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ORIGINAL ARTICLE

Use of microcomputed tomography for the evaluation of canal filling quality depending on the part of root canal*

Zastosowanie mikrotomografi rentgenowskiej do oceny jakości wypełnienia w poszczególnych odcinkach kanału korzeniowego*

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Abstract

Introduction. *High-resolution microcomputed tomography (microCT) is an emerging technology with several applications to endodontics.* ***Aim of the study****: To analyse in detail root canal fillings in the apical third, in the middle and coronal thirds in in vitro conditions with the use of microCT.* ***Material and methods.*** *Eighty single roots were prepared with the "step-back" technique or with a Pro File system using the "crown-down" technique. Each main group was divided into two subgroups and obturated with either cold lateral (CL) condensation or thermoplastic (Th) compaction with System B and Obtura II. The distribution of voids (number and volume) was assessed by means of microCT.* ***Results.*** *In the apical third of the root canal, in total over three times more external voids (e-voids) (598) with a greater volume than internal voids (i-voids) (167) were found. In the middle third the numbers of i-voids (664) and e-voids (651) were similar. The mean volume of i-voids was higher among root canals filled using CL condensation as compared to Th compaction (p=0.001). The greatest number of i-voids (3872) and e-voids (1888) were found in the coronal third. The mean volume of i-voids was higher among root canals filled using CL condensation as compared to those filled by means of Th compaction (p=0.001).* ***Conclusions.*** *Irrespective of the obturation*

Streszczenie

Wprowadzenie. *Rentgenowska mikrotomografia komputerowa (microCT) ma liczne zastosowania w endodoncji.* ***Cel pracy.*** *Ocena in vitro wypełnienia kanału korzeniowego w części przywierzchołkowej, w połowie wysokości oraz w części dokoronowej za pomocą microCT.* ***Materiał i metody.*** *80 jednokorzeniowych zębów opracowano techniką step-back lub pilnikami ProFile metodą crow-down. Każdą grupę podzielono losowo na 2 podgrupy i wypełniono kondensacją boczną gutaperki na zimno (CL) lub metodą termoplastyczną (Th) za pomoca Systemu B i Obtura II. Rozmieszczenie szczelin (ich liczbę i objętość) oceniono za pomocą microCT.* ***Wyniki.*** *W części przywierzchołkowej stwierdzono ogółem ponad trzykrotnie więcej szczelin zewnętrznych (e-voids) 598 o większej objętości niż wewnętrznych (i-voids) 167. W środkowej części kanału liczba i-voids (664) i e-voids (651) była podobna. Średnia objętość i-voids była wyższa wśród kanałów wypełnionych metodą CL w porównaniu do Th (p=0,001). W części dokoronowej stwierdzono największą liczbę i-voids (3872) i e-voids (1888). Średnia objętość i-voids była wyższa wśród kanałów wypełnionych CL w porównaniu do wypełnionych Th (p=0,001).* ***Wnioski.*** *Niezależnie od zastosowanej metody obturacji najszczelniej wypełniona była część przywierzchołkowa zaś*

KEYWORDS:
microCT, part of root canal, canal filling

HASŁA INDEKSOWE:
mikrotomografia, część kanału korzeniowego, wypełnienie kanałowe

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methods, the most hermetically filled part of the root canal was the apical third while the coronal third was the least hermetically filled part. E-voids with a greater volume predominated in the apical part, while numerous small i-voids were detected closer to the crown.

najmniej szczelnie część dokoronowa kanału. W części przywierzchołkowej przeważały e-voids, w części dokoronowej liczne drobne i-voids.

Introduction

Ingle's studies have shown that 60% of endodontic failures were caused by incorrect, incomplete obturation of root canals.[1] Therefore, various experimental (*in vitro*) methods have been used to examine the sealing ability of material and root canal obturation techniques in terms of bacterial microleakage.[2-8]

Many methods and laboratory tests have been used so far, but they have some limitations. Research carried out on sections or fractures of the teeth may be inaccurate because of the possibility of loss of a part of the filling or damage during the cutting process. Moreover, the assessment is made only at the selected height of the tooth, which does not reflect the quality of filling in the entire root.[2] Methods based on the fluid filtration technique are reproducible and accurate, but there are no generally accepted standards for their use, and the results obtained may be affected by the pressure, duration of the study or the time that has passed since the canal filling.[3,4] The microbial penetration test may indicate the presence of microorganisms in a filled root canal. The test will reveal the presence of bacteria when the voids extend over the entire length of the root canal, but is excluded in case of sealers with a strong antibacterial activity.[5] Commonly used conventional radiographs are two-dimensional, and the result depends on the projection.[6] The use of cone beam computed tomography (CBCT) is becoming more and more popular in modern endodontics. There are, however, conflicting reports in the available literature on the usefulness of CBCT for the assessment of the quality of fillings.[7,8] Many authors have proven that in the case of detection of voids inside or outside the filling, the intraoral digital radiography system (RVG) is a more sensitive method. The study conducted by *Huybrechts* et al.[7] showed that digital radiographs detect the voids of 200 and 300µm better than CBCT does. So the detection of gaps depends on possibilities and characteristics of the recording equipment. The conclusions of the study of *Karagenç* et al.[9] are a proof of the difficulties in assessing the quality of root canal fillings. The authors examined coronal microleakage with four different methods: fluid filtration, electrochemical method, dye penetration and microbial penetration test. The results differed depending on the test method used. A low correlation between the results of microleakage of dye and the clinical success was also reported by *Oliver* and *Abbot*.[10] Different results, however, were reported by *Camps* and *Pashley*[11] who, having examined the quality of fillings by means of the dye penetration, fluid filtration and CBCT tests, did not find any differences in the results of conducted tests.

Difficulties in a clear assessment of the quality of fillings using the above-mentioned tests resulted in a search for new methods. One of them is the X-ray microcomputed tomography (microCT) which is a non-invasive analytical method objectively evaluating the inside of a filled root. High-resolution images used in the test make it possible to distinguish, with high precision, the filling material and the tooth structures. They can also detect cracks, their size and spatial resolution.[12] The samples may be qualitatively and quantitatively evaluated with the use of software and algorithms.[13,14] The evaluation of the sealing ability is performed on individual scans, and then three-dimensional reconstructions reflecting the inside of a filled canal in reality are made. A high sensitivity of microCT was proven by the study of *Moeller* et al.,[15] in which the voids detected in the RVG images were confirmed and verified by microCT, while CBCT gave a falsely positive image of voids compared to microCT.

The aim of this study was to analyse in detail, using microCT, the quality of root canal fillings in the apical third, in the middle third and in the coronal third of root canal.

Material and methods

One hundred extracted human single-rooted teeth with single canal and no root caries, restoration, apical resorption or previous endodontic treatment were selected. Teeth with straight or slightly curved canals (up to 10° relative to long axis) were included in the study. Following a preliminary analysis of the teeth, which were magnified 2.5 times by means of a magnifier, twenty teeth with visible signs of resorption and cracks within the root, with incompletely formed apices and patent root canals were excluded from the study.

Finally, the crowns of eighty teeth were cut off at the level of the cementoenamel junction by means of a turbine diamond drill with water cooling. Root lengths were 14 mm. The canals were opened and the working length was determined by introducing a size 10 file until it exited from the apex. The working length was determined 1 mm short of this measurement.

The teeth were randomly divided into four groups of twenty samples:

Group 1 – canals prepared manually and filled with the thermoplastic (Th) compaction,

Group 2 – canals rotary-prepared and filled with the thermoplastic (Th) compaction,

Group 3 – canals prepared manually and obturated with cold lateral condensation (CL) of gutta-percha,

Group 4 – canals rotary-prepared and obturated with cold lateral condensation (CL) of gutta-percha.

Canals from Groups 1 and 3 were prepared manually using the step-back technique with S-file files to the apical size 35/2. Canals from Groups 2 and 4 were prepared with the crown-down technique using NiTi instruments in the ProFile system (Dentsply-Maillefer, Switzerland) to the apical size of 35/4 according to sequences specified by the manufacturer. The instruments were mounted on the contra-angle handpiece of the EndoIt endodontic micromotor (VDW, Germany) with programmed torque and rotary speed for each ProFile instrument. During the preparation the canals were irrigated with 2% NaOCl. After the preparation all canals were irrigated with 5 ml of 17% EDTA in order to remove the smear layer, and then with 2% NaOCl and saline solution. The canals were dried with standardised paper points.

All instrumented canals were filled with gutta-percha with the Tubli-Seal zinc oxide eugenol sealer (Kerr, Italy). Canals from Groups 1 and 2 were filled with the thermoplastic (Th) compaction using the System B (Sybron Endo, USA) and Obtura II (Obtura Spartan, USA). The periapical canal third was obturated using a gutta-percha cone with the size of 0.02/35 in Group 1 and with the size of 0.04/35 in Group 2. The condensation was performed by means of a System B plugger. The remaining part of the canal was obturated with the injection method using the Obtura II unit.

Canals from Groups 3 and 4 were obturated with cold laterally condensed gutta-percha. The apical section with the size of 02/35 in Group 3 and 04/35 in Group 4 was coated with a thin film of the sealer and placed into the canal at its full working length. The condensation was performed using N°. 30 and 25 spreaders and additional cones in the same size. The canal orifices were obturated with the Ketac Cem Radiopaque glass ionomer cement (3M ESPE, Germany). The roots were placed in saline solution at room temperature for seven days to allow the canal filling material to set completely.

MicroCT was performed by means of the Benchtop CT 160 Xi x-ray scanner (Nikon Metrology, Tring, UK), with a voltage of 110 kV and the amperage of 50 μA. The samples were scanned every 0.2° until the full rotation by 360° was done. The voxel size was 12x12x12 μm^3. After the microCT scan, two roots from Group 3 and Group 4, respectively, were eliminated due to cracks, which made it impossible to conduct further measurements.

MicroCT provided a three-dimensional image of the inside of filled roots. In order to evaluate the filling quality the root was divided into three equal parts: apical, middle and coronal thirds (Fig. 1). The division started 1 mm from the root apex and ended at the canal orifice. For each canal third, the number of internal voids (i-voids) entirely surrounded by the filling material and external voids (e-voids) occurring at the dentine/material interface as well as the mean volume of the voids in mm^3 were determined (Fig. 1). The voids were detected and measured using a special void detection algorithm, which was described in detail in the previous publication.[14]

Statistical analysis

Obtained findings of the study were statistically analysed using the Statistica 8.0 statistical package (StatSoft, Poland) by means of parametric tests with the significance level of $p<0.05$. The two-way analysis of variance (ANOVA) was used to test the influence of root canal preparation and filling methods on the number and mean volume (mm^3) of voids. The significance of differences among the mean values in groups being evaluated was determined by means of the post-hoc Tukey's HSD test.

Results

Mean values of the number and volume of voids for three basic parts of the root canal are shown in Figs. 2-4. The analysis of microCT tomograms revealed the occurrence of e-voids and i-voids in all canal segments in all scanned tooth groups (Fig. 1). E-voids with a greater volume predominated in the apical part, while numerous small i-voids were detected closer to the crown. The numbers of both types of voids were similar.

In the apical third of the root, over three times more e-voids than i-voids were found. E-voids occupied also a greater volume than i-voids. (Fig. 2). No statistically significant differences in the volume of i-voids and e-voids depending on the analysed root canal preparation and filling techniques were found ($p>0.05$). The greatest number of i-voids with the greatest mean volume was observed in Group 1. The greatest number of e-voids and at the same time the smallest number of i-voids was recorded in Group 4. The lowest number of e-voids was found in Group 3 (Fig. 2).

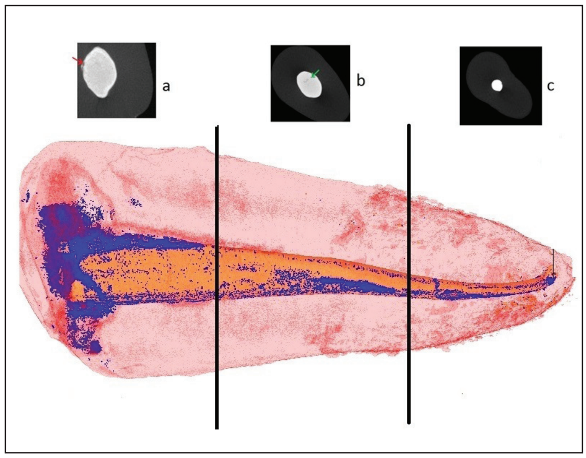

***Fig. 1.** Examples of root cross-sections obtained during a microCT scan; a – in the coronal part, b – in the middle part of the root, c – in the apical part. The red arrow shows e-voids, the green arrow – i-voids.*

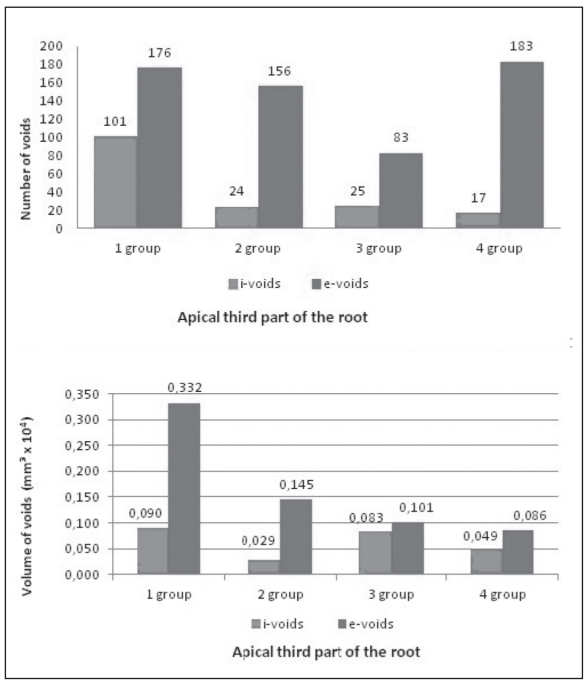

***Fig. 2.** Number (top figure) and volume (mm^3) (bottom figure) of i-voids and e-voids in the apical third of the root in analysed groups: Group 1 – canals prepared manually and filled with thermoplastic (Th) compaction, Group 2 – canals rotary-prepared and filled with thermoplastic (Th) compaction, Group 3 – canals prepared manually and obturated with cold lateral (CL) condensation of gutta-percha, Group 4 – canals rotary-prepared and obturated with cold lateral (CL) condensation of gutta-percha.*

In the middle third of the root, the numbers of i-voids and e-voids were similar. A statistically significant difference in the volume of i-voids depending on the canal filling technique was

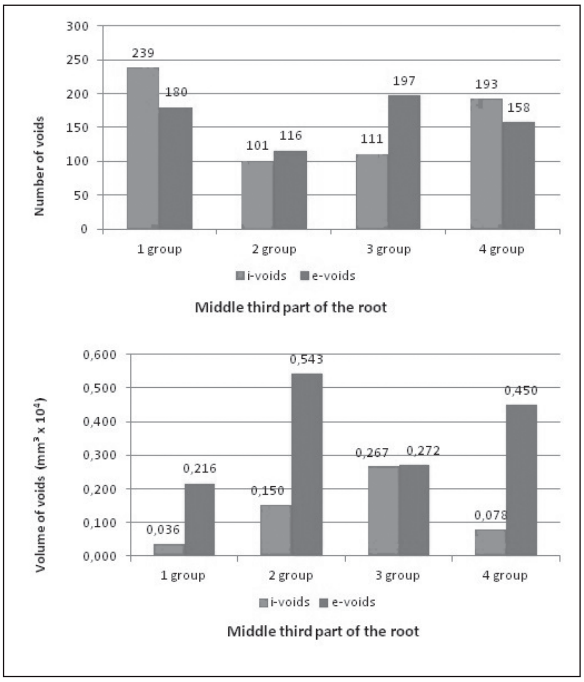

Fig. 3. Number (top figure) and volume (mm3) (bottom figure) of i--voids i e-voids in the middle third of the root in analysed groups: Group 1 – canals prepared manually and filled with thermoplastic (Th) compaction, Group 2 – canals rotary-prepared and filled with thermoplastic (Th) compaction, Group 3 – canals prepared manually and obturated with cold lateral (CL) condensation of gutta-percha, Group 4 – canals rotary-prepared and obturated with cold lateral (CL) condensation of gutta-percha.

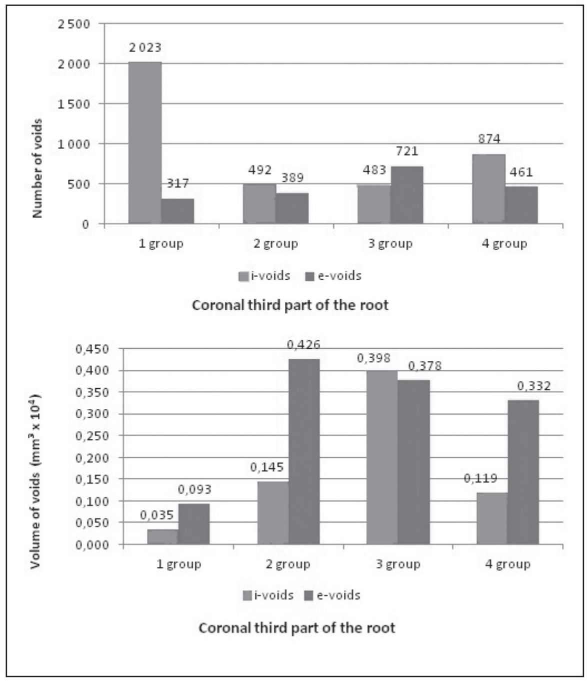

Fig. 4. Number (top figure) and volume (mm3) (bottom figure) of i-voids i e-voids in the coronal third of the root in analysed groups: Group 1 – canals prepared manually and filled with thermoplastic (Th) compaction, Group 2 – canals rotary-prepared and filled with thermoplastic (Th) compaction, Group 3 – canals prepared manually and obturated with cold lateral (CL) condensation of gutta-percha, Group 4 – canals rotary-prepared and obturated with cold lateral (CL) condensation of gutta-percha.

shown (p=0.001). The mean volume of i-voids was higher among the canals filled with the CL condensation method compared to those filled using Th compaction. Also a statistically significant difference in the volume of e-voids between the analysed root canal preparation techniques (p=0.016) in favour of the canals prepared using rotary instruments was shown (Fig. 3).

The greatest numbers of i-voids (altogether 3872) and e-voids (altogether 1888) were found in the coronal third of the root canal compared to the remaining parts (Fig. 4). In respect of the size, however, e-voids occupied three times more volume. A statistically significant difference in the volume of i-voids depending on the root canal filling technique was shown (p=0.001). The mean volume of i-voids was higher among root canals filled using CL condensation compared to those filled with Th compaction. However, the greatest number of small i-voids (2023) was found in Group 1. At the same time, in this group, the number of e-voids (317) with the smallest volume compared to other groups was found (Fig. 4).

Discussion

MicroCT imaging can provide high resolution images as well as qualitative and quantitative analysis of teeth, bones and implants.[16] In endodontics, microCT has been used for the evaluation of root canal anatomy and morphology following the instrumentation.[17,18] This method is also applied to evaluate the root canal filling sealing ability.[7,12,15,19-25] Not only is microCT rapid and non-invasive, but also the results are reproducible and comparable with histological studies.[16,19]

It is important to obturate the whole length of root canal. Based on the present study results the voids were detected in all samples. This is in accordance with some studies.[7,12,15,19-25] The occurrence of voids in filled canals is influenced by many factors such as internal canal system anatomy, canal wall preparation quality, kind, consistency and amount of sealer used, and canal filling techniques.[20] While the conditions prevailing in the voids inside the filling material are less favourable for the development of microorganisms, the voids occurring at the canal wall interface are potential ways of penetration of bacteria and their toxins from the side of both the crown of a tooth[26] and the root apex.[24] From the clinical point of view, the distribution of such voids depending on the distance from the root apex seems to be also particularly significant. In this study, the smallest number of voids was found in the apical region of root canal and the greatest number in the coronal part, irrespective of the root canal preparation and the filling technique used. These results are as expected and may be explained by the typical canal filling technique. During the filling process the attention is focused primarily on the hermetic obturation of the apical part of the root canal following adequate, precise selection of the master cone. A properly fitted cone closely adheres to canal walls in this part and ensures proper obturation. In addition, the canal is the narrowest in this part and a smaller amount of filling material is required. On the other hand, the canal widening like a funnel towards the orifice requires a greater amount of material, which makes it more difficult to condense. A similar distribution of occurrence of voids was obtained in the study of *Moeller* et al.[15]

In the apical part of the root canal, greater numbers of i-voids and e-voids were found among the canals filled with the thermoplastic technique compared to those filled with CL condensation. The smallest number of voids in the apical part was found among the canals prepared manually and filled with CL condensation, which is related to a precisely fitted cone sealing the canal lumen and a limited use of the spreader and the additional cones in this area. A small number of i-voids detected in the apical part among the canals filled with the CL condensation technique proved that in this part the canal was filled primarily with the master cone. Similar results were obtained by *Moeller* et al. [21] and *Keleş* et al.[20] Also *Zogheib* et al.[22] obtained similar findings in their research. However, the authors evaluated different canal filling methods and sealing materials: RealSeal1 (Resilon) and Thermafil (gutta-percha) with the AH Plus sealer. Filled teeth were evaluated with the use of microCT in a very high resolution below 4 micrometres, but only at three selected levels: 1, 3 and 5 mm from the root apex. The authors did not find any differences in the percentage of voids in the apical third of the root with the use of both techniques. Nevertheless, statistically most voids were located at the distance of 1 mm from the root apex in both compared techniques.

In the middle part of the root canal, comparable numbers of i-voids and e-voids in the analysed groups were found, but i-voids were three times larger. Even though the number of i-voids was similar in analysed groups, their volume was statistically greater among the canals filled using the thermoplastic technique. E-voids with a greater volume predominated among the mechanically prepared canals. Many authors investigating the canal filling quality observed that in the case of canal obturation by means of the thermoplastic technique a great number of voids were found at the interface between the apical and middle parts of the root canal, i.e. at the point where the System B filling ends and the Obtura II obturation begins. Also at this level, the canal becomes more oval in the cross-section, thus more difficult to fill.[27] A similar distribution of voids in a filled root canal was observed in the microCT scan done by *Mirfendereski* et al.[23] Statistically fewer voids and a more homogenous filling at the distance between 0 and 6 mm from the root apex were noted by the authors in the case of use of the obturator system (ProTaper Obturators). In the case of obturation with System B/Calamus the greatest number of voids was detected at the interface of the apical and middle parts of the root canal. In the middle part of the root the voids constituted 12% of the filling material volume, whereas in the remaining canal parts that value was 3%. Similar observations were also made by *Anbu* et al.[28] in a study conducted by means of CBCT. The present research has not confirmed such correlation.

Conducted analysis revealed a greater number of i-voids than e-voids in the coronal part of the root in both analysed canal-filling techniques. A great number of internal voids reduces the filling homogeneity and may lead to the occurrence of coronal microleakage from the side of the oral cavity.[29] A distinctly greater number of i-voids with a smaller mean volume observed in samples filled with the thermoplastic technique results from the canal filling technique using System B and Obtura II. The thermoplastic technique is a multi-stage method of gutta-percha insertion by compacting it with pluggers, which may lead to the formation of i-voids.[23,24] On the other hand, research studies have proven that warm gutta-percha may shrink during setting, which lowers the filling quality, especially in the root apex region.[30] Not insignificant is also the impact of high temperature on sealer properties, which has been duly proven in the present study. Among the canals filled with the CL condensation technique in the coronal part a greater number of e-voids compared to the thermoplastic method was found. The canal becomes wide in the orifice region, thus it is more difficult to condense the gutta-percha cones sufficiently closely, which have a greater volume in this region. According to our own research, among the canals filled with the CL condensation technique the filling was homogeneous only in the apical part. A lower homogeneity of the filling in remaining canal parts has also been proven by research studies of other authors.[13,26]

Conducted analysis has proven that the microCT technique is effective for the evaluation of root canal filling quality; however, this methods has its limitations. The resolution of microCT (voxel size) directly influences the minimum size of detectable voids. Moreover, there is a limitation related to the use of materials with a high contrast, which interferes with the formed image and makes it difficult to detect small voids, especially at the filling/root dentine interface. To minimise this effect a sealer whose contrast was similar to gutta-percha was chosen so that the material distinctly differed from root dentine.

Conclusions

The study has proven that the microCT is a sensitive tool for the evaluation of root canal filling quality because it detects voids with the size of even 0.00003 mm^3. Irrespective of the root canal preparation and filling technique used, the highest sealing quality is achieved in the apical part of the root canal, and the lowest sealing quality in the coronal part. Parietal voids detected in the apical part of the root canal are greater than numerous small voids concentrated closer to the crown. The presence of parietal voids near the root apex is significant from the clinical point of view because it may lead to the occurrence of bacterial microleakage and consequent complications of endodontic treatment.

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