Application of Cone-beam Computed Tomography in the Endodontic Practice

Dr Slavena Svetlozarova Georgieva

ABSTRACT

On

DISSERTATION FOR AWARDING EDUCATIONAL AND SCIENTIFIC DEGREE

"PhD"

Medical University of Varna

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"PhD"

in the scientific specialty "Therapeutic Dentistry"

Supervisor:

Assoc. prof. dr Tsvetelina Iliyanova Borisova-Papancheva, phd

Medical University of Varna

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The dissertation is written on 228 pages, illustrated with 100 figures and 115 tables. The literature contains 376 sources, of which 5 in Cyrillic and 371 in Latin.

The dissertation was admitted to the public defense of the Department Council of the Department of Conservative Dentistry and Oral Pathology, held on 21.10.2021.

Table of Content **Стр.**

Abbreviations used

CBCT – cone-beam computed tomography

CT – computed tomography

3D- three-dimensional

2D – two-dimensional

RC – root canal

RCS – root canal system

SDT– sound dental tissues

I. Introduction

In endodontic practice, clinical examination and data, obtained from radiographic imaging are extremely important for preoperative diagnosis and the choice of treatment method. The information obtained from the radiographic imaging supports the clinical investigations and provides the clinician with an opportunity for a more accurate visualization of the examined region. Conventional two-dimensional radiographs provide accessible and high-resolution images, remaining the most popular method for paraclinical diagnosis of diseases, involving the pulp and periodontium. Despite their many advantages, two-dimensional radiographs are characterized by a somewhat limited diagnostic potential. The advantages of cone-beam computed tomography as a diagnostic tool in the field of endodontics have already been described and analyzed by numerous studies around the world. The possibility for three-dimensional analysis of the studied region, as well as the options for performing accurate linear measurements, greatly expand the diagnostic potential of CBCT, making it applicable in more complex cases of endodontic pathology, as well as in planning and conducting combined conservative surgical treatment.

In the present study we aim to investigate the application of cone-beam computed tomography in the field of endodontics. The results of this study are expected to shed light on the diagnostic potential of CBCT by making it easier for the clinician to choose a diagnostic tool when planning and conducting endodontic treatment.

II. Aim and Tasks

Aim

To study the possibilities of CBCT in the detection and diagnosis of anatomical variations of the endodontic space and the root canal system among the Bulgarian population.

Tasks

1. Establishment of bilateral symmetry in the Bulgarian population in terms of the number of roots, root canals and the type of configuration of the root canal system by groups of teeth.

2. Establishing the frequency of available additional root canals and the type of configuration of the root canal system by groups of teeth among the Bulgarian population.

3. Determining the average working length by group of teeth in the Bulgarian population.

3.1. Comparison between the working length determined on the basis of measurement by electrometric method and cone-beam computed tomography.

4. Investigation of the frequency of denticles in the RCS and root fractures, which occurred after endodontic treatment, among the Bulgarian population.

III. Materials and Methods

1. Materials and methods for task 1

Object of study: 127 patients in need of cone-beam computed tomography to diagnose and plan upcoming dental treatment.

Unit of observation: total number of roots and root canals of each tooth, as well as the number of root canals in one root.

The place of the study is the Department of X-ray Diagnostics at the University Medical and Dental Center (UMDC), Varna.

The study was performed by two operators analyzing the three-dimensional images independently of each other.

Including criteria: three-dimensional images that cover the entire upper and / or lower jaw of the examined patients, depending on the group of analyzed teeth.

Excluding criteria: patients under 18 years of age and over 69 years of age, patients with contraindications for X-ray examination, patients without at least one symmetrical pair of fully developed teeth and without endodontic treatment of the study groups. Teeth with large metal restorations, teeth with incomplete root development, third molars and teeth with endodontic treatment were also not included in the study.

Study methodology: CBCT images were obtained after scanning with a conical beam tomograph Planmeca ProMax 3D Max. The CBCT image is stored and read by the Planmeca Romexis image processing software. The studied images are oriented to the axial, sagittal and frontal planes. The axial and sagittal sections of the three-dimensional images were examined in detail in order to determine the number of roots, root canals and the configuration of the RCS of the analyzed teeth. The examination in the axial plane was performed after the cursor was moved in the corona-apical direction until it reached a level located apically from the apex (s) of the examined teeth, and then - in the apico-coronary, to determine the number of roots, root canals and type configuration of the root canal system (Fig. 1). The measurement thus described was performed three times.

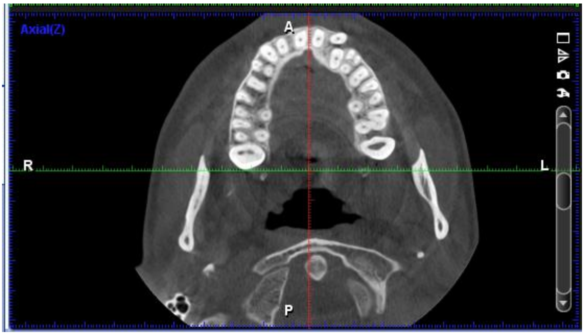


Fig. 1 - Analysis in the axial plane for the upper jaw - movement of the cursor in the apico-coronary direction

The analysis in the sagittal plane is performed by changing the axis of the examined tooth in the sagittal plane until the moment when it is possible to visualize the root canal along its entire length from the orifice to the apical foramen. The cursor is moved to the starting position distal to the examined tooth and follows a gradual movement to the medial in order to visualize the type of configuration of the root canal system (Fig. 2).

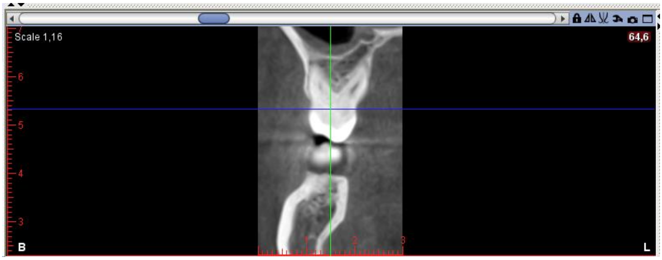


Fig. 2. Analysis in the sagittal plane for the upper molars

The *1974 Vertucci F* classification was used to classify the RCS configuration type. The results are recorded in tables and statistically processed with a specialized statistical analysis package IBM SPSS Statistics 20.

Object of study: 234 symmetrical pairs of maxillary first or second molars, 223 symmetrical pairs of mandibular first or second molars, 120 symmetrical pairs of mandibular canines, 246 symmetrical pairs of mandibular incisors, 115 symmetrical pairs of maxillary second premolars.

2. Materials and methods for task 2

Subject of study: 127 patients with at least one endodontically untreated, fully developed tooth from the groups of teeth included in the study.

Unit of observation: total number of roots and root canals of each tooth, as well as the number of root canals in one root.

The place of the study is the Department of X-ray Diagnostics at the University Medical and Dental Center (UMDC), Varna.

The study was performed by two operators analyzing three-dimensional images independently of each other.

The inclusion and exclusion criteria are already described in the methodology of Task 1.

Study methodology: CBCT images were obtained after scanning with a conical beam tomograph Planmeca ProMax 3D Max. The axial and sagittal sections of the three-dimensional images were studied in detail according to the methodology already described in Task 1. The study was performed separately for each available endodontically untreated and fully developed tooth from the groups of teeth included in the study. The presence or absence of an additional root canal was reported. The results are recorded in tables and statistically processed with a specialized statistical analysis package IBM SPSS Statistics 20.

Object of examination: 230 maxillary first molars, 231 maxillary second molars, 230 mandibular first molars, 230 mandibular second molars, 248 mandibular central incisors, 250 mandibular lateral incisors, 250 mandibular canines, 230 maxillary second premolars.

3. Materials and methods for task 3

Object of the study: 140 patients in need of conical-tomography in order to diagnose and plan upcoming dental treatment.

Examination unit: The measurement was performed separately for each root canal of a tooth included in the examination. The average working length in each of the examined groups of teeth was reported.

Place of the study: the three-dimensional images were made in the Department of X-ray Diagnostics at the University Medical and Dental Center (UMDC), Varna.

The study was performed by two operators analyzing three-dimensional images independently of each other.

Including criteria: the three-dimensional images should cover all or part of the upper and / or lower jaw of the examined patients, containing at least one tooth from the analyzed group of teeth. The included patients were aged 18-69, with no contraindications for X-ray examination. The examined teeth have completed root development and no endodontic treatment.

Excluding criteria: patients under 18 years of age and over 69 years of age, patients with contraindications for X-ray examination. Teeth with radiographic data for the presence of apical resorption, as well as teeth with strongly curved roots and root canals, which do not allow the measurement to be performed in one plane, were not included in the study. Teeth with incomplete root development, teeth with endodontic treatment, as well as teeth with large metal restorations were excluded from the study.

Study methodology: CBCT-images were obtained after scanning with a conical beam tomograph Planmeca ProMax 3D Max. The methodology for determining the working length on the three-dimensional images begins with their orientation to the axial, sagittal and frontal planes. The axis of the examined tooth in the sagittal plane changes until the moment when it is possible to visualize the root canal along its entire length from the orifice to the apical foramen. Using the linear measurement option of the Planmeca Romexis image processing software, the working length is measured from the enamel-cement junction of the examined tooth (orifice level) to the area of the apical foramen (Fig. 3). 0.5 mm is subtracted from the obtained value in mm, with which we aim for the determined value to reflect the distances to the physiological constriction.

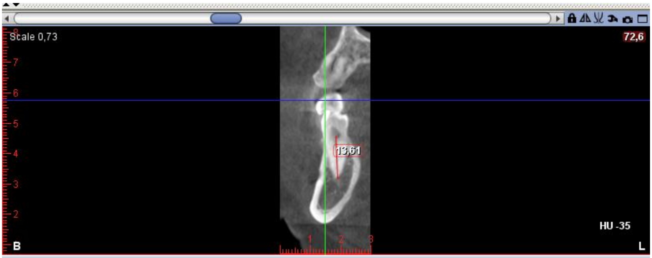


Fig. 3. Methodology for measuring the working length in the sagittal plane

The measurement was performed separately for each tooth included in the study, as well as for each individual root canal of the multi-rooted teeth. The average working length in each of the studied groups was reported. The results are recorded in tables and statistically processed with a specialized statistical analysis package IBM SPSS Statistics 20.

230 teeth from each indicated group were analyzed, meeting the set criteria for inclusion in the study.

4. Materials and Methods for subtask 3.1.

Subject of the analysis under subtask 3.1. are 130 single-rooted teeth subject to endodontic treatment due to existing diseases of the pulp and / or periodontium.

Table. 1. Distribution of the total number of teeth included in the study by groups

Teeth	Брой
Maxillary and mandibular incisors	45
Maxillary and mandibular canines	24
Maxillary and mandibular premolars	31
Total	100

Object of study: 70 patients aged 18-69 years without systemic diseases and contraindications for X-ray examinations. Prior to the endodontic treatment, conical tomography was ordered for the purpose of diagnosis and planning of upcoming dental treatment and not for the purposes of the present examination and the planned endodontic treatment.

Examination unit: the working length of the root canal of each tooth included in the examination.

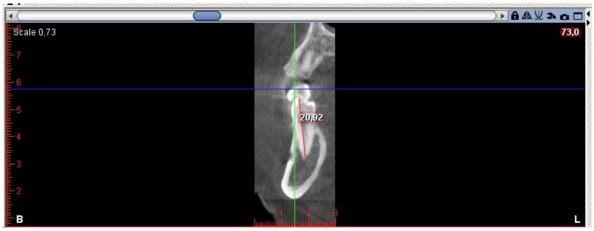
Place of research: Sector of X-ray Diagnostics at the University Medical and Dental Center (UMDC), Varna.

The study was performed by two operators analyzing three-dimensional images independently of each other.

Inclusion criteria: the analyzed teeth should be single-rooted with fully completed root development, without available radiographic data for external root resorption and without clinical and radiological data for endodontic treatment performed so far.

Exclusion criteria: teeth with endodontic treatment, incomplete root development, multi-rooted teeth, as well as single-rooted teeth with strongly curved roots and root canals, which do not allow the measurement to be performed on three-dimensional images in one plane. Single-rooted teeth with more root canals available were not included in the study. Teeth with radiographic evidence of external root resorption, as well as those with extensive metal restorations, were excluded from the present study.

Study methodology: CBCT-images were obtained after scanning with a conical beam tomograph Planmeca ProMax 3D Max. The procedure for determining the working length on the three-dimensional images follows the one already described in task 3. Using the linear measurement option, the working length is measured from the highest point of the crown of the examined tooth to the area of the apical foramen (Fig. 4). 0.5 mm is subtracted from the obtained value in mm, with which we aim for the determined value to reflect the distance to the physiological constriction. In this way we achieve equal conditions for both parts of the task.



Фиг. 4. Measurement in the sagittal plane

The methodology for determining the working length by electrometric method is as follows:

1. Preparation of the endodontic cavity, localization and expansion of the orifice, vital or mortal extirpation and removal of the canal contents.
2. Irrigation with 5.25% sodium hypochlorite solution and saline, drying with paper points.
3. An ISO №15 K-file is inserted in the root canal, which is connected to an apex locator - Apex ID (KerrDental). The file is inserted into the root canal until the apical foramen is reached, which is visualized by the appearance of a value of 0.0 on the apex locator display and an audible signal. Then the file is pulled until the physiological narrowing is reached - a value of 0.5 appears on the display of the apex locator and a sound signal.
4. Upon reaching this position, the silicone stopper of the file is placed in contact with the highest part of the crown of the examined tooth. The file is removed from the root canal and

the distance from the tip of the instrument to the siliconestopper is measured with an endodontic ruler. The value obtained is recorded. Measurements in which the value read on the apex locator display does not remain stable for 5 seconds are not included in the present study.

The working length measured electrometrically in clinical conditions and on CBCT-images was reported and compared. The results are recorded in tables and statistically processed with a specialized statistical analysis package IBM SPSS Statistics 20.

5. Materials and Methods for task 4

A) Examination of the frequency of the presence of denticles in the RCS

Subject of study: CBCT-images of 30 patients

Place of research: The three-dimensional images were made in the Department of X-ray Diagnostics at the University Medical and Dental Center (UMDC), Varna.

The study was performed by two operators analyzing three-dimensional images independently of each other.

Including criteria: the three-dimensional images should cover the entire upper and / or lower jaw or a segment of the upper and / or lower jaw and meet the requirement to contain at least one endodontically untreated and not restored with metal restoration tooth.

Exclusion criteria: Teeth with endodontic treatment, incomplete root development, metal restorations and third molars were not included in the study.

Study unit: 738 endodontically untreated and fully developed teeth were examined, including: 209 maxillary and mandibular incisors, 119 maxillary and mandibular canines, 216 maxillary and mandibular premolars, 194 maxillary and mandibular molars.

Methodology of the study: The patients included in the study were divided into two age groups: the age group of patients under 40 years of age and the age group of patients at / over 40 years of age. CBCT images were obtained after scanning with a cone-beam tomograph Planmeca ProMax 3D Max. The studied images are oriented to the axial, sagittal and frontal planes. The examination of the axial and sagittal sections follows the methodology already described in Task 1. In cases where the axial and sagittal sections do not carry the necessary information and definite data, the examined teeth are analyzed three-dimensionally also in the frontal plane. The presence of denticles and calcifications in the RCS of the examined teeth was reported, as well as the location in the pulp chamber or in the root canals.

The study was performed separately for each available endodontically untreated and fully developed tooth that meets the set criteria. The results are recorded in tables and statistically processed with a specialized statistical analysis package IBM SPSS Statistics 20.

B) Examination of the frequency of root fractures that occurred after endodontic treatment

Subject of analysis: CBCT-images of 71 patients in need of cone-beam computed tomography to diagnose and plan upcoming dental treatment.

Place of the study: The three-dimensional images were made in the Department of X-ray Diagnostics at the University Medical and Dental Center (UMDC), Varna.

The study was performed by two operators analyzing three-dimensional images independently of each other.

Unit of study: The presence of a fracture line along the root of each endodontically treated tooth included in the study and / or the presence of atypically located bone resorption around its root was examined.

Including criteria: The condition that CBCT images selected to participate in the study must meet is the presence of at least one endodontically treated distal tooth with a treatment history of at least 5 years, which is established by anamnestic data.

Excluding criteria: Teeth with incomplete root development, third molars, as well as teeth with extensive metal restorations are not the subject of the study.

A total of 241 endodontically treated distal teeth were examined, which lacked the clinical symptoms associated with this type of dental pathology on the part of the patient. 152 of the examined distal teeth are molars and 89 - premolars.

Study methodology: CBCT images were obtained after scanning with a conical beam tomograph Planmeca ProMax 3D Max. A root fracture on three-dimensional images is the presence of separation of two adjacent root fragments, which is observed in at least two consecutive sections without any continuation of the separation to adjacent bone structures, as well as observation of the fracture line in at least two of the studied three planes. As the existence of a root fracture, we also assume the presence of atypically located bone resorption around the root in the presence of an intact endodontic space or an exactly performed endodontic treatment of the tooth. Cases with the presence of metal restorations or RC-filling materials, leading to the appearance of multiple artifact lines, spreading along the entire length of the root and the adjacent bone structure, we consider negative in terms of the presence of fracture lines. Cases of available bone resorption around the root of teeth with inexactly performed endodontic treatment or available involvement of the endodontic, located at the typical sites for the development of lesions of endodontic origin, are also considered negative in terms of the presence of root fractures.

The examined teeth were analyzed in the axial and sagittal plane according to the methodology already described in task 1. In cases where the axial and sagittal sections do not carry the necessary information and definite data, the examined teeth are analyzed three-dimensionally also in the frontal plane.

The results of task four are reported by indices from 0 to 2 *(Bernardes R. et al. 2009*), namely (Table 2):

Table. 2. Definition of the indices used to evaluate the results

Index 0	Lack of fracture line and atypically located bone resorption.
Index 1	Presence of a weak fracture line and / or bone resorption, for which infection in the endodontic space as an etiological cause cannot be completely ruled out. It is not possible to make an unambiguous diagnosis without information from the anamnesis and clinical studies.
Index 2	Presence of a well-defined fracture line and / or atypically located bone resorption around the root of a tooth with exactly performed endodontic treatment.

The obtained results are registered in tables and are subject to statistical analysis with a specialized statistical analysis package IBM SPSS Statistics 20. The percentage of root fractures in the examined endodontically treated teeth was reported. The percentage of cases in which a definite diagnosis of the presence of a root fracture can be made on the basis of the three-dimensional image is reported.

IV. Results and Discussion

1. Results from task 1.

A) In the group of maxillary molars

All studied 468 maxillary first and second molars have three roots. The presence of bilateral symmetry with respect to the number of roots of the maxillary molars was detected in 100% of the studied cases.

Symmetry regarding the number of root canals was found in 189 of the 234 pairs studied (80.8%). The remaining 45 (19.2%) of the studied symmetrical pairs are characterized by the presence of asymmetry in terms of the number of root canals.

Of the 234 pairs of maxillary molars examined, symmetry regarding the configuration of the root canal system in the medio-vestibular root was found in 172 pairs (73.5%). In the remaining 62 pairs (26.5%) asymmetry was observed regarding the configuration of the RCS in the medio-vestibular root. 74 (39%) of the studied symmetrical pairs of maxillary molars have a second additional medio-buccal root canal and a medio-vestibular root with two root canals. Symmetry regarding the configuration of the RCS in the medio-vestibular root was found in 62 (83.8%) of the studied pairs of symmetrical maxillary molars with an additional root canal. Asymmetry regarding the configuration of the RCS in the medio-buccal root in the presence of an additional second medio-buccal root canal was found in 12 (16.2%) of the studied symmetrical pairs.

B) In the group of mandibular molars

Symmetry regarding the number of roots was found in 218 (97.8%) of the studied symmetrical pairs. Asymmetry was observed in 5 (2.2%) of the studied symmetric pairs.

Bilateral symmetry regarding the number of root canals was found in 193 (86.5%) of the studied pairs. Symmetrical mandibular molars with different number of root canals were observed in 30 (13.5%) of the studied pairs.

Symmetry regarding the configuration of the RCS was found in 167 (74.9%) of the studied pairs. In 56 (25.1%) of the studied pairs the symmetrical molars are characterized by a different configuration of their RCS.

C) In the group of mandibular canines

Symmetry regarding the number of roots was found in 117 (97.5%) of the studied canine pairs. Bilateral mandibular canines with different numbers of roots were found in 3 (2.5%) of the examined patients.

Symmetry regarding the number of root canals was found in 116 (96.7%) of the studied pairs. At 4 (3.3%) asymmetry was found with respect to the number of root canals.

Only 1 (0.8%) of the studied symmetric pairs showed asymmetry with respect to the RCS configuration. The remaining 119 (99.2%) are characterized by an identical root canal configuration.

D) In the group of mandibular canines

All 246 (100%) of the studied pairs have one root and are symmetrical to the opposite tooth. Symmetry regarding the number of root canals was found in 239 (97.2%) of the studied pairs. At 7 (2.8%) asymmetry was found with respect to the number of root canals.

238 (96.7%) of the pairs included in the study were characterized by an identical root canal configuration. Asymmetry regarding the RCS configuration was found in 8 (3.3%) of the examined pairs of teeth.

E) In the group of maxillary second premolars

Bilateral symmetry regarding the number of roots of the examined teeth was established in 110 (95.7%) of the considered symmetrical pairs. In the remaining 5 (4.3%) a different number of roots of symmetrical teeth is found.

Symmetry regarding the number of root canals was found in 107 (93%) of the studied pairs. At 8 (7%) asymmetry was found with respect to the number of root canals.

100 (87%) of the pairs included in the subtask are characterized by an identical RC configuration. Asymmetry regarding the RCS configuration was found in 15 (13%) of the examined pairs of teeth.

Discussion of the results of task 1.

The analysis of the results for the group of maxillary molars showed that in nearly 1/5 of the studied cases an additional second mesio-buccal RC of maxillary molars was found in one of the molars in the oral cavity and was absent in the opposite tooth of the same name.

An analysis of the results for the group of mandibular molars revealed a high percentage of symmetry with respect to the number of roots of symmetrical pairs of opposite mandibular molars. Regarding the presence of bilateral symmetry in the number of root canals of symmetrical mandibular molars, this percentage is lower - 86.5%. The percentage of asymmetry with respect to the configuration of the RCS in the mesial and distal root of the mandibular molars is even higher. In ¼ of the studied cases the mutual position of the two mesial or the two distal root canals in the mesial or distal root of the mandibular molars, respectively, does not correspond to that of the opposite tooth of the same name. In their study, *Plotino G. et al. 2013* examined the presence of bilateral symmetry in maxillary and mandibular molars in terms of the number of root canals and the configuration of the RCS, using CBCT as a diagnostic tool. The authors found 71.1% symmetry in maxillary first molars and 79.6% symmetry in maxillary second molars. 15.6% of the studied pairs of maxillary first molars are characterized by the presence of a maxillary first molar with 3 roots and 3 root canals and a symmetrical opposite maxillary first molar with 3 roots and 4 root canals. Pairs of maxillary second molars with the same type of asymmetry were observed in 14.8% of the examined patients. The results in the groups of mandibular first and second molars are similar - 30% asymmetry is found in mandibular first molars and 20% - in the second mandibular molars.

The results of our study, which also uses CBCT as a diagnostic tool to establish the presence of bilateral symmetry in terms of the number of root canals and the type of RCS - configuration, are similar. We also found a higher percentage of asymmetry in the groups of the first mandibular and maxillary molars than in the second. This can be explained by the greater variability of the RCS of these groups of teeth, as well as the higher frequency of the presence of additional root canals in them than in the second molars of the upper and lower jaw, which is confirmed by the results of task 2.

An analysis of the results for the group of mandibular canines revealed a high percentage of symmetry in terms of the number of roots, root canals and the type of RCS configuration when there are more root canals in one root of symmetrical pairs of opposite mandibular canines.

When analyzing the results for the group of mandibular incisors, it was found that all studied mandibular incisors have 1 root. Asymmetry in the number of root canals and the type of RCS configuration is rare.

After analyzing and comparing the results, we find that here, as in the group of mandibular canines, a higher percentage of symmetry is found between the endodontic configurations of symmetrical pairs of teeth. This percentage is significantly higher than the percentage of symmetry that we find in the groups of maxillary and mandibular molars. This is explained by the higher frequency of the presence of additional root canals in the molars than in the modibular frontal teeth, as well as by the more complex root canal system of the multi-rooted teeth.

This established higher percentage of bilateral symmetry can serve as a guide, but not as a final assessment of the endodontic configuration in cases where endodontic treatment of symmetrical teeth is necessary simultaneously or at different periods of time.

In their study, *Kayaoglu G. et al. 2015* considered the existence of bilateral symmetry regarding the number of roots and root canals of mandibular frontal teeth, using CBCT as a diagnostic tool. The authors found 100% symmetry regarding the number of roots of mandibular central incisors and 94.8% symmetry regarding the number of root canals, 99.8% symmetry regarding the number of roots of mandibular lateral incisors and 89.8% symmetry regarding the number of root canals and 95.5% symmetry regarding the number of roots of mandibular canines and 93.3% symmetry regarding the number of their root canals.

When analyzing the results for the group of maxillary second premolars, a high percentage of symmetry was found regarding the number of roots of symmetrical pairs of maxillary second premolars. 93% of the studied pairs of teeth are characterized by symmetry regarding the number of root canals. The percentage of symmetry regarding the RCS configuration is lower - 87%. This means that even in cases where opposing second maxillary premolars have the same number of root canals, the relative position of these root canals, the presence of a connection between them, and the level of this connection may vary.

When comparing the results obtained in the study of different groups of teeth, it was found that regardless of the different percentages of bilateral symmetry available in terms of the number of root canals and the type of RCS configuration, asymmetry can always be observed. The possibility of the existence of opposite teeth from one group in the mouth of a patient with a different number of root canals and their different configuration must be taken into account. The analysis of each clinical case should be performed independently, and the information on the morphology of the RCS of the opposite tooth of the same name, if any, serves as a guide, but never replaces a thorough clinical analysis. The results of the study show that even in cases where the number of root canals of teeth from one group is the same, their configuration may differ.

The frequencies obtained by us for the presence of bilateral symmetry of the individual groups of teeth in terms of the number of roots, root canals and the type of RCS configuration differ to varying degrees from the results of other studies affecting other populations. The differences can be explained by the different ethnicity of the examined patients, as well as by the different methodology of the conducted examinations and technical characteristics of the used cone-beam computed tomographs and software for image processing. The results of task 1 show that it is incorrect to judge the configuration of the RCS of a tooth to be treated by the state of the RCS of the opposite symmetrical tooth of the same name.

2. Results from task 2

A) Determining the frequency of available second medio-vestibular root canal of maxillary first molars and the type of root canal system configuration

All studied 230 maxillary first molars have three roots - mesio-vestibular, disto-vestibular and palatal.

163 (70.9%) of the studied first molars have 4 root canals - mesio-vestibular, disto-vestibular, palatal and second additional mesio-vestibular canal. The two mesio-vestibular canals are located in 100% of the cases in the mesio-vestibular root of the tooth. In the remaining 67 (29.1%) of the examined maxillary first molars, a second medio-vestibular root canal was not detected.

In the presence of two root canals in the medio-vestbular root, the most common configuration of RCS in the medio-vestibular root is type IV according to the Vertucci classification - 91 (55.8%) of the examined teeth, followed by type II - 65 (39 , 9%) of the examined teeth, type V - 4 (2.5%) of the examined teeth and type VI - 2 (1.2%) of the examined teeth. In maxillary first molars with one medio-vestibular root canal, its configuration is type I Vertucci (Fig. 5).

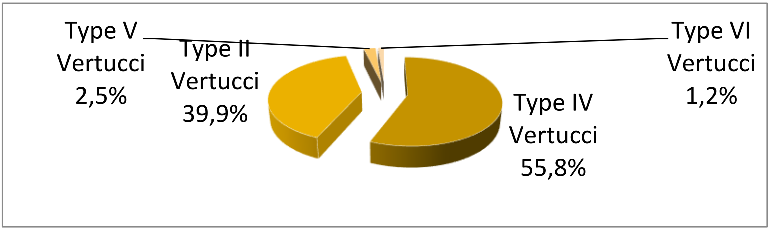


Fig. 5. Distribution of the different types of RCS configuration in the medio-vestibular root of maxillary first molars with second medio-vestibular root canal

B) Determining the frequency of available second medio-vestibular root canal of maxillary second molars and the type of root canal system configuration

All studied 231 maxillary second molars have three roots - medio-vestibular, disto-vestibular and palatal.

77 (33.3%) of the studied second molars have four root canals - medio-vestibular, dysto-vestibular, palatal and second additional medio-vestibular root canal. The two medio-vestibular canals are located in 100% of the cases in the medio-vestibular root of the tooth. 154 (66.7%) of the studied maxillary second molars have three root canals.

In the presence of two root canals in the medio-vestbular root, the most common configuration of the RCS in the medio-vestibular root is type IV according to the Vertucci classification - 44 (57.1%) of the examined teeth, followed by type II - 33 (42 , 9%) of the examined teeth (Fig. 6)

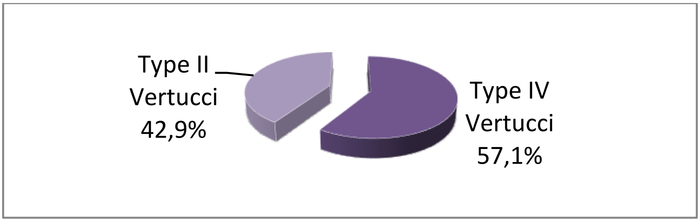


Fig. 6. Distribution of the different types of RCS configuration in the medio-vestibular root of maxillary second molars with four RCs

C) Determining the frequency of available second distal root canal of mandibular first molars and the type of root canal system configuration

Of the studied 230 mandibular first molars, the morphology of RCS with 3 root canals - medio-vestibular, medio-lingual and distal, was found in 160 (69.6%) of the studied cases. In all examined teeth these 3 root canals are located in 2 roots - medial and distal. Four root canals - medio-vestibular, medio-lingual, disto-vestibular and distol-lingual were found in 67 (29.1%) of the examined mandibular first molars. In 2 (0.9%) cases mandibular first molars were found with two root canals - 1 mesial and 1 distal. 1 (0.9%) mandibular first molar with 5 root canals was found - two distal and three mesial.

The most common configuration of the RCS in the mesial root is type IV according to the Vertucci classification - 179 (77.8%) of the examined teeth, followed by type II - 45 (19.6%), type I (in a configuration with one medial root canal) - 3 (1.3%), type VI - 2 (0.9%), type VIII - 1 (0.4%) (Fig. 7).

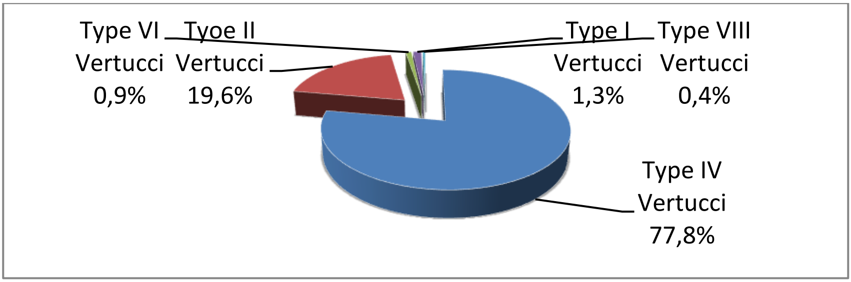


Fig. 7. Distribution of KKS configuration types in the medial root in mandibular first molars

The most common RCS configuration in the distal root is type I (with a single distal root canal configuration) - 164 (71.3%), followed by type II of the Vertucci classification - 29 (12.6%), type IV - 21 (9.1%) and type V - 16 (7%) (Fig. 8).

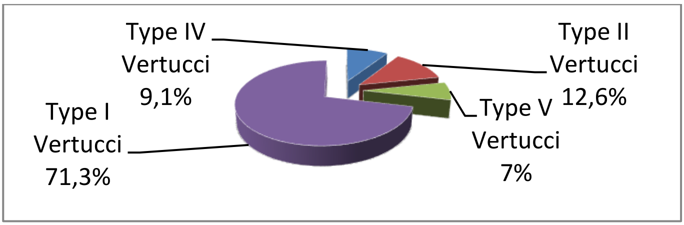


Fig. 8. Distribution of the different RCS configurations in the distal root of the mandibular first molars

D) Determining the frequency of available second distal root canal of mandibular second molars and the type of configuration of the root canal system

Of the studied 230 mandibular second molars, the morphology of RCS with 3 root canals - mesio-vestibular, mesio-lingual and distal, was found in 204 (88.7%) of the studied cases. RCS with 4 root canals was detected in 8 (3.5%) of the examined cases, and one with 2 root canals, one medial central and one distal, in 18 (7.8%) of the examined cases. The sex distribution shows that in 62.5% (5 of the detected mandibular second molars with additional root canal) of the cases this more complex morphology of the RCS is found in men, and in the remaining 37.5% - in women. In 61.1% of the detected mandibular second molars with two root canals, such a configuration of RCS is observed in men, and in the remaining 38.9% - in women.

Regarding the configuration of the RCS in the mesial root of the mandibular second molars, it was found that the most common type of configuration is type IV of the Vertucci classification - 61.7% of the cases studied by us (142 mandibular second molars). 136 of these molars have 3 root canals and the remaining 6 - 4 root canals. A type II configuration from the Vertucci classification was found in 27.4% of the cases we studied (63 mandibular second molars), of which 61 had 3 root canals and the remaining 2 had 4 root canals. A type I configuration from the Vertucci classification was found in 10.9% of the cases we studied (25 mandibular second molars) (Fig. 9).

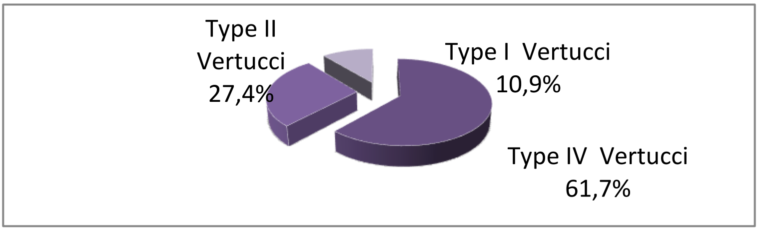


Fig. 9. Frequency of different types of RCS configuration in the mesial root of mandibular second molars

Regarding the configuration of the RCS in the distal root of the mandibular second molars, it was found that the most common type of configuration is type I of the Vertucci classification - the presence of a single root canal in the distal root. This configuration is observed in 96.5% of the cases studied by us (222 mandibular second molars). Type IV and type V configurations of the Vertucci classification are found in 1.3% of the cases studied by us (3 mandibular second molars, respectively). Vertucci type II configuration was detected in 0.9% of the analyzed cases (2 mandibular second molars) (Fig. 10).

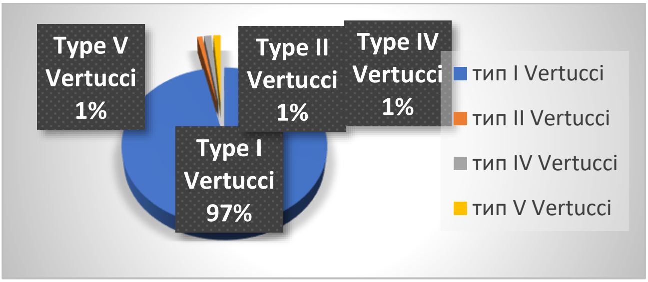


Fig. 10. Frequency of different types of CCS configuration in the distal root of mandibular second molars

E) Determining the frequency of available second root canal of mandibular central incisors and the type of configuration of the root canal system

All studied 248 mandibular central incisors have 1 root containing 1 or 2 root canals - vestibular and lingual. 184 (74.2%) of the studied mandibular central incisors have 1 root canal. A second additional root canal was found in 64 (25.8%) of the studied cases.

In the presence of two root canals, the most common RCS configuration is type II according to the Vertucci classification - 23 (35.9%) of the examined teeth, followed by type V - 19 (29.7%), type IV - 17 26.6%) and type III - 4 (6.2%) of the examined teeth (Fig. 11).

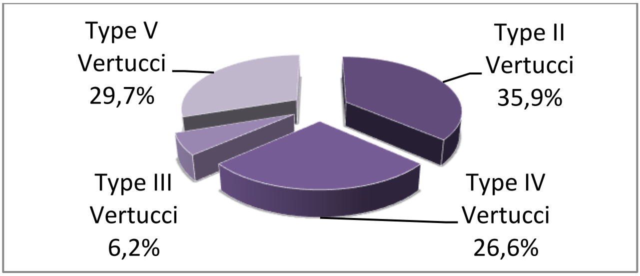


Fig. 11. Distribution of different types of RCS configuration in mandibular central incisors with 2RCs

F) Determining the frequency of the available second root canal of mandibular lateral incisors and the type of configuration of the root canal system

All 250 mandibular lateral incisors examined had 1 root containing 1 or 2 root canals - vestibular and lingual. 188 (75.2%) of the examined mandibular lateral incisors have 1 root canal. A second additional root canal was found in 62 (24.8%) of the studied cases.

In the presence of two root canals, the most common configuration of the RCS is type IV according to the Vertucci classification - 24 (38.7%) of the examined teeth, followed by type II - 16 (25.8%), type V-12 19.4%) and type III –10 (16.1%) of the examined teeth (Fig. 11).

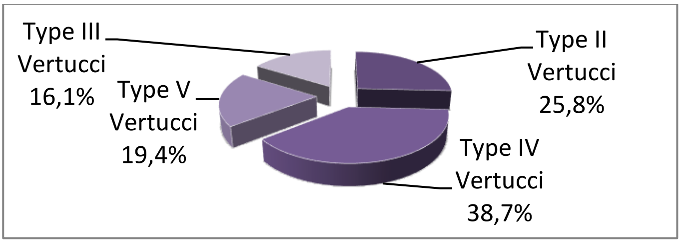


Fig. 11. Distribution of different types of RCS configuration in mandibular lateral incisors with two root canals

G) Determining the frequency of available second root canal of mandibular canines and the type of configuration of the root canal system

247 (98.8%) of the examined 250 mandibular canines have one root, containing 1 root canal in 98.8% (244) of the cases or 2 root canals - vestibular and lingual in 3 (1.2%) of the examined teeth. Mandibular canines with 2 roots and 2 root canals were found in 3 (1.2%) of the studied cases. A second root canal was found in 6 (2.4%) of the 250 mandibular canines examined. The configuration of the root canal system in mandibular canines with two root canals in one root is type II according to the Vertucci classification. In the case of mandibular canines with two roots and two root canals, the configuration of the RCS in them is type I according to the Vertucci classification. 3 of the mandibular canines with two root canals (50%) have a configuration of RCS type II according to the Vertucci classification, and the remaining 3 (50%) - type I according to the Vertucci classification.

H) Determining the frequency of available second root canal of maxillary second premolars and the type of root canal system configuration

Table. 3. Distribution of maxillary second premolars by number and percentage

Teeth	Number	%
• With 1 root and 1 RC	116	50,5%
• With 1 root and 2 RCs	81	35,2%
• With 2 roots and 2 RCs	33	14,3%
Total	230	100%

116 (50.4%) of the maxillary second premolars studied by us have one root canal. A second root canal was found in 49.6% (114) of the maxillary second premolars (Table 3).

The most common RCS configuration of maxillary second premolars with one root is Vertucci type I (58.9%) - for maxillary second premolars with one root, followed by type II of the Vertucci classification - 36 (18.3%), followed by type IV - 31 (15.7%), type V - 8 (4.1%), type III - 4 (2%) and type VI - 2 (1%) of the studied cases. In maxillary second premolars with two root canals, the most common RCS configuration is Vertucci type II - 36 (31.6%), followed by type I - 33 (28.9%), type IV - 31 (27.2 %), type V - 8 (7%), type III - 4 (3.5%) and type VI - 2 (1.8%).

Discussion of the results of task 2:

Analysis of the results for the group of maxillary first molars revealed a high frequency of available additional second mesio-vestibular root canal, located in the mesio-vestibular root -70.9%. The high frequency of the presence of this additional canal in maxillary first molars among the Bulgarian population necessitates its special search in the preparation of the endodontic access and the localization of the orifices. Due to the fact that this variation of RCS is detected in the vestibulo-lingual direction, the presence of an additional medio-vestibular root canal cannot always be diagnosed by two-dimensional radiographic images due to the superimposition of anatomical structures. CBCT allows detailed diagnosis of the presence of an additional root canal and its configuration, but due to the increased radiation dose, the use of this test as a routine before endodontic treatment is limited.

The configuration of the two root canals in the medio-vestibular root also points to the need for increased attention when performing endodontic treatment. In 43% of the cases studied by us, the configuration of the RCS in the medio-vestibular root is more complex, with mergers and / or bifurcations of the root canal at different levels. Proper diagnosis and analysis of the baseline situation reduces the risk of iatrogenic accidents, which are often observed in the treatment of RCSs with a more complex configuration.

An analysis of the results for the group of maxillary second molars revealed a lower frequency of available additional root canal in the medio-vestibular root than in the first - 33.3%. Despite the lower frequency of the presence of an additional root canal in the maxillary second molars than in the first molars, caution is needed here when performing endodontic treatment. The preparation of hard dental tissues for endodontic access, as well as the treatment of the floor of the pulp chamber and the localization of the orifices, should be aimed at the conscious search for an additional root canal. In 42.9% of the cases studied by us, the configuration of the RCS in the medio-vestibular root is more complex with fusion of the root canals apically. The reported frequency of second medio-vestibular root canal in maxillary molars varies from study to study. *Plotino G. et al. 2013* in their study reported the presence of this additional root canal in 38.5% of the analyzed first maxillary molars and 13.4% of the examined second maxillary molars, and the authors here also use CBCT as a diagnostic tool. It has been found that the reported percentage of the presence of this additional root canal increases over the years due to the improvement of the diagnostic tools used to detect it. Frequencies of second medio-vestibular root canal in maxillary molars up to 93% have been reported in the literature *(Smadi L. et al. 2006), (Ng et al.). Tian X. et al. 2016*, conducting a study in China, found the presence of a second medio-vestibular root canal, respectively, 67.8% and 29.7% of the studied first and second maxillary molars. The differences in the frequencies obtained from our study can be explained both by the differences in the cone-beam computed tomographs and image processing software used and by the different populations studied. It has been established that in the presence of differences in the morphology of the RCS in different groups of teeth, there is an ethnic and genetic predisposition *(Skidmore A. et al. 1971)*. A study conducted by *Gusiyska A. in 2015*, which also examined representatives of the Bulgarian population, reported the presence of a second mesio-vestibular root canal in 90.44% of the studied first and 50.91% of the studied second maxillary molars. The author suggests that the mesio-vestibular root of the maxillary molars should always be treated as having two root canals, and the second one should always be consciously searched for. The differences in these results can be explained by the technical and software differences of the cone-beam computed tomographs and image processing programs used. The results of our study show a higher percentage of frequency of the second mesio-vestibular root canal in the maxillary first than in the maxillary second molars, which is in line with the results of the sources reviewed in the literature.

In our study, we found that in the presence of a second mesio-vestibular root canal in maxillary molars, the most common RCS configuration in the mesio-vestibular root is type IV of the Vertucci classification, which is consistent with the results of another study conducted by *Guo J. et al. 2014*, examining the North American population. *Gomes Alves C. et al. 2018* in their CBCT study conducted in Brazil, found the most common configuration in the mesial root Vertucci type II. The differences can be explained by the already described genetic and ethnic predisposition for different features in the morphology of the RCS.

Analysis of the results for the group of mandibular first molars revealed a 29.1% incidence of the presence of a second distal root canal of mandibular first molars. The configuration of the two root canals in the mesial root points to the need for increased attention during endodontic treatment. In 20.5% of the cases studied by us, the configuration of the RCS in the mesial root is more complex, with fusion of the root canals at different levels. A more complex configuration of the RCS in the distal root in the presence of more than one distal root canal requires increased attention and analysis of the initial situation in order to reduce the risk of iatrogenic errors. Analysis of the results for the group of mandibular second molars revealed a 3.5% incidence of the presence of a second distal root canal of mandibular second molars. The results of our study show that the configuration of RCS with two root canals is more common among the Bulgarian population than the configuration ofthe RCS with a fourth additional root canal.

De Pablo O. et al. 2010 reported that the most common RCS configurations in the mesial root of mandibular first molars are Vertucci type II and IV, and in the distal root - type I, followed by type II and IV, which partially coincides with the results of our study.

Regarding the number of roots of mandibular molars, it was found that in the Mongoloid race mandibular molars with 3 roots are significantly more common, and it is believed that this anatomical variation is significantly more common in Indians and members of the Chinese population.

Regarding the number of root canals of mandibular molars, the frequency of the presence of a fourth root canal was reported in 30.5% of the mandibular first and 2.5% of the mandibular second molars, results that are close to those obtained by us *(Kashyap R. et al. 2017)*. *Demirbuga S. et al. 2013* with a CBCT study also found a higher incidence of mandibular molars with three root canals.

An analysis of the results for the group of mandibular central incisors revealed a 25.8% frequency of available additional second root canal of mandibular central incisors among representatives of the

Bulgarian population. The high frequency of the presence of this additional canal in mandibular central incisors among the Bulgarian population necessitates its special search in the preparation of the endodontic access and the localization of the orifices. An analysis of the results for the group of mandibular lateral incisors revealed a 24.8% frequency of available additional second root canal in mandibular lateral incisors among representatives of the Bulgarian population.

The results of our study correspond to the frequency of additional root canal in mandibular incisors reported by *Kalaitzoglou M. et al. 2018* in a study conducted in Brazil - 28.7% incidence in central and 30.1% in lateral mandibular incisors. The authors report the most common configuration of the RCS type III Vertucci, without reporting the presence of Vertucci type IV, which we found to be most common in mandibular lateral incisors with two root canals.

The incidence of a second root canal was reported in mandibular central incisors - 4-67.5%, and in lateral - 10.6-63% *(Sert S. et al. 2004*). These significant differences in reported frequencies are mainly explained by the different methodologies and diagnostic tools used in the studies performed. CBCT was found to allow the detection of a higher percentage of additional root canals than two-dimensional radiographs, but also found an 80% correlation between conical tomography and direct examination after tooth separation *(Neelekanten P. et al. 2010).*

The results of the study show that the presence of a second root and / or second root canal of mandibular canines is rare among members of the Bulgarian population, which is in line with the results of other studies examining other populations.

Kayaoglu G. et al. 2015 reported a frequency of second root in mandibular canines 2-4%, and second root canal - 3.3-8.4%.

Analysis of the results for the group of maxillary second premolars revealed 50.5% frequency of maxillary second premolars with one root canal and one root, 35.2% frequency of maxillary second premolars with one root and two root canals and 14.3% frequency of maxillary second premolars with two roots and two root canals. A second root canal is found in 49.6% (114) of the maxillary second premolars.

The high frequency of the presence of a second root canal in second maxillary premolars (49.6%) among the Bulgarian population necessitates its special search in the preparation of the endodontic access and the localization of the orifices.

The results of our study are consistent with the results of *Alqedairi A. et al. 2018*, which found that the most common are maxillary second premolars with one root, followed by those with two. The configuration of the RCS Vertucci type II and type IV in the presence of two root canals is established, which also partially coincides with the results obtained by us for the most common configuration of RCS Vertucci type II in the presence of two root canals. Other studies examining the number of root canals in maxillary second premolars found a frequency of the presence of type I configuration of RCS - the presence of one root canal in 53.4% of the studied members of the Pakistani population *(Nazeer M. et al. 2018)* and 49.4 % of the representatives of the Turkish population *(Celikten B. et al. 2016)*, which are also close to the values obtained by us, despite the studied different ethnic groups.

Our results regarding the frequency of the presence of additional root canals in the different studied groups of teeth and the distribution by types of RCS configuration differ to different degrees from the results of other studies affecting other populations. The differences can be explained by the already mentioned different ethnicity of the studied patients and by the different technical characteristics of the used diagnostic tools and software for image processing.

3. Results from task 3

A) Determination of the average working length of maxillary incisors

In statistical analysis of the results obtained for the group of central incisors, we found an average value of the working length, determined after measurement on CBCT-images - 11,363 mm.

The box plot diagram illustrates that the median (50th percentile) is not mid-located, therefore the distribution of data on the reported working length is asymmetric (Fig. 12).

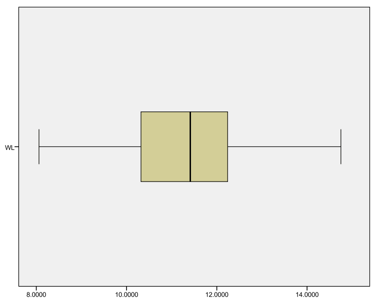


Fig. 12. Box plot diagram of the working lengths of central incisors measured on a CBCT

In a statistical analysis of the results obtained for the group of lateral incisors, we found an average value of the working length, determined after measurement on CBCT-images - 11.14 8 mm.
The box chart illustrates that the median (50th percentile) is not mid-located, therefore the distribution of data on the reported working length is asymmetric (Fig. 13).

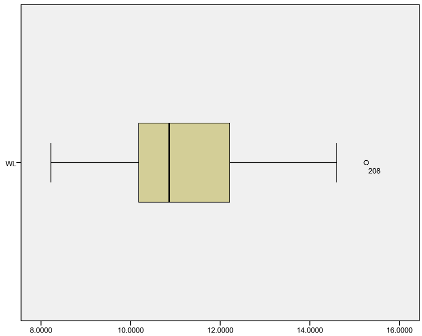


Fig. 13. Box plot diagram of the working lengths of lateral incisors measured on a CBCT

B) Determination of the average working length of maxillary canines

In a statistical analysis of the results obtained for the group of maxillary canines, we found an average value of the working length, determined after measurement on CBCT-images - 13.9397 mm.

The box plot diagram illustrates that the median (50th percentile) is not mid-located, therefore the distribution of data on the reported working length is asymmetric (Fig. 14).

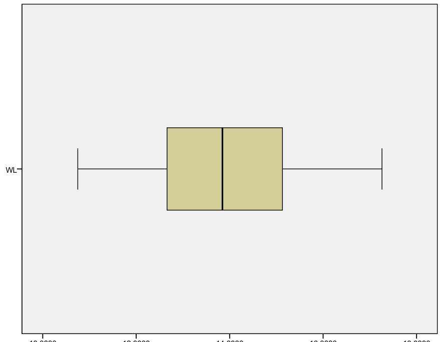


Fig. 14. Box plot diagram of the working lengths of maxillary canines measured on a CBCT

C) Determination of the average working length of maxillary premolars

In a statistical analysis of the results obtained for the vestibular root canal of the maxillary first premolars, we found an average value of the working length, determined after measurement on CBCT-images - 10.99 mm.

In statistical analysis of the results obtained for the palatal root canal of the maxillary first premolars, we found an average value of the working length, determined after measurement on CBCT-images - 10.72 mm.

The box plot chart illustrates that the median (50th percentile) is not mid-located, therefore the distribution of data on the reported working length is asymmetric (Fig. 15).

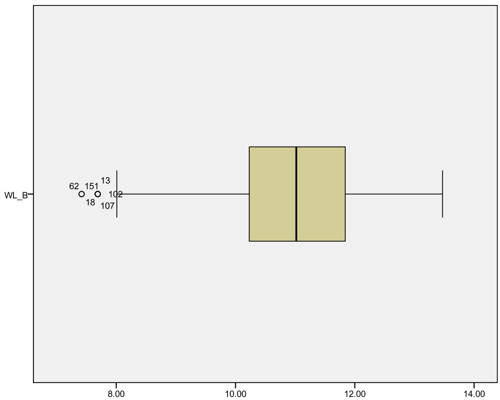


Fig. 15. Box plot diagram of the working lengths of the vestibular root canals of the maxillary first premolars measured on a CBCT

The box plot diagram illustrates that the median (50th percentile) is not median, so the distribution of data on the reported working length of the palatal root canal is asymmetric (Fig. 16).

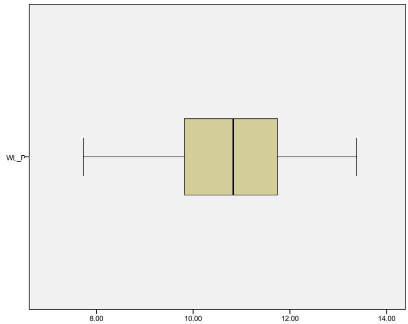


Fig. 16. Box plot diagram of the working lengths of the palatal root canals of the maxillary first premolars measured on a CBCT

In a statistical analysis of the results obtained for the group of maxillary second premolars, we establish an average value of the working length, determined after measurement on CBCT-images - 11,142 mm.

The box plot diagram illustrates that the median (50th percentile) is not mid-located, therefore the distribution of data on the reported working length is asymmetric (Fig. 17).

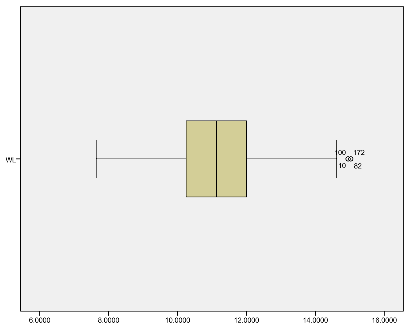


Fig. 17. Box plot diagram of the working lengths of the maxillary second premolars measured on a CBCT

D) Determination of the average working length of maxillary molars

In a statistical analysis of the results obtained for the medio-vestibular root canal of maxillary first molars, we found an average value of the working length, determined after measurement on CBCT-images - 10.6575 mm.

The box plot diagram illustrates that the median (50th percentile) is not mid-located, therefore the distribution of data on the reported working length is asymmetric (Fig. 18).

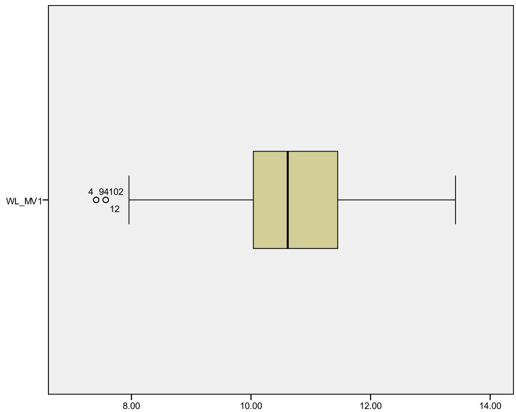


Fig. 18. Box plot diagram of the working lengths of the medio-vestibular root canal of maxillary first molars measured on a CBCT

Second medio-vestibular root canal is observed in 107 (46.5%) of the maxillary first molars studied by us and is absent in the remaining 123 (53.5%). The mean working length of the second medio-vestibular root canal was reported based on the maxillary first molars in which it was observed.

In statistical analysis of the results obtained for the second medio-vestibular root canal of maxillary first molars, we establish an average value of the working length, determined after measurement on CBCT-images - 10.13 mm.

The box chart illustrates that the median (50th percentile) is not mid-located, so the distribution of data on the reported working length is asymmetric.

In a statistical analysis of the results obtained for the disto-vestibular root canal of maxillary first molars, we found an average value of the working length, determined after measurement on CBCT-images - 10.4156 mm.

The box plot diagram illustrates that the median (50th percentile) is not mid-located, therefore the distribution of data on the reported working length is asymmetric (Fig. 19).

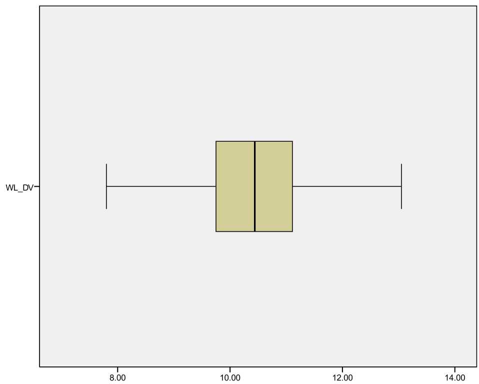


Fig. 19. Box plot diagram of the working lengths of the disto-vestibular root canal of maxillary first molars measured on a CBCT

In statistical analysis of the results obtained for the palatal root canal of maxillary first molars, we found an average value of the working length, determined after measurement on CBCT-images - 11.2283 mm.

The box plot diagram illustrates that the median (50th percentile) is not mid-located, therefore the distribution of data on the reported working length is asymmetric (Fig. 20).

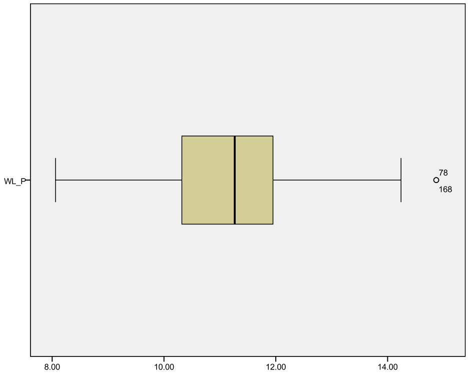


Fig. 20. Box plot diagram of the working lengths of the palatal root canal of the maxillary first molars measured on a CBCT

In a statistical analysis of the results obtained for the medio-vestibular root canal of maxillary second molars, we found an average value of the working length, determined after measurement on CBCT-images - 10.8379 mm.

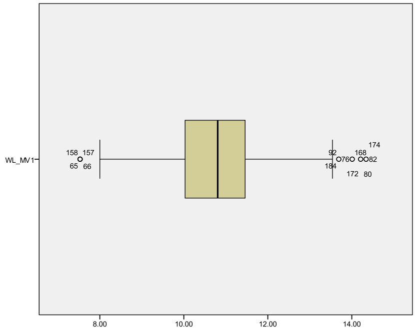


Fig. 21. Box plot diagram of the working lengths of the medio-vestibular root canal of maxillary second molars measured on a CBCT

The box plot diagram illustrates that the median (50th percentile) is not mid-located, therefore the distribution of data on the reported working length is asymmetric (Fig. 21).

Second medio-vestibular root canal is observed in 37 (16.1%) of the maxillary second molars studied by us and is absent in the remaining 193 (83.9%). The mean working length of the second medio-vestibular root canal was reported based on the maxillary second molars in which it was observed.

In statistical analysis of the results obtained for the second medio-vestibular root canal of maxillary second molars, we establish an average value of the working length, determined after measurement on CBCT-images - 10.0516 mm.

The box chart illustrates that the median (50th percentile) is not mid-located, so the distribution of data on the reported working length is asymmetric. The value of asymmetry obtained from the descriptive statistical analysis of the data - 0.504, which falls in the range from -1 to +1, indicates that no significant asymmetry of the data is observed. An extreme value is reported.

In a statistical analysis of the results obtained for the disto-vestibular root canal of maxillary second molars, we found an average value of the working length, determined after measurement on CBCT-images - 10.4652 mm.

The box plot diagram illustrates that the median (50th percentile) is not mid-located, therefore the distribution of data on the reported working length is asymmetric (Fig. 22).

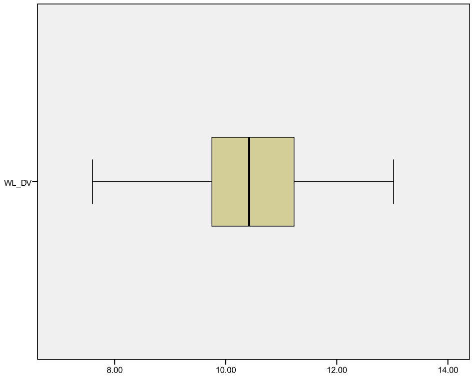


Fig. 22. Box plot diagram of the working lengths of the disto-vestibular root canal of maxillary second molars measured on a CBCT

In statistical analysis of the results obtained for the palatal root canal of maxillary second molars, we found an average value of the working length, determined after measurement on CBCT-images - 10.9879 mm.

The boxing chart diagram illustrates that the median (50th percentile) is not mid-located, therefore the distribution of the data regarding the reported working length is asymmetric (Fig. 23)

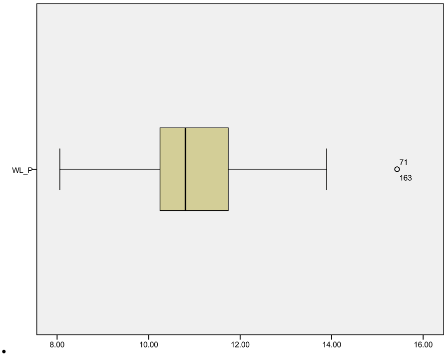


Fig. 23. Box plot diagram of the working lengths of the palatal root canal of the maxillary second molars measured on a CBCT

E) Determination of the average working length of mandibular incisors

In a statistical analysis of the results obtained for the working length of mandibular central incisors, we establish an average value of the working length, determined after measurement on CBCT-images - 10.8967 mm.

The box plot diagram illustrates that the median (50th percentile) is not mid-located, therefore the distribution of data on the reported working length is asymmetric (Fig. 24).

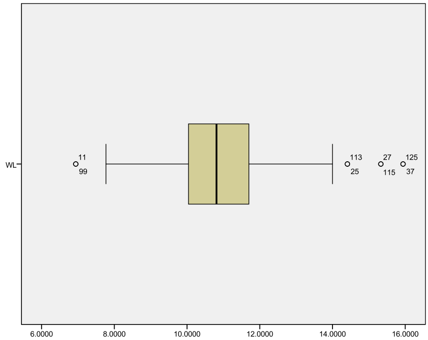


Fig. 24. Box plot diagram of the working lengths of mandibular central incisors measured on a CBCT

In statistical analysis of the results obtained for the working length of mandibular lateral incisors, we establish an average value of the working length, determined after measurement on CBCT-images - 11.2488 mm.

The box plot diagram illustrates that the median (50th percentile) is not in the middle, so the distribution of data on the reported working length is asymmetric (Fig. 25).

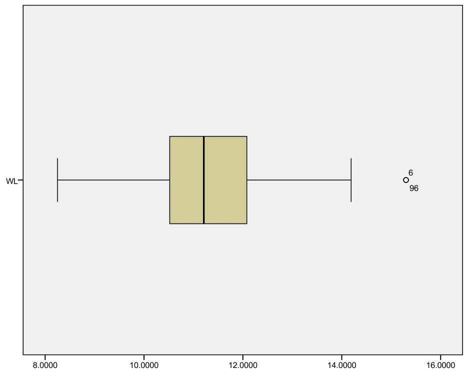


Fig. 25. Box plot diagram of the working lengths of mandibular lateral incisors measured on a CBCT

F) Determination of the average working length of mandibular canines

In a statistical analysis of the results obtained for the working length of mandibular canines, we establish an average value of the working length, determined after measurement on CBCT-images - 11,606 mm.

The box chart illustrates that the median (50th percentile) is not mid-located, therefore the distribution of data on the reported working length is asymmetric (Fig. 26).

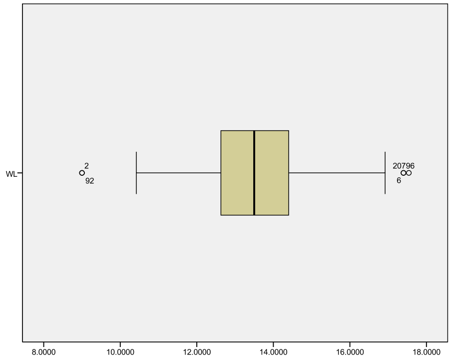


Fig. 26. Box plot diagram of the working lengths of mandibular canines measured on a CBCT

G) Determination of the average working length of mandibular premolars

In a statistical analysis of the results obtained for the working length of the mandibular first premolars, we establish an average value of the working length, determined after measurement on CBCT-images - 11.8814 mm.

The box plot diagram illustrates that the median (50th percentile) is not mid-located, therefore the distribution of data on the reported working length is asymmetric (Fig. 27).

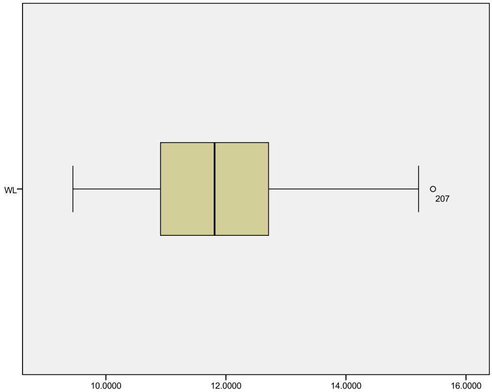


Fig. 27. Box plot diagram of the working lengths of the mandibular first premolars measured on a CBCT

In a statistical analysis of the results obtained for the working length of the mandibular second premolars, we establish an average value of the working length, determined after measurement on CBCT-images - 11.39 mm.

The box plot diagram illustrates that the median (50th percentile) is not mid-located, therefore the distribution of data on the reported working length is asymmetric (Fig. 28).

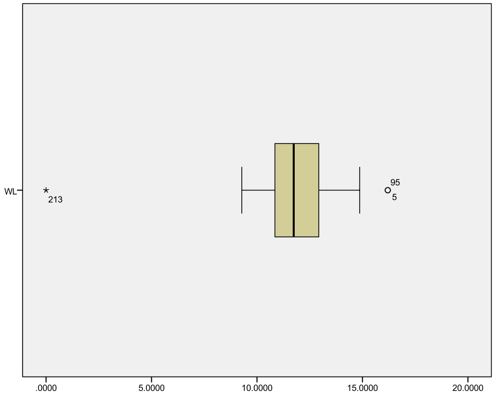


Fig. 28. Box plot diagram of the working lengths of the mandibular second premolars measured on a CBCT

H) Determination of the average working length of mandibular molars

In a statistical analysis of the results obtained for the working length of the mesio-vestibular root canal of the mandibular first molars, we establish an average value of the working length, determined after measurement on CBCT-images - 10.7279 mm.

The box plotdiagram illustrates that the median (50th percentile) is not mid-located, therefore the distribution of data on the reported working length is asymmetric (Fig. 29).

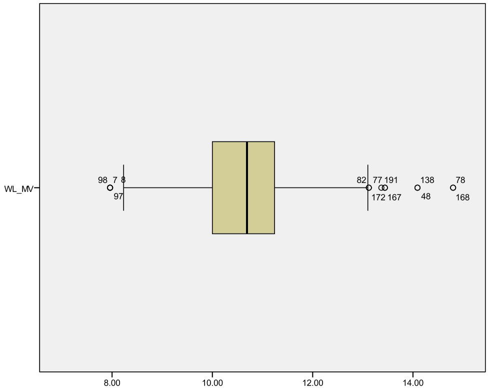


Fig. 29. Box plot diagram of the working lengths of the mesio-vestibular root canal of the mandibular first molars measured on a CBCT

In statistical analysis of the results obtained for the working length of the medio-lingual root canal of the mandibular first molars, we establish an average value of the working length, determined after measurement on CBCT-images - 10.9733 mm.

The box PLOT diagram illustrates that the median (50th percentile) is not mid-located, therefore the distribution of data on the reported working length is asymmetric (Fig. 30).

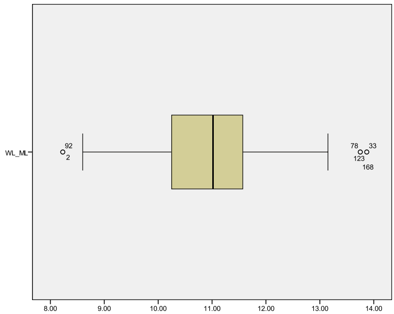


Fig. 30. Box plot diagram of the working lengths of the mesio-lingual root canal of the mandibular first molars measured on a CBCT

In statistical analysis of the results obtained for the working length of the distal root canal of the mandibular first molars, we establish an average value of the working length, determined after measurement on CBCT-images - 10.9391 mm.

The box plot diagram illustrates that the median (50th percentile) is not mid-located, therefore the distribution of data on the reported working length is asymmetric (Fig. 31).

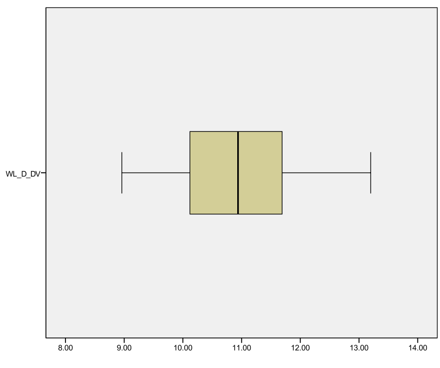


Fig. 31. Box plot diagram of the working lengths of the distal root canal of the mandibular first molars measured on a CBCT

A second distal root canal is observed in 42 (18.3%) of the mandibular first molars we studied and is absent in the remaining 188 (81.7%). The average working length of the second distal root canal was reported based on the mandibular first molars in which it was observed.

In statistical analysis of the results obtained for the second distal root canal of mandibular first molars, we found an average value of the working length, determined after measurement on CBCT-images - 10.7555 mm.

The box chart illustrates that the median (50th percentile) is not mid-located, so the distribution of data on the reported working length is asymmetric.

In a statistical analysis of the results obtained for the working length of the mesio-vestibular root canal of mandibular second molars, we establish an average value of the working length, determined after measurement on CBCT-images - 10.2087 mm.

The box plot diagram illustrates that the median (50th percentile) is not mid-located, therefore the distribution of data on the reported working length is asymmetric (Fig. 32).

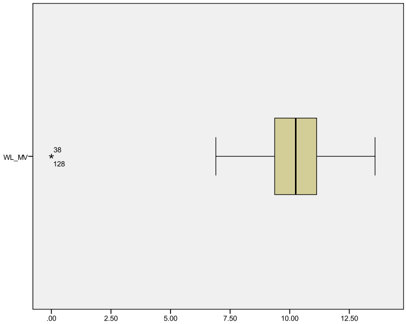


Fig. 32. Box plot diagram of the working lengths of the mesio-vestibular root canal of mandibular second molars measured on a CBCT

In a statistical analysis of the results obtained for the working length of the mesio-lingual root canal of mandibular second molars, we establish an average value of the working length, determined after measurement on CBCT-images - 10.1449 mm.The box plot diagram illustrates that the median (50th percentile) is not mid-located, therefore the distribution of data on the reported working length is asymmetric (Fig. 33).

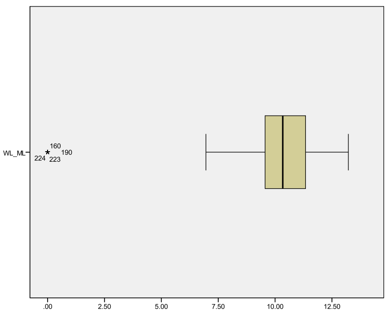


Fig. 33. Box plot diagram of the working lengths of the mesio-lingual root canal of the mandibular second molars measured on a CBCT

In statistical analysis of the results obtained for the working length of the distal root canal of mandibular second molars, we establish an average value of the working length, determined after measurement on CBCT-images - 10.8013 mm. The box plot diagram illustrates that the median (50th percentile) is not mid-located, therefore the distribution of data on the reported working length is asymmetric (Fig. 34).

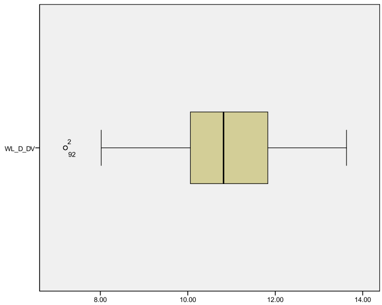


Fig. 34. Box plot diagram of the working lengths of the distal root canal of mandibular second molars measured on a CBCT

A second distal root canal is observed in 6 (2.6%) of the mandibular second molars we studied and is absent in the remaining 224 (97.4%). The working length of the second distal root canal is not presented due to the small number of teeth in which it is found in our study, and the resulting lack of statistical significance of the presented results.

Discussion of the results of task 3

After analysis of the results, we establish relatively close values of working lengths of maxillary central and lateral incisors. An average working length of maxillary canines was found, which is higher than that of the central and lateral incisors of the upper jaw.

Insignificant differences were found in the measured working lengths of the maxillary first and second premolars.

The obtained results show that in maxillary first molars the length of the palatal root canal is the largest, followed by that of the mesio-vestibular and disto-vestibular canal. In the presence of a second mesio-vestibular root canal, it has a shorter length than the first. With regard to the second maxillary molars, the length of the palatal root canal is also the largest here, followed by those of the mesio-vestibular and disto-vestibular canals. In the presence of a second mesio-vestibular root canal, it has a shorter length than the first.

The analysis of the obtained results shows a similar working length in mandibular central and lateral incisors. When comparing the obtained results with those from the group of maxillary central and lateral incisors, we found similar working lengths of the incisors of the upper and lower jaw. After analysis of the results, we found a greater length of the root canal in mandibular canines than in mandibular central and lateral incisors.

Similar values of working length of the mandibular first and second premolars are established. When comparing the results from the group of maxillary premolars, we find higher values of the length of the root canals in the mandibular.

After analysis of the results, we found that in mandibular first molars the mesio-vestibular and mesio-lingual root canal have similar lengths. In the presence of two distal root canals, their length is similar. With regard to the mandibular second molars, we obtain similar results as in the first molars - the two mesial root canals have similar working lengths.

The values of working lengths by groups of teeth of the upper and lower jaw established by the analysis of our results are average values, having mainly indicative character during endodontic treatment, and cannot replace the use of methods for determining working length in the course of treatment. The results obtained by us differ to varying degrees from the results of other studies affecting other populations. The differences can be explained by the different ethnicity of the patients studied, as well as by the different technical characteristics of the diagnostic tools and software used for processing the three-dimensional images.

4. Results from subtask 3.1.

When analyzing the results obtained for the group of incisors, we establish an average value of the working length determined after measurement on CBCT-images - 19,788 and the average value of the working length after measurement with an apex locator is 19,967.

When comparing the values of the working length determined by CBCT and by apexlocator in the group of incisors, we establish a correlation value of 0.959. The value of the correlation is close to 1, which means that a high degree of dependence between the two types of measurement is established. Significance Sig. = 0.000 < 0.01, therefore the correlation coefficient is considered statistically significant.

For the purposes of statistical processing of the obtained results, we assume as a null hypothesis the absence of a statistically significant difference between the two types of measurement in all three studied groups of teeth. As an alternative hypothesis, we assume the presence of a statistically significant difference between the measurements with apexlocator and on CBCT-images.

After statistical processing of the results from the group of incisors, we establish the average value of the reported difference between the two types of measurement - -0.1786667. The determined p-value is 0.033. With a confidence interval of 95% ($\alpha = 5\%$) we can say that the difference between CBCT-measurement and measurement by electrometric method in the general population is statistically significant for the group of incisors.

When analyzing the results obtained for the group of canines, we found an average value of the working length determined after measurement on CBCT-images - 23,415 and the average value of the working length after measurement with an apex locator is 23,688.

When comparing the values of the working length determined by CBCT and by apexlocator in the group of canines, we establish a correlation value of 0.997. Here, too, a high degree of dependence between the two types of measurement is established and the correlation coefficient is considered statistically significant.

After statistical processing of the results for the group of canines, we establish the average value of the reported difference between the two types of measurement - -0.2725. The determined p-value is 0. With a confidence interval of 95% ($\alpha = 5\%$) we can say that the difference between CBCT-measurement and measurement by electrometric method in the general population is statistically significant for the group of canines.

In the p-values obtained after statistical processing for the groups of incisors and canines, we have reason to reject the null hypothesis in favor of an alternative hypothesis at a significance level of $\alpha = 1\%$, $\alpha = 5\%$ or $\alpha = 10\%$. With 99%, 95% or 90% certainty we can say that the difference between CBCT-measurement and apexlocator measurement in the general population is statistically significant for both groups.

When analyzing the results obtained for the group of premolars, we establish an average value of the working length determined after measurement on CBCT-images - 18,920645 and the average value of the working length after measurement with an apexlocator is 18,984.

When comparing the values of the working length determined by CBCT and by apexlocator in the group of premolars, we establish a correlation value of 0.948. Here, as in the group of incisors, a high degree of dependence between the two types of measurement is established, the correlation coefficient is considered statistically significant.

After statistical processing of the results for the group of premolars we establish the average value of the reported difference between the two types of measurement - -0.0632258. The determined p-value is 0.485. With a confidence interval of 95% ($\alpha = 5\%$) we can say that the difference between CBCT-measurement and measurement by electrometric method in the general population is not statistically significant for the group of premolars.

Given the p-value obtained after statistical processing for the group of premolars, we have no reason to reject the null hypothesis in favor of an alternative hypothesis at a level of significance $\alpha = 1\%$, $\alpha = 5\%$ or $\alpha = 10\%$. We do not have sufficient information to claim that the difference between CBCT measurement and apexlocator measurement in the general population is statistically significant at $\alpha = 1\%$, $\alpha = 5\%$ or $\alpha = 10\%$ (confidence interval 99%, 95% or 90%).

Discussion of the results of subtask 3.1.

After analysis of the results of subtask 3.1. for the group of incisors we establish an average value of the reported difference between the two types of measurement - -0.1786667. At the 95%

confidence interval we selected for the study, we found that the difference between CBCT measurement and electrometric measurement in the general population was statistically significant for the group of incisors. In the group of canines we report an average value of the difference between the two types of reporting - -0.2725, which we also report as statistically significant. For the group of premolars we report an average value of the difference between the two methods of measurement - 0.0632258, which we cannot determine as statistically significant.

Due to the fact that in clinical practice when determining the working length differences in the measured values below 0.5 mm are not taken into account, the results of our study show that CBCT is a method that can be used to determine the working length of the root canal during endodontic treatment.

Possible variations in the anatomy of the apical area of the root canal sometimes make it difficult to accurately position the area of physiological constriction. Despite the generally accepted position of the physiological constriction of 0.5 mm to 1 mm from the radiological apex of the tooth, the possibility of variations in its level can lead to errors associated with over-instrumentation and compression of the canal-filling agent. The electrometric method, as one of the most commonly used methods for determining the working length, is characterized by varying degrees of accuracy according to the in vivo and in vitro studies performed. It was found that the accuracy of determining the working length by apexlocator is greatest in the presence of healthy periapical tissues or those with minimal pathological changes. Various factors can affect the reliability of electrometric measurement.

The results of our study prove that the determination of working length based on CBCT-measurement is a method characterized by an accuracy compatible with that of the electrometric method.

The high radiation load, as well as the higher cost, severely limit the application of CBCT as a means of determining the working length. The accuracy and the possibility for clinical application of the electrometric method make the appointment for CBCT-scan for such a purpose irrational. In the presence of strongly curved root canals, where it is not possible to perform the measurement in one plane, the accuracy of the CBCT measurement is expected to decrease.

The differences in the measured values by the two methods may be due to minimal displacement of the coronary landmark despite our attempts to unify the coronary reference point, as well as some inaccuracies in measurement on CBCT-images in the presence of minimal and unreported curves of roots and root canals of the teeth included in the study. In the presence of significant curvatures of the root canals, which do not allow the measurement on the three-dimensional images to be performed in one plane, we expect greater differences in the obtained values.

The smaller observed difference of the reported working lengths by the two methods in the group of premolars may be due to their straighter roots, and thus root canals, than those of the incisors and canines.

5. Results of task 4

A) Examination of the frequency of the presence of denticles in the RCS

The study included 738 teeth from the following groups (Table 4):

Table. 4. Distribution of the teeth included in the study by groups

Total	738
Incisives	209
Canines	119
Premolars	216
Molars	194

The presence of calcifications in the RCS was observed in 54 (7.3%) of the 738 teeth included in the study. In 57% (31) of the examined teeth the calcifications are found in the pulp chamber, and in the remaining 43% (23) - in the root canals.

Of the 209 incisors examined, denticles in the pulp chamber were detected in 1 (0.5%) of them. In 2 (0.9%) of the examined premolars and 28 (14.4%) of the examined molars, denticles were found in the pulp chamber. No denticles were found in the canine group.

Of the 209 incisors examined, calcifications in the root canals were found in 4 (1.9%) of them. In 7 (3.2%) of the examined premolars and 12 (6.2%) of the examined molars, calcifications were found in the root canals. No calcifications were found in the canine group.

Regarding the age distribution, it was found that 32 (59.2%) of the teeth with denticles and calcifications were found in patients in the age group of / over 40 years. 11 (34.4%) of these calcifications are found in the form of denticles in the pulp chamber, and the remaining 21 (65.6%) - in the root canals of the examined teeth.

In the group of patients under 40 years of age, 22 teeth (40.8%) with calcifications and denticles were found - 20 (91%) of them in the pulp chamber and 2 (9%) - in the root canals of the examined teeth. Of the 31 teeth with denticles found, 20 (64.5%) belonged to the age group under 40 years of age and 11 (35.5%) - to / over 40 years of age.

Discussion of the results of the frequency of the presence of denticles in the RCS

The analysis of the results shows the presence of calcifications in 7.3% of the examined teeth. The localization distribution shows a slightly higher percentage of denticles in the pulp chamber - 57% than available calcifications in the root canals - 43%.

The age distribution in the volume of our study shows a predominance in the frequency of denticles / calcifications in patients of / over 40 years of age - 59.2%.

The presence of calcifications in the pulp chamber and root canals can make it very difficult to perform routine endodontic treatment, on the one hand preventing the localization of orifices, and on the other - the mechanical treatment of root canals. Preliminary radiographic analysis helps to localize calcifications in the RCS and thus reduces the risk of iatrogenic accidents during treatment. In order to be visualized on radiographs, the denticles must be larger than 200 μm. Detection of denticles on periapical or bitewing radiographs can be very difficult due to the superposition of the strong shadow of the alveolar bone. The images obtained from CBCT eliminate the overlap of anatomical structures and this defines them as a more accurate diagnostic tool than conventional radiographic images in the detection of denticles.

Regarding the type of teeth examined, as well as other studies on the subject, we find the highest percentage of denticles and calcifications in the group of molars. The reason for this may be related to the larger volume of the pulp chamber compared to other groups of teeth, which is also related to the larger amount of pulp tissue and better blood supply, which can help the formation of precipitates in the pulp chamber. Regarding the age distribution in the course of our study, we found a higher frequency of available denticles and calcifications in the root canals in patients in the age group of / over 40 years of age, which can be explained by age-related changes occurring in the endodontic, as well as with a prolonged persistence of chronic trauma and inflammatory processes.

The incidence of denticles and calcifications obtained by us differs to varying degrees from the results of other studies affecting other populations. When using the same diagnostic tool - CBCT, different studies report different frequencies of available denticles, which is explained by the different ethnicity of the subjects and the different technical characteristics of cone-beam computed tomography and imaging software, and also with the scope of the examination - affecting only the pulp chamber, or the pulp chamber and the root canals of the examined teeth.

B) Study of the frequency of root fractures that occurred after endodontic treatment among the Bulgarian population.

The study included 241 distal teeth (Table 5).

Table. 5. Distribution of the total number of teeth by groups

Total	241
Molars	152 (63%)
Premolars	89 (37%)

Index 0 is found in 207 of the teeth we examined, index 1 - in 25 of them, of which in 14 the presence of a fracture line is assumed and in 11 the presence of atypical bone resorption directs us to the presence of a root fracture. Index 2 is found in 9 of the 241 teeth we examined.

In 14 (56%) of the 25 teeth found by us with index 1, the presence of a fracture line of the tooth root on the three-dimensional images is assumed, and in the remaining 11 (44%) the presence of atypical bone resorption is observed. Endodontic origin was excluded. In all 9 (100%) of the teeth we found with index 2, the presence of atypical bone resorption was detected. The presence of a clearly visible fracture line is not established in any of the endodontically treated teeth studied by us.

All cases of suspected fracture lines on the root surface of endodontically treated distal teeth described by us belong to index 1 - on the basis of three-dimensional images a root fracture cannot be definitively and unambiguously diagnosed on the basis of this indicator. Of the 20 cases of atypical bone resorption, 11 (55%) of them belong to index 1 and 9 (45%) - to index 2.

Within the 241 teeth examined by us, in 207 (85.9%) no pathological changes were detected on the three-dimensional images, in 14 (5.8%) the presence of a fracture line can be assumed, in 11

(4.6%)) the presence of atypical bone resorption is assumed, but endodontic etiology cannot be completely ruled out and in 9 (3.7%) of them - the presence of atypical bone resorption is established, in which we can exclude endodontic character.

Of the 89 premolars studied by us, index 0 is observed in 81 (91%) of them, index 1 - in 7 (7.9%) and index 2 - in 1 (1.1%) of them.

Of the 152 molars we studied, index 0 was observed in 126 (82.9%) of them, index 1 - in 18 (11.8%) and index 2 - in 8 of them (5.3%).

Discussion of the results for the frequency of root fractures, which occurred after endodontic treatment, among the Bulgarian population.

After analysis of the obtained results, it was found that 85.9% of the examined endodontically treated distal teeth did not show radiographic signs of an existing root fracture such as the presence of a fracture line and / or atypically located bone resorption around the root of the tooth.

Root fractures of devitalized teeth in many cases are asymptomatic or with mild symptoms. One of the main features of root fractures of some longevity is the presence of bone resorption, located atypically around the root of devitalized teeth, and the inability to associate this resorption with an infection of endodontic or periodontal origin.

In the course of our research on three-dimensional images, we were unable to visualize a clear fracture line of the root, assuming that this was the result of artifacts caused by the strong shadow of the canal fillers. On the three-dimensional images we manage to find an atypically located bone resorption, in which we do not find a direct connection with the apical space and therefore we assume that it is not of endodontic nature. In cases of atypical bone resorption present, leading to an existing root fracture, the fracture line is not clearly visible on the three-dimensional images. Accordingly, we include the possibility that this bone loss may have another etiology.

In the scope of our study, our results show that CBCT allows the detection of existing bone resorption, as well as establishing its parameters such as size, distance to neighboring important anatomical structures, ratio to the root of the tooth, endodontic space, etc., but does not allow definite establishment of a fracture line of the roots of teeth with obstructed root canals. As a non-invasive diagnostic tool in the search and detection of root fractures, CBCT can be used as an additional method, always preceded by a preliminary clinical examination and conventional X-ray examination.

The distribution by groups of teeth shows more affected molars than premolars, which may be related to the greater masticatory load that this group of teeth takes. The strength of the masticatory load depends not only on the position of the tooth in the dentition, but also on additional factors related to the patient, such as the characteristics of the bite, the presence of reduced dentition or not, the type of masticatory muscles, etc. which out study has not taken into account.

V. Conclusion

In the field of endodontic practice, clinical and imaging studies are extremely important in order to perform optimal preoperative diagnosis. Properly selected imaging studies complement the clinical examination and allow a more detailed assessment of the study area. Conventional and digital radiographic methods, which allow obtaining high-resolution images, are still among the most commonly used methods for diagnostic imaging in routine endodontic practice. However, their diagnostic potential is limited. Their two-dimensional nature is not able to present the complex volumetric characteristics of the endodontic and periapical tissues, as well as their relationships with neighboring anatomical structures. The information obtained can sometimes be difficult to interpret, especially in more complex cases with atypical anatomy of the root canal system, as well as in the occurrence of intraoperative complications. Understanding the complexity of the root canal system of each tooth is the basis for the success of the treatment. Any underestimation of the baseline condition leads to an increased risk of iatrogenic events and thus may affect the long-term survival of endodontically treated teeth.

The results of our study prove the role of CBCT in the field of endodontics in terms of assessing the configuration of the RCS, the detection of anatomical variations of the endodontic space and the diagnosis of pathological conditions.

VI. Conclusions

1. Bilateral symmetry regarding the number of roots, RCs and type of RCS configuration is often found in the groups of mandibular canines, mandibular incisors and maxillary second premolars. It is less common in the group of maxillary molars and in the group of mandibular molars. When comparing the results, it is found that regardless of the different percentages, asymmetry can always be observed and it is incorrect to judge the configuration of the RCS of the tooth to be treated by the state of the RCS of a symmetrical tooth.

2. Most often additional RCs are found in maxillary first molars with the most common RC-configuration in MB-root - Vertucci type IV. Less commonly, additional RCs are found in maxillary second and mandibular first molars with Vertucci type IV configurations for maxillary molars and Vertucci type II configuration in the distal root and Vertucci type IV in the mesial root in mandibular molars, respectively. Second RC in maxillary second premolars is found in nearly half of the cases we studied with the most common Vertucci type II configuration. In ¼ of the cases we studied, the mandibular central and lateral incisors have an additional second RC with the most common configurations, Vertucci type II and Vertucci type IV, respectively.

3. The determination of working length in single-rooted teeth on the basis of CBCT measurement is a method characterized by an accuracy comparable to that of the electrometric method.

4. Most denticles and calcifications in the RCS are found in the group of molars.

5. CBCT-examination can be used in the diagnosis of root fractures of endodontically treated teeth.

VII. Contributions

Confirmatory contributions:

1. The advantages of CBCT application in the field of endodontics have been proven.

2. The high frequency of available additional root canals in maxillary and mandibular molars, maxillary second premolars and mandibular incisors is confirmed.

3. The accuracy of the CBCT measurements when determining the working length is confirmed.

4. The possibilities to establish the configuration of the RCS and the presence of denticles and calcifications in the RCS are confirmed by CBCT-diagnostics.

5. The role of CBCT diagnostics in helping to detect root fractures is confirmed.

Contributions of original character for the country:

1. For the first time, a study with such a scope was performed, aimed at proving the application of CBCT in the field of endodontics.

2. For the first time a comparative study of the accuracy of determining the working length by CBCT - measurement and by electrometric method was performed.

3. For the first time the frequency of available additional root canals by groups of teeth among the Bulgarian population was established, using CBCT as a diagnostic tool.

4. For the first time a CBCT study was conducted, aiming to establish bilateral symmetry between the number of roots, RCs and the type of RCS configuration in symmetrical pairs of teeth among the Bulgarian population.

5. For the first time a CBCT study was conducted, aimed at analyzing the configuration of the root canal system in each root by groups of teeth among the Bulgarian population.

VIII. Publications and participation in scientific forums

1. Publications:

- Slavena Svetlozarova, Tsvetelina Borisova-Papancheva. Cone Beam Computed Tomography as a Diagnostic Tool in Endodontics A Review of the Literature. Adv Dent & Oral Health. 2019; 11(1): 555810.
- Svetlozarova S., The Morphology of Maxillary First and Second Molars, Analyzed by CBCT - a Review of Literature, Medinform 2020; 7(2): 1249-1255.
- Svetlozarova S. C-Shaped Root Canal System– A Review of Literature. Adv Dent & Oral Health. 2020; 13(2): 555859.

2. Participation in scientific forums:

- 3D –Imaging in Endodontics- Advantages and Limitations. 29th Assembly of IMAB, May 2019, Varna, Bulgaria
- CBCT Evaluation of Root Fractures – 31st Assembly of IMAB, October 2021, Plovdiv, Bulgaria