentation is inherent in the bidirectional change of SMI value. Specifically, the cross-sectional shape change from round to irregular after eccentric instrumentation reduces the SMI value, while smoothing the canal walls increases the SMI value. These two opposite processes cause fluctuation in SMI values, resulting in the loss of statistical signifcance .

In this work the ΔSMI values are not significantly different between the groups. Unlike ΔA/ΔV, the SMI did not change significantly after canal instrumentation in straight or in curved human canals.

(3-D Micro-CT/ acrylic delta A/V and delta SMI)

ΔSA/ΔV values are statistically different between the two acrylic groups and the ΔSMI values are not signifficantly different between the groups.

Despite previous studies showing the usefulness of SMI tracking, it did not prove effective in the current work. Our observation is in line with some recently published results where significant differences in SMI between tested groups have not been detected. The SMI value changes of resin simulated root canals reflect solely the deformity of the cross-sectional shape, while those of natural teeth reflect both the cross-sectional deformity of the canals and the smoothing of the canal walls.

(2-D Micro-CT)

Cross-sectional shape change of straight resin root canals showed that even in this simplifed morphology the operator usually prepares one side of the root canal wall more effectively than the others. Consequently, the cross-sectional shape of prepared root canals changed from regular to irregular, resulting in eccentricity. This finding was also reflected in the trend of the determined form factor and roundness values. When pre- and postinstrumentation values are compared, it is seen that after the instrumentation the form factor decreased significantly, the eccentricity increased significantly and the roundness value did not show any statistical difference.

6. New results

1. It is proved with our measurements that the apical transportation created by root canal enlargement procedures with Flexofile files occur more frequently and severly in the case of curved rather than straight root canals.

2. It is proved that the long duration sealing ability of the different types of root canal sealers in the initial phase (1 mounth) basically depends on the morphology of the root canals but later (1 year) the type of sealer dominates this evaluation.

3. It has been proved that the first time in dentistry used π* statistical test can effectively analyse different experimental factors (root canal form, root canal filling material, leakage categories, time) together.

4. It is realised in our work that the SMI can not exactly characterize the success and failure rate of root canal enlargement. This new realisation could lead to the conclusion that the three-dimensional and two-dimensional investigations of SMI m-CT parametres should be pursued further.

5. It is proved by our study that the deltaA/deltaV index is a more sensitive factor of the 3-D root canal enlargement evaluation than the delta SMI value.

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List of publications related to the dissertation

1. **Juhász, A.**, Hegedűs, C., Márton, I., Benyó, B., Orhan, K., Dobó Nagy, C.: Effectiveness of Parameters in Quantifying Root Canal Morphology Change after Instrumentation with the Aid of a Microcomputed Tomography.
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2. **Juhász, A.**, Verdes, E., Tőkés, L., Kóbor, A., Dobó Nagy, C.: The influence of root canal shape on the sealing ability of two root canal sealers.
   Int. Endod. J. 39 (4), 282-286, 2006.
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   IF: 1.429

List of other publications

3. Mensch, K., Simonffy, L., Dombi, C., Szabó, B. T., Varga, J., **Juhász, A.**, Dobó Nagy, C.: Endodontic and microsurgical treatments of maxillary lateral incisor dens invaginatus in combination with cone-beam-computed tomography fusion imaging.
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1. **Juhasz, Alexander**; Hegedus, Csaba; Marton, Ildiko; Benyo, Balazs; Orhan, Kaan; Dobó-Nagy, Csaba: Effectiveness of Parameters in Quantifying Root Canal Morphology Change after Instrumentation with the Aid of a Microcomputed Tomography. BIOMED RESEARCH INTERNATIONAL 2019 Paper: 9758176, 6 p. (2019)

2. Mensch, Karoly; Simonffy, Laszlo; Dombi, Csaba; Szabó, Bence Tamas; Varga, Jozsef; **Juhasz, Alexander**; Dobo-Nagy, Csaba: Endodontic and microsurgical treatments of maxillary lateral incisor dens invaginatus in combination with cone-beam-computed tomography fusion imaging. ORAL RADIOLOGY 33: 2 pp. 147-152., 6 p. (2017)

3. **Juhász, A**; Varga, J.; Dobó, Nagy Cs: Micro-CT investigation of Pro Taper instrumented root. In: ACTA PHYSIOLOGICA HUNGARICA pp. 110-111., 2 p. (2010)

4. **Juhász, Alexander** Mikroszivárgás-vizsgálatok az endodonciában (Módszertani összefoglaló). FOGORVOSI SZEMLE 101 pp. 19-28., 10 p. (2008)

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