MEDICAL UNIVERSITY - PLOVDIV

FACULTY OF DENTAL MEDICINE

DEPARTMENT OF OPERATIVE DENTISTRY AND ENDODONTICS

Head of Department: Prof. Dr. Neshka Manchorova-Veleva, DSc

DR. KOSTADIN IVANOV ZHEKOV

OBTRUTION OF THE ROOT CANAL SYSTEM WITH HYDRAULIC CONDENSATION AND BIOCERAMIC SEALER

SUMMARY OF A PhD THESIS

of a dissertation for the award of
educational and scientific degree "DOCTOR"

Supervisor: **Assoc. Prof. Dr. Vessela Stefanova, PhD**

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The dissertation contains 184 pages and is illustrated with 10 tables and 41 figures. The bibliography contains 318 sources, of which 11 in Cyrillic and 307 in Latin.

Note: In the abstract the numbering of the tables and figures does not correspond to the numbering in the dissertation.

The research from the dissertation was performed in the Department of Operative Dentistry and Endodontics, the Department of Imaging, Dental Allergology and Physiotherapy at the Faculty of Dental Medicine, and the Department of Medical Physics and Biophysics at the Faculty of Pharmacy - Plovdiv University.

Scientific jury:
Chairman: Prof. Dr. Neshka Manchorova-Veleva, DSc

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The public defense of the dissertation before a scientific jury will take place on 03.02.2022 from 11.00 at Zoom (https://zoom.us/j/98922988774).

The materials on the defense are available at the Scientific Department of MU-Plovdiv, 15A Vasil Aprilov Blvd., and on the website of the Medical University - Plovdiv.

CONTENTS

Abbreviations used

KKS – root - canal system
GP – gutta-percha
TZT – hard dental tissues
LC – lateral condensation
HC – hydraulic condensation
MTA – mineral trioxide aggregate
BKM – bioceramic material
BKS – bioceramic sealer
NPEL – non-surgical endodontic retreatment
KK – root canal
KPM – root canal filling material
RD – working length
OZE – Surgical dentistry and endodontics
DDM – Pediatric Dentistry
ODM – General Dental Medicine
FR – Formalin - resorcinol
COE – Zinc oxide - eugenol
MB – Methylene blue
AU – absorption units
HOME – digital optical microscopy
CBCT – Cone Beam Computer Tomography

I. INTRODUCTION

The success of endodontic treatment is a multifactorial. It depends on the perfect performance of each of the stages of the endodontic triad, as well as on the quality of the post-endodontic restoration.

Gutta-percha (GP) itself does not have adhesive properties to the root canal wall. Therefore, it is always applied together with a sealer, which ensures the sealing of the endodontic space as an intermediary between the base material and the dentin of the root canal wall. It forms a barrier to microorganisms and body fluids, preventing them from diffusing coronally, apically or laterally.

Grossman postulated the requirements for an "ideal" endodontic sealer more than 70 years, but to this day no one has been created. However, the group of the latest, so-called "bioceramic" or tricalcium silicate endodontic sealers, attracts the attention of clinicians with its promising properties. They are hydrophilic in nature, have antibacterial properties, exceptional biocompatibility, proven bioactivity, chemical adhesion to dentin and expand upon hardening.

However, these sealers are not indicated for use with the three-dimensional obturation technique, proposed by Schilder. Temperature fluctuations during its implementation degrade some properties of bioceramic materials and can lead to unsatisfactory results. The manufacturers recommend that they be used with cold techniques - lateral condensation (LC) or hydraulic condensation (HC).

It is recommended to use coated and/ or impregnated with bioceramic (calcium silicate) particles gutta-percha pins, which chemically bond to the sealer, and thus eliminate the possibility of percolation of fluids between the gutta-percha pin (core) and the endodontic sealer. The use of an impregnated calibrated gutta-percha pin is based on the "monoblock" concept, reaching its apogee with the development of bioceramic technologies.

Hydraulic condensation is an easy and fast alternative to the current methods for obstruction of KKS presenting promising results. It is based on the use of a calibrated gutta-percha pin and a hydrophilic endodontic sealer. Due to the hydrophilic nature of the material and the perfectly matching gutta-percha pin (endodontic synchrony), the latter acts as a piston, which pushes the sealer in all directions of the complex KKS, providing a reliable three-dimensional obturation. In this case, however, the latter is achieved quickly and easily, without the use of expensive equipment, and with comparable, if not superior clinical results.

II. AIM AND TASKS

2.1. AIM

The aim of the present dissertation is to study the peculiarities of obturation of the root canal system with the technique of hydraulic condensation and bioceramic endodontic sealer.

2.2. TASKS

To achieve the aim formulated in this way, we set ourselves the following tasks:

1. To study through a survey method the attitude of dentists from Plovdiv region to the application of bioceramic endodontic sealers in their clinical practice.
2. To study the micropermeability of root canal obturation using the technique of hydraulic condensation and bioceramic sealer BioRoot RCS.
3. To explores the possibility of re-performing endodontic treatment and evaluation of residual canal filling material in root canals obstructed by hydraulic condensation and bioceramic endodontic sealer.
   - 3.1. To study the possibility of achieving apical patency in root canals obstructed by a bioceramic sealer and a gutta-percha pin, positioned respectively on the RD and 2 mm shorter than the RD.
   - 3.2. To make a three-dimensional topographic characteristic of the residual material on the root canal wall after preparation of pre-obturated root canals using 3D cone-beam tomography (3D CBCT) and a microscope.
4. To carry out clinical study on the healing process after root canal obstruction by hydraulic condensation and BioRoot RCS.
5. To develop clinical protocols for optimizing the application and removal of bioceramic endodontic sealers.
   - 5.1. Protocol for obturation of root canals by hydraulic condensation and bioceramic endodontic sealer.
   - 5.2. Protocol for removal of bioceramic endodontic sealer BioRoot RCS from the root canal.

III. MATERIALS AND METHODS

3.1. Research of the attitude of dentists from Plovdiv region to the application of bioceramic endodontic sealers in their clinical practice.

Anonymous questionnaires were distributed to 200 dentists from the Plovdiv region, mainly at events organized by the Bulgarian Dental Association (BDA). Of these, 164 were correctly completed, which were subjected to statistical processing using licensed software Numbers 6.2 (Apple Inc.) and SPSS version 26 (IBM), and applied Z-test to compare two relative partitions.

Object of observation: Approach of dentists in the application of bioceramic sealers in endodontic practice.

Observation units: Dentists who filled in the questionnaire correctly.

Signs of observation: Gender, age, experience, specialty, data on practices, frequency of endodontic treatment, approach in the choice of material and method for obturation of the CSF, tracking the results of endodontic treatment

Observation time: March 2019 - April 2020

Place of observation: The survey was conducted through individual presentation of questionnaires during events organized by the BDA.

Surveillance authorities: For the purposes of the survey, the dissertation is personally engaged in the task.

Registration: For the purposes of the study, an original questionnaire was developed, which contains 20 questions, nine of which are socio-demographic, and the rest concern the studied signs of observation.

Statistical processing: A Z-test was applied to compare two relative proportions in independent samples.

3.2. Investigation of micropermeability in root canal obturation using the technique of hydraulic condensation and bioceramic sealer BioRoot RCS.

The materials on the experimental formulation of this task are partially provided by the national research program "Young Scientists and Postdoctoral Students" at the Ministry of Education and Science, Medical University - Plovdiv and the Faculty of Dental Medicine.

Object of observation: 42 single-rooted teeth.

Observation units: The individual tooth included in a system of Eppendorf tubes.

Signs of observation: Filtration of 2% methylene blue after application of a pressure of 1 atm for 1 hour.

Observation time: August 2020

Place of observation: Department of Operative Dentistry and Endodontics at the Faculty of Dental Medicine, Department of Medical Physics and Biophysics at the Faculty of Pharmacy, Medical University – Plovdiv

Surveillance authorities: To carry out the experiment, the dissertation works together with an expert from the Department of Medical Physics and Biophysics, Faculty of Pharmacy, Medical University –- Plovdiv.

Registration: TECAN spectrophotometer, Sunrise
Statistical processing: Variation analysis Kruskal-Wallis test and Dunn's Multiple Comparison test.

- **Sample preparation**

For this study, 42 extracted human single-rooted teeth were used without endodontic treatment. After extraction, the teeth were mechanically cleaned with a curette of organic residues, placed in oxygenated water for 24 hours, then washed and stored under appropriate conditions (0.5% solution of Thymol and 40C).

On each of them, the coronary part is removed by means of a diamond separator so as to obtain specimens with a standardized length of 12 mm. A standard endodontic cavity with diamond drills and a turbine tip was dissected and the contents of the pulp chamber were removed by round metal drills and washes with sodium hypochlorite. This is followed by the passage of the root canals (CC) of all teeth with a K-file №10 and the establishment of apical patency. The working length (RD) is measured using an apex locator and a simulation setup. After the preparation of a smooth road with manual K-files №10, 15 and 20, the machine preparation of KK is started.

The Pro Taper system was used for 12 of the samples (PT6 group) Gold (PTG, Densply Meillefer, Switzerland), which is characterized by variable conicity embedded in the design of the file, which determines the spatial characteristics of the resulting preparation. For the remaining 24 (groups C4 and BC4) use the iRace system (FKG, Switzerland), characterized by a constant taper of the instruments, providing constant (fixed) conicity of the obtained root canal preparation.

For group PT6, the files from the Pro Taper system are used sequentially Gold until the working length is reached with file F3 (D0 = 0.3 mm; 9% taper in the apical 3 mm), and for groups C4 and BC4 the files from the iRace system are applied successively until reaching RD with file R3 (D0 = 0.3 mm; 4% permanent taper along the entire length of the CC).

Irrigation is performed with 2.5% sodium hypochlorite on each instrument change. The final irrigation is performed with 17% EDTA sound activated for 1 minute. and 2.5% sodium hypochlorite sound activated for 3 min. and subsequent washing with sterile saline for neutralization of irrigation solutions. The root canals are dried with sterile paper pins from the appropriate system until the last paper pin is removed dry from the CC.

The BioRoot RCS endodontic sealer (Septodont, France) is mixed according to the manufacturer's instructions, and applied to the root canal by means of a Lentulo-type duct filler mounted on an endomotor (X-Smart, Densply) and driven by600 rpm. After entering the sealer, the gutta-percha pin from the respective system is also introduced. Before being inserted into the canal, the pin is smeared with a small amount of sealer and inserted slowly until the apical border of the

preparation is reached, then cut with a hot instrument and plunged into the orifice area. The endodontic cavity is closed with a temporary i-Pro filling(Dental, Italy) and the sample is placed in saline with 0.5% thymol, where it is left for 4 weeks for final curing of the sealer.

- **Research design:**

The study included 42 single-rooted teeth, divided into 3 experimental and 2 control groups:

- Group C4 (n = 12) - teeth obtured by the technique of synchronized hydraulic condensation by bioceramic sealer BioRoot RCS and non-impregnated gutta-percha pin (FKG).
- Group BC4 (n = 12) - teeth obtured by the technique of synchronized hydraulic condensation by bioceramic sealer BioRoot RCS and impregnated gutta-percha pin - BC Points (FKG).
- Group PT6 (n = 12) - teeth obtured by the technique of asynchronous hydraulic condensation by bioceramic sealer BioRoot RCS and non-impregnated gutta-percha pin F3 (ProTaper Gold).
- Negative control group C- (n = 3) - the teeth are covered with three coats of varnish along the entire length of the root.
- Positive control group C + (n = 3) - the teeth have prepared but not obtured root canals.

Each of the prepared samples, after drying with lignin paper, is fixed in an Eppendorf tube (1.5 ml) with a cut bottom (A) so that at least 6 mm from its root protrude beyond the end of the vessel. Place 0.5 ml of 2% methylene blue in the same tube. Place the lower part of the tube in another tube (C) containing 1 ml of distilled water so that the apical 3 mm of the root is immersed in the water. Epoxy resin applied in two layers was used for fixation, each of which solidified independently in 20 minutes. Schematically, the experimental unit is shown in Figure 1.

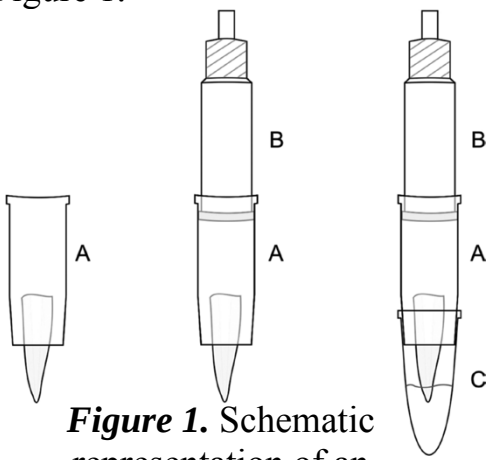


Figure 1. Schematic representation of an experimental unit from the experimental setup.

The upper part of the dye container (A) is fixed again by means of epoxy resin for a silicone hose (B), which is connected to a pressure source by means of T-adapters. The samples thus prepared are incorporated into a common system to which a constant pressure of 1 is applied atm. for a period of 60 minutes. The free end of the last T-shaped adapter is connected to a manometer for direct reading of the pressure in the system.

After the specified time the container with receiving solution (C) is separated from

container A without contaminating the solution and the caps of the lower Eppendorf tube (C) are closed. The closed samples are placed in a suitable tripod and marked with markers.

- **Used equipment**

The samples are analyzed on spectrophotometer TECAN, Sunrise. The spectrophotometer *TECAN, Sunrise* allows fast and accurate photometric measurements in 96-well plates, which determines its use in both clinical laboratories for routine diagnostics and research. The device allows for universal absorption analysis thanks to the function of adjusting the wavelength in a wide range - from 340 to 750 nm.

To determine the results of the present methylene blue filtration test, it is necessary to calibrate the apparatus to the peak value of the absorption of visible light by the dye. For this purpose, a standard absorption curve is used, showing the peak of absorption of visible light from methylene blue - 650 nm.

The spectrophotometer *Sunrise* works with Magellan data management, control and analysis software, which allows the preparation of calibration rights for each experiment (Fig. 2). This facilitates the automatic conversion of the measured absorption units into specific numerical values.

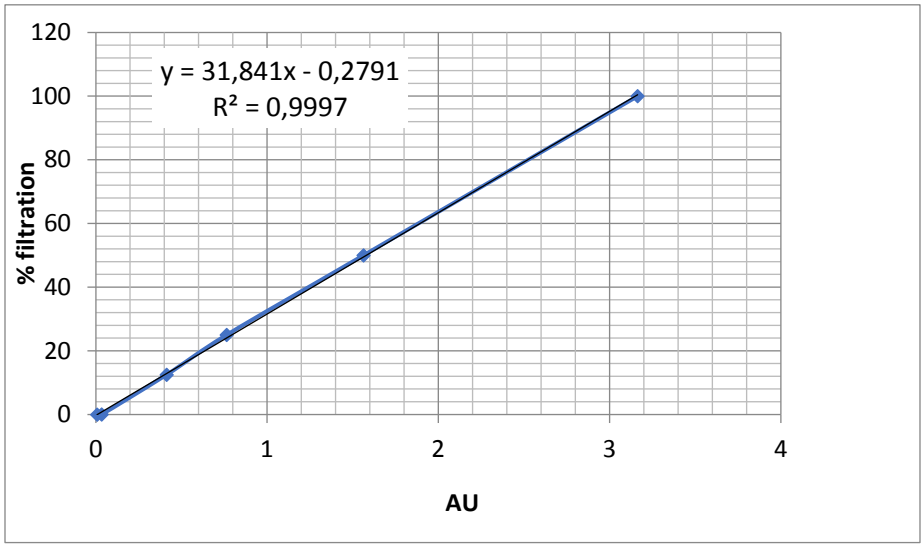


Figure 2. Calibration line: penetration of methylene blue (MB) [% filtration] - absorption at 650 nm [AU].

Calibration rights need to be prepared before each experiment. It helps to automatically convert the absorption percentage of an electromagnetic wave with a wavelength of 650 nm from methylene blue into absorption units (AU). It is built on the basis of 5 selected levels of absorption as the corresponding numerical values of AU are: at 0.025% absorption 0.033 AU are calculated, at 12.5% - 0.413 AU, at 25% - 0.763 AU, at 50% - 1.563 AU and at 100 %. absorption - 3.163 AU.

3.3. Investigation of the possibility of performing repeated endodontic treatment and evaluation of the residual channel filling material for root canals obstructed by hydraulic condensation and bioceramic endodontic sealer.

The experimental research on this task, including two subtasks, is funded by the intra-university project "Doctoral and postdoctoral programs" DPDP №11/ 2019 of the Medical University - Plovdiv.

To establish the possibility of non-surgical re-endodontic treatment of root canals obstructed by hydraulic condensation and bioceramic sealer (task 3), we set two subtasks.

In the first (subtask 3.1.) We aim to study the possibility of achieving apical patency of pre-obstructed root canals by hydraulic condensation and bioceramic endodontic sealer. To objectify the results of this study, we use a three-dimensional cone-beam X-ray examination (3D CBCT), which provides detailed information about the exact position of the re-prepared root canal.

In the second (subtask 3.2.) We examine the effectiveness of various endodontic instruments and solvents on the degree of removal of canal filler from the wall of the CC. The evaluation is performed by two different methods. The first is a three-dimensional cone-beam X-ray examination (3D CBCT), which makes it possible to measure the volume of residual CPS, and the second is optical microscopy, which provides data on the type of CPS, as well as the area of the root canal wall. remains covered by KPS after repeated endodontic therapy.

3.3.1. Research of the possibility of achieving apical patency in root canals obstructed by a bioceramic sealer and a gutta-percha pin positioned respectively on the RD and 2 mm shorter than the RD.

Object of observation: Prepared samples of extracted human teeth (n = 120).
Observation units: Root canal obturated by the technique of hydraulic condensation and bioceramic endodontic sealer BioRoot RCS.
Signs of observation:achieving patency of the apical opening; separation of an endodontic instrument; transport of the apical opening
Observation time: September 2019 - March 2021
Place of observation: Faculty of Dental Medicine, Medical University - Plovdiv, Plovdiv
Surveillance authorities: The dissertation together with Ch. Assistant Dr. Stella Nicheva, MD from the Department of Operative Dentistry and Endodontics, Faculty of Dental Medicine,Medical University - Plovdiv.
Research method:3D cone beam computed tomography.
Description of the equipment used:3D cone-beam tomograph - Hyperion X9 (MyRay®); specialized software - iRys Viewer v8.0. (MyRay®)

- **Sample preparation**

Extracted human teeth were used (n = 120). After extraction, the teeth were mechanically cleaned with a curette of organic residues, placed in a 10% solution

of formalin for 24 hours, and then stored under appropriate conditions (0.5% solution of Thymol and a temperature of 4^0C). A standard endodontic cavity with diamond drills and a turbine tip was dissected and the contents of the pulp chamber were removed by round metal drills and washes with sodium hypochlorite. The root canals (CC) of all extracted teeth with K-file №10 are followed and apical patency (AP) is established. The working length (RD) is measured using an apex locator and a simulation setup. After the preparation of a smooth road with manual K-files №10, 15 and 20, the machine preparation of KK is started. The files from the Pro Taper Gold (PTG) system are used sequentially until the working length is reached with F2 (25.08). The coronary part of each tooth is removed by means of a diamond separator so as to obtain specimens with a standardized length of 12 mm. Each file is discarded after use with five root canals.

Irrigation is performed with 2.5% sodium hypochlorite on each instrument change. The final irrigation was performed with 17% EDTA sound activated for 1 minute and 2.5% sodium hypochlorite sound activated for 2 minutes and subsequent washing with sterile saline. Dry with sterile calibrated paper pins for 1 minute in each root canal. The samples were randomly divided into four experimental and one control groups.

The endodontic sealer BioRoot RCS (Septodont, France) is mixed according to the manufacturer's instructions, and applied to the root canal using a Lentulo-type duct filler (№25, 25 mm long), mounted on an endomotor (X-Smart, Densply) and driven with 600 rpm ./min (for all groups). For group 0 (n = 10) the obturation ends without placing a gutta-percha pin (control). After the formation of a vertigo in the area of the orifice, the root canal is considered filled. For group 1 (n = 60) the calibrated gutta-percha pin F2 of the Pro Taper Gold system was modified by cutting 2 mm from its tip. It is introduced slowly into the root canal and for the samples from group 1 its modified tip is 2 mm from the apical opening. In the samples from group 2 (n = 50) the pin is not modified and is inserted slowly as its tip reaches the apical opening (of working length). For all groups, before inserting into the channel, the pin is rolled in a small amount of sealer to facilitate wetting and reduce the risk of pores. The pin is inserted slowly until the apical border of the preparation for group 2 (or 2 mm shorter for group 1) is reached, after which it is cut with a hot tool in the area of the orifice. After removing the excess from the sealer, the endodontic cavity was closed with a temporary Coltosol F (Coltene®) and the sample was placed in saline with 0.5% thymol, where it was left for 4 weeks for the sealer to finally harden. then cut with a hot tool in the area of the orifice. After removing the excess from the sealer, the endodontic cavity is closed with a temporary Coltosol F (Coltene®) and the sample is placed in saline with 0.5% Thymol, where it stays for 4 weeks for final hardening of the sealer. then cut with a hot tool in the area of the orifice. After removing the excess from the sealer, the endodontic cavity was closed with a temporary Coltosol F (Coltene®) and the sample was placed in saline with 0.5% thymol, where it was left for 4 weeks for the sealer to finally harden.

- **Research design**

Samples from group 0 are obturated without core and represent a control group. After obturating by placing the 2mm coronary gutta-percha pin from the apical border of the preparation, the group 1 samples were subsequently randomly divided into three more groups depending on the type of solvent to be used in the re-preparation process. In group 2 specimens, the core (gutta-percha pin) is positioned at the working length so that its tip coincides with the apical border of the preparation.:

- Group 0 (n = 10): control
- Group 1 (n = 20): without solvent
- Group 1-b (n = 20): chloroform
- Group 1-c (n = 20): citric acid 40%
- Group 2 (n = 50): the gutta-percha pin is on the RD

After the temporary obturation was removed, the specimens were processed as follows:

Group 0: It starts with sequential use of files (D1, D2, D3) from the Pro Taper Retreatment (PTR) system, driven by an endomotor X-Smart (Dentsply Maillefer) with constant rotation and speed of 500 rpm for D1 and 400 rpm for D2 and D3, with torque control set to 3 N / cm2. In case the machine files do not advance into the root canal, an attempt is made to engage the tip of a hand file (K-file № 25, 20, 15) by reciprocal movements and manually reaching the apical opening. If this fails, the RD is measured again to the level of penetration and the root canal is prepared there by sequentially using Pro Taper Gold instruments (250 rpm and torque 3N / cm2) until the new RD is reached with file F3.

Group 1: To remove the filler material, hstarts with sequential use of files (D1, D2, D3) of the Pro Taper Retreatment (PTR) system, via the same endomotor with the same settings as in group 1-0. If the RD is not reached with any of the D-files, the preparation is started with hand tools (K-files, H-files). An attempt is made to engage the tip of the hand file by reciprocating movements and manually reaching the apical opening. If this fails, the RD is measured again to the level of penetration and the root canal is prepared there by sequentially using Pro Taper Gold instruments (250 rpm and torque 3N / cm2) until the new RD is reached with file F3.

Group 1-b: To remove the filler material, hstarts with sequential use of files (D1, D2, D3) of the Pro Taper Retreatment (PTR) system, via the same endomotor with the same settings as in group 1-0. One drop of 0.1 ml of chloroform is placed in the root canal for 2 minutes to soften the gutta-percha after using the D1 instrument. The softened gutta-percha is then removed by sequentially using D2 and D3 until RD is reached. If the RD is not reached with any of the D-files, the preparation is started with hand tools (K-files, H-files). An attempt is made to engage the tip of the hand file by reciprocating movements and manually reaching the apical opening. In the absence of commitment, 0.1 ml of chloroform is added to the QC and a retry is performed. If this fails, the RD is measured again to the

level of penetration and the root canal is prepared there by sequentially using Pro Taper Gold instruments (250 rpm and torque 3N / cm2) until the new RD is reached with file F3.

Group 1-c: The technique used here is analogous to that used in group 1-a. One drop of 0.1 ml of chloroform is placed in the root canal for 2 minutes to soften the gutta-percha after using the D1 instrument. The softened gutta-percha is then removed by sequentially using D2 and D3 until RD is reached. If the RD is not reached with any of the files, the D-files proceed to the preparation with hand tools, analogous to group 1-a. In the absence of hand tools, chloroform was removed by saline and one drop (0.1 ml) of citric acid (40% Citric Acid, Cercamed®) was placed in the canal and retried.

Group 2: The technique for walking the obturated root canal applied to the samples from this group is absolutely analogous to that from group 1-a.

After completion of the preparation of the obturated root canals of group 0, group 1-a, group 1-b, group 1-c and group 2, passive irrigation of the root canals is performed with sequential application of a solution of 17% EDTA and 2.5% sodium hypochlorite, when replacing the solution in the root canal, an intermediate irrigation with saline is performed. The root canals are dried with sterile paper pins.

3.3.2. Three-dimensional topographic characteristics of the residual material on the root canal wall after preparation of pre-obturated root canals by means of 3D cone-beam tomography (3D CBCT) and microscope.

Object of observation: Residues of canal filling material: endodontic sealer BioRoot RCS; calibrated gutta-percha pin from the Pro Taper system.
Observation units: axial, transverse and sagittal sections of 3D ClCT examination; high resolution photos taken under magnification with a microscope and digital camera
Place of observation: Faculty of Dental Medicine, Medical University - Plovdiv
Observation time: September 2020 - March 2021
Surveillance authorities: The dissertation together with a specialist in image diagnostics Ch. Assistant Dr. Petya Kanazirska, MD at the Department of Imaging, Dental Allergology and Physiotherapy, SPF, MU-Plovdiv, Plovdiv.
Signs of observation: amount of residual material in the root canal; localization of the residual material; area of the root canal wall covered with obturation material; type of residual obturation material.
Research method: 3D cone beam computed tomography; optical microscopy; high resolution photos under magnification.
Description of the equipment used: 3D cone-beam tomograph - Hyperion X9 (MyRay®)**;** specialized software: iRys Viewer v8.0. (MyRay®); ImageJ (version 1.53, Maryland, USA); stereomicroscope; digital camera - Sony Alpha 7 with full frame sensor.

Research design: For the purposes of this study, the samples from group 2 of subtask 3.1 are used. (n = 50). The methodology for preparation (preparation) of the root canals and the achievement of apical patency is described and performed in subtask 3.1. For the purposes of this experiment, the samples prepared in the previous subtask were divided into five subgroups depending on the additional processing of the root canal wall:

- Group 2 (n = 10): hand and rotary tools only
- Group 2-b (n = 10): with the participation of ultrasonic instruments (Pro Ultra, Dentsply®)
- Group 2-in (n = 10): involving the SAF system
- Group 2-d (n = 10): involving the SAF system and chloroform
- Group 2-d (n = 10): with the participation of the SAF system and chelator (40% Citric Acid, Cerkamed®)

- **Additional treatment of the root canals to remove the canal filler from the wall of the root canal**

For group 2 (n = 10) the preparation is completed after reaching RD with file F3 (30.09). Each file is discarded after use with five root canals.

For **group 2-b** (n = 10) After completion of the preparation of the obstructed root canals, passive ultrasonic activation of the irrigation solution is performed by ProUltra Endo Tips with numbers 6, 7 and 8 (Dentsply Sirona). A solution of 17% EDTA (for 1 min) and 2.5% sodium hypochlorite (for 2 min) was activated sequentially, and intermediate irrigation with saline was performed when the solution was replaced in the root canal. Finally, the root canals are dried with sterile paper pins.

For **group 2-in** (n = 10) after reaching RD with file F3 proceed to additional preparation with file from the SAF system (ReDent Nova, Ra'anana, Israel). Initially, the smooth road is checked. The SAF file has a pre-prepared smooth path requirement of up to 20.02 for straight channels and 20.04 for curved root canals. Before mounting the endomotor manually, an attempt is made to reach the RD by passively inserting the file. If it does not reach the RD, a correction of the smooth path is made. If it reaches the RD by passive introduction there is no need for corrections and the file is mounted on the endomotor.

The SAF file is driven by a special endo-motor EndoStation ™, equipped with an integrated peristaltic pump, which allows simultaneous and continuous irrigation during the procedure. A special head RDT3-NX (ReDent Nova) is mounted on the hand piece, which allows for two types of tool movements - reciprocating and rotary. It also contains a mechanism that allows the file to rotate slowly when not engaged in the channel, but completely stops the rotation after tightening in the walls of the channel. The rotation speed is set to 5000 rpm, which leads to 5000 vibrations per minute and amplitude of 0.4 mm. SAF was used for 2 minutes in each channel under continuous irrigation with 2.5% sodium hypochlorite at a flow rate of 4 ml / min-1. The free rotation of the file must occur

with each removal movement, when SAF is released from the channel walls. This ensures that when the SAF enters the channel during reciprocating motion, it will be in a different position each time, thus ensuring even preparation of the channel walls. This arbitrary position of entry also allows the asymmetrical tip of the file to follow curves or to cross thresholds along the root canal. SAF files are disposable and are discarded after use on a single root canal. Finally, the root canal is washed with saline and dried with a paper pin. thus ensuring uniform preparation of the canal walls. This arbitrary position of entry also allows the asymmetrical tip of the file to follow curves or to cross thresholds along the root canal. SAF files are disposable and are discarded after use on a single root canal. Finally, the root canal is washed with saline and dried with a paper pin. thus ensuring uniform preparation of the canal walls. This arbitrary position of entry also allows the asymmetrical tip of the file to follow curves or to cross thresholds along the root canal. SAF files are disposable and are discarded after use on a single root canal. Finally, the root canal is washed with saline and dried with a paper pin.

In group 2-d (n = 10), the preparation with the SAF system was combined with the use of the solvent chloroform. After 2 minutes of operation with the SAF file under continuous irrigation with 2.5% sodium hypochlorite and sequential removal of the irrigant by rinsing with saline, the root canal is dried with a paper pin. This is followed by the introduction of a drop of chloroform into the QC and the re-introduction of the file from the SAF system. The peristaltic pump is switched off and simultaneous irrigation is stopped. The movements, speed and amplitude of work with SAF are similar to those of group 2-b, the only difference being the absence of simultaneous irrigation. The operating time of SAF in the presence of chloroform is 1 min per CC. After this time, the root canal is washed with saline and dried with a paper pin.

In group 2-e (n = 10) the procedure is absolutely analogous to that in group 2-d, the only difference being in the type of solvent used. In this group, instead of chloroform, a chelator is used - 40% citric acid solution (40% Citric Acid, Cerkamed®).

After further processing of the test specimens, the latter were subjected to a three-dimensional computer cone-beam X-ray study (3D CBCT) to measure the volume of KPS residues in the root canal.

- **Measurement of the volume of the residual KPS through 3D CBCT examination and specialized software**

The experimental samples (n = 50) are arranged in the platforms made of non-X-ray contrast material (styrofoam). Then each platform is fixed on the stand for the patient's chin in the computer cone-beam tomograph – Hyperion X9 (MyRay®).

After scanning, the scans are processed using the specialized software iRys Viewer v8.0. (MyRay®). Due to the fact that this software does not have a volume measurement function, the data is transferred to other software. For this purpose, the scans are exported in "single file DICOM" format from the menu "File-> Save in DICOM ...".

To obtain information on the amount (volume) of the residual channel filling material, we use the free version of Horos® (v3.3.6), which allows for segmentation of objects from the cone-beam study based on the value (density) of the single voxel. After importing the DICOM directory and switching to the sagittal view, the “Growing Region Segmentation” option is selected from the ROI (Region Of Interest) menu. A pane opens in which the appropriate algorithm is selected - "Threshold (lower / upper bounds)", as well as the values of the single voxel to be segmented.

In order to be able to distinguish the canal filling material from the tooth structures, we measured the values of the voxel density in different zones. The resulting value of the voxel (in specific units) falling within the range of the weakest shadow (the most saturated black, where there is no scanned object) is "-1000", and the values responsible for the different strength of the shadow vary widely borders. According to ISO 6876: 2012, the requirement for duct filling agents is to have an X-ray contrast corresponding to a minimum of 3 mm aluminum, which means that each duct filling material has a higher X-ray contrast than TZT. Therefore, the density value of a voxel must be determined, which is the boundary between the strong shadows of the TZT and the even stronger shadows corresponding to the channel filler.

The highest value for dentin measured by us is 2810, and the lowest value for canal filler is 3004. By setting parameters for the lower limit 3000 and 20,000 for the upper, we were able to segment only the canal filler, without including in the measurement dental structures.

Segmentation is started by pointing the cursor at any point in the image with a strong shadow corresponding to the channel filler. It is not necessary to specify the boundaries in the different slices, as the program itself segments the voxels with the preset values from all slices.

After the automatic segmentation of the residual channel filler, the option “Compute ROI volume ...” is selected again from the ROI menu, which opens a new window with a three-dimensional image of the segmented part of the cone-beam examination corresponding to the residual channel filler. The image can be rotated and enlarged. In the field below the three-dimensional image is the information about the volume of the segmented object in cubic millimeters (mm3), median (Mean), standard deviation (SDev), as well as the minimum (Min) and maximum (Max) value of the voxel density entering the scope of the measurement.

For each of the samples, numerical values for the volume, average value of the voxel density in the segmented volume and the standard deviation are recorded in a specially developed table. The average values for each of the groups were calculated and the obtained data were subjected to statistical analysis.

- **Preparation of samples for digital optical microscopy.**

In order to be subjected to optical microscopy, the samples of group 2 must be divided into two halves so that the root canal becomes open without disturbing the position and amount of residual material in it. For this purpose, longitudinal

incisions are made along the buccal and lingual surface of the test specimens using a 0.2 mm thick diamond disk. Special care is taken to ensure that the notches do not enter the root canal. A straight spatula is inserted into these grooves and by turning it the tooth is divided into two longitudinal halves. One part of the volume of the channel and respectively the remaining content in it (KPS) remain in one half, and the other part - in the other half.

The two halves of each sample were taken with a Sony Alpha 7 digital camera mounted on a Flexion Advanced microscope (CJ-Optik, Germany). The microscope is equipped with a 4K - Imaging Port and Vario Focus lens, allowing for depth of focus, ensuring that every part of the captured object (halved sample) will be in focus. In order to standardize the setting, all teeth are photographed from the same distance, at the same magnification (x20) and with the same camera settings (ISO 800, MM -0.3, 1/160). Contrast for intraoral photography is used as a background. To prevent the lens from moving during shooting, the camera is set to self-timer mode, with the time interval between pressing the button and taking a picture set to 10 seconds. "The minimal movements caused by the operator pressing the shutter button are distracted and disappear within the specified time"

- **Determination of the area of residual channel filling agent**

The photos from each sample are entered into the ImageJ software program. ImageJ has a tool for manual delineation of the area of interest (ROI) after which its area is automatically calculated. Only the areas with available duct filling are enclosed by both halves of the separated sample. The gutta-percha and sealer areas were fenced separately, and the data were recorded in the respective tables originally developed for the purpose of the experiment. The numerical values of the area occupied by the root canal filling material are added to obtain a total value for the respective sample. The data obtained from us for the occupied area are in number of pixels.

To convert the obtained data into square millimeters, we need to measure the number of pixels occupying an area of one square millimeter. Using the Rectangle Outline tool, draw a square with a side of a linear millimeter. The length of the linear millimeter is borrowed from a ruler located next to the sample.

39,204 pixels correspond to one square millimeter. The conversion of data from the number of pixels into square millimeters is done by dividing the number of pixels corresponding to the area occupied by the channel filling material by the root canal by the number of pixels corresponding to the area of 1 mm^2. In this way we obtain information about the area of the residual channel filler in mm^2.

The residual KPS is registered both for the whole channel and for every third of it. The area of the residual material was calculated both for the whole channel in each group and for every third in the same group. In addition, the area was calculated for every third for the different groups.

The obtained data are subjected to statistical processing and analysis using SPSS v26 software.

3.4. Clinical study of the healing process after root canal obstruction by hydraulic condensation and BioRoot RCS.

Object of observation: Patients in need of primary or repeated endodontic treatment.

Observation units: Root canal obtured by the technique of hydraulic condensation and tricalcium silicate sealer BioRoot RCS.

Place of observation: Department of Operative Dentistry and Endodontics, Faculty of Dental Medicine, Medical University - Plovdiv and private dental practice.

Observation time: January 2017 - July 2021

Surveillance authorities: Dr. Kostadin Zhekov, Department of Surgical dentistry and endodontics, Faculty of Dental Medicine, MU - Plovdiv

Signs of observation: Clinical and radiological criteria for the healing process.

Registration: For this purpose, an individual clinical card and a document for informed consent have been prepared, which each patient signs.

Research method: Clinical examination and paraclinical examination - two-dimensional sectoral digital parallel radiographs

- **Selection of patients**

For the purposes of this study, more than 100 patients were examined who sought dental help from the dissertation in the period 2017 - 2021, or were referred by general practitioners of LDM or by specialists in other fields of dental medicine during the same period. Eligibility criteria include adults, no uncontrolled comorbidities, no history of infection, pregnancy or mental retardation. After careful selection, patients aged 21 to 70 years were included in the study.

All patients have completed and signed a declaration agreeing that the treatment data will be used for scientific purposes. They have also signed an informed consent detailing the potential risks of endodontic treatment.

- **Selection of clinical cases**

The selection of clinical cases was carried out according to the criteria for the need for radical endodontic treatment. These include nosological units from the group of irreversible pulpitis and the group of chronic periodontitis. The diagnosis is made on the basis of a detailed clinical examination, including history, examination, vitality tests, probing, percussion and diagnostic radiography.

- **Clinical protocol in the treatment of irreversible pulpitis**

After disinfection of the oral cavity, by rinsing with an antiseptic solution, local anesthesia is performed. Terminal infiltrative anesthesia is applied to all maxillary teeth in the area of the buccal transitional fold. For teeth from the lower jaw to the second premolar, terminal infiltrative anesthesia is again used buccally, and for molars - wire anesthesia according to the Weisbrem method. The anesthetic used is Ubistesin (3M ESPE) with a content of 4% articaine and adrenaline 1/200 000 (red ring) and an aspiration carpule injector (3M ESPE).

All cases were treated under isolation from a rubber dam placed before the endodontic access. This prevents iatrogenic infection in the root canals. The procedure continues under visual control with magnification and intense LED lighting. The endodontic access is performed through a turbine tip and a diamond drill until the tectum cavum pulpae is reached. After penetration of the pulp chamber, the roof is removed by means of ultrasonic tips with or without a diamond coating. The contents of the pulp chamber are removed by means of a sterile metal drill at slow speed (micromotor). Prior to the examination of the root canals, a viscous chelator based on EDTA (RC Prep Gel) is placed in the pulp chamber to prevent collagen blockage. K-file №10 with a pre-curved tip is slowly introduced into the root canal by reciprocal movements until a feeling of tightening, after which it is removed, cleaned and re-introduced through the reservoir of EDTA-gel into the pulp chamber. When the K-file is strongly tightened №10, a smaller K-file number is taken - №08 or 06. The file is connected to an apex locator (iPex 2, NSK) each time it is inserted into the root canal. The procedure for inserting the file until tightening, removing and cleaning and subsequent insertion is repeated until the physiological apical narrowing is reached, which is reported by the data on the display of the apex locator (value 0.5) and the corresponding sound signal, as well as the digital tactile sensation. apical resistance (DTUAS). Followed by a preparation for creating a smooth path with hand tools K-file № 15 and №20, or with machine tools - Pathfile (Dentsply, Maillefer), mounted on an endomotor TC-Mate 2 (NSK) with speed and torque control (torque), recommended by the manufacturer (300 rpm; 2.0 N / sm2). The endomotor has a factory device for connection to an apex locator to control the level of preparation in real time. After providing a smooth path for each root canal, proceed to its conical formation. The viscous chelator was washed from the pulp chamber and replaced with 2.5% sodium hypochlorite solution (Chloaxid 2.5%; Cerkamed). The tools from the Pro Taper system are used in a strict sequence, following the protocol of the system. Irrigation with 2.5% sodium hypochlorite is performed before each file introduction (and not every shift). It ends with a finishing file from the system - F2, F3 or F4, depending on the characteristics of the root canal. A completed preparation is considered to be in which the finishing (machine) file is introduced manually to the apical border of the preparation, without having to perform filing movements with it (passively). After the preparation, the final irrigation is started by activating the irrigation solution - 17% EDTA solution (1 min); saline; 2.5% sodium hypochlorite solution (3 min); saline. The solution is activated by sound energy and a polymer tip (EndoActivator®, Dentsply Sirona), with each of the root canal solutions being renewed every 30 seconds. After the last saline wash, the latter is aspirated from the root canal by retracting the plunger of the irrigation syringe. Drying is performed using sterile calibrated paper pins from the Pro Taper system, and in each channel the pin stays for 1 minute.

The BioRoot RCS bioceramic endodontic sealer is mixed according to the manufacturer's instructions on a sterile glass plate (on a smooth surface) using a

sterile plastic spatula. It is dosed in a ratio of 1 measuring spoon of powder to 5 drops of liquid. The sealer is sequentially introduced into each root canal with a Lentulo-type duct filler mounted on the endomotor and driven at 600 rpm. to the formation of a vertigo in the area of the orifice. Calibrated gutta-percha pins are coated with a thin layer of stirred sealer before being inserted into the root canals. They are introduced slowly into the QC until the sensation of resistance, after which they are cut at the level of the orifice by an electric plug (System B). After filling all the root canals of a tooth, the excess sealer is removed from the pulp chamber.

In the absence of the possibility of definitive coronary sealing, a temporary sealing of the endodontic cavity is performed by means of a temporary Coltosol F (Coltene) filling, and a Teflon strip mediator is placed between the latter and the floor of the pulp chamber. If possible, permanent coronary sealing of the root canal system is performed by adhesive bonding of a liquid composite material intended for application in portions up to 4 mm thick (Filtek Bulk Fill, 3M). X-ray control of the root canal obturation is performed by digital parallel sector graph. The definitive restoration of the coronary defect is performed according to the indications - directly or indirectly.

- **Clinical protocol in the treatment of chronic periodontitis**

In the treatment of chronic periodontitis, the presence or absence of KPS in the root canals is established by X-ray examination (segmental, orthopantomography or 3D CBCT).

Local anesthesia is applied at the base of the gingival papillae for painless placement of the cofferdam clamp (supracrystalline technique). After adequate isolation of the operative field, a standard endodontic access is prepared by means of a turbine tip and a diamond drill.

Under magnification, the contents of the pulp chamber are removed and the orifices of all root canals are located. In the presence of obturating material in the root canals, the files from the Pro Taper Retreatment system (D1, D2 and D3) are applied sequentially in each root canal. If necessary, hand tools (K-files; H-files) are also used. After establishing apical patency and a smooth path (sliding path), the preparation is continued by sequential application of the files from the Pro Taper system in strict compliance with the protocol for working with them. The anatomical apical opening is considered to be the apical limit of preparation in chronic periodontitis, which is confirmed by the value of the display of the apex locator – 0.00.

In the absence of exudation, odor and pain (spontaneous or percussion), a final irrigation procedure is performed. 2.5% sodium hypochlorite solution (3 min) was applied and activated in the indicated sequence; saline; 17% EDTA solution (1 min); saline; 2.5% sodium hypochlorite solution (3 min); saline. Activation of the solution is carried out analogously to the treatment of irreversible pulpitis. After the last saline wash, it is aspirated from the root canal by retracting the plunger of the irrigation syringe. Drying is performed using

sterile calibrated paper pins from the Pro Taper system, and in each channel the pin stays for 1 minute.

The procedures for root canal obstruction, CCC sealing and definitive recovery do not differ from that for irreversible pulpitis. X-ray control of the endodontic obturation is mandatory.

Evaluation of the quality of endodontic treatment is performed during a control clinical examination on the 6th and 12th month after the procedure. The clinical examinations are performed in an office of dental medicine on the territory of the Department of Operative Dentistry and Endodontics, Faculty of Dental Medicine, Medical University - Plovdiv.

The criteria for assessing the healing process are grouped into two categories:

- **Clinical** – no spontaneous pain, no pain from temperature irritant, no pressure pain, no mobility
- **Radiological** – preserved Lamina dura, normal width of the periodontal space

During a follow-up visit to each patient, an assessment is made of the healing process of the treatment by performing a detailed clinical examination and paraclinical examination - two-dimensional digital radiography using a parallel technique.

- **Registration of clinical signs:**
- **Medical history** - data on spontaneous or provoked pain, duration of pain, characteristic of the pain, effect of analgesics
- **Inspection** - changes to the color of the mucosa around the apex, the presence or absence of a fistula, the characteristics of the available fistula
- **Palpation -** lymph node involvement
- **Pain when pressed**- a standard percussion sensitivity test is performed on the treated tooth. Vertical percussion is performed on the occlusal surface of the tooth by means of the handle of the dental probe. The presence or absence of pain is reported. This is followed by horizontal percussion on the vestibular and lingual walls of the tooth, again taking into account the presence or absence of pain. A comparative (vertical) percussion test is also performed, which percusses the occlusal surfaces of the test and its adjacent teeth. The presence or absence of a difference in sensation is reported, not a pain response.
- **Spontaneous pain** - reported according to anamnestic data.
- **Pain from temperature irritant** - reported according to anamnestic data.
- **Mobility**- the mobility test is performed through the handles of two instruments from the dental set - a dental probe and a dental mirror, positioned buccally and lingually. Mobility is reported on the Miller scale.

- **Registration of paraclinical signs:**

The paraclinical examination is performed in the Department of Imaging, Dental Allergology and Physiotherapy "in Faculty of Dental Medicine, Medical University - Plovdiv. They are appointedtwo-dimensional digital radiographs by parallel technique using an intraoral holder of the photosensitive sensor. X-ray examination is performed by qualified X-ray technicians.

The criteria for evaluation by radiographic features are: adaptation of the canal filling material to the walls of the root canal; level of root canal obstruction relative to the radiological apex; changes in the size of the periapical lesion (periapical index - PAI).

To evaluate the radiographic criteria, digital parallel radiographs were examined twice by two specialists in "Operative Dentistry and Endodontics". The dissertation and his / her supervisor examine each of the digital radiographs independently of each other, using the image magnification option available in the software. The contrast adjustment option provides the ability to darken and lighten the image until optimal contrast is obtained to assess the adaptation of the KPS, its level relative to the radiographic apex, and the periapical index (PAI). The results are registered in three stages - immediately after obturation (onset), at a follow-up examination at 6 months and at a follow-up examination at 12 months, and are entered in a timely manner in the prepared clinical maps.

An index scale is used to assess the healing process after endodontic treatment (periapical index - PAI), proposed by Orstavik in 1986 as a simplified version of the radiographic method for interpretation of Brynolf from 1967 and consists of 5 categories numbered from 1 to 5.

Based on the obtained clinical results, a clinical protocol is created for the application of a bioceramic sealer with the technique of hydraulic condensation, in non-surgical endodontic treatment of irreversible pulpitis and periodontitis.

3.5. Development of clinical protocols for optimization of the application and removal of bioceramic endodontic sealers.

3.5.1. Protocol for root canal obturation by hydraulic condensation and bioceramic endodontic sealer.

Based on the literature review and the conducted clinical study of task 4, a clinical protocol for effective application of bioceramic endodontic sealers with the technique of hydraulic condensation is developed and proposed.

3.5.2. Protocol for removal of bioceramic endodontic sealer BioRoot RCS from the root canal.

Based on the literature review and the experiments of task 3, a protocol for removal of bioceramic endodontic sealer BioRoot RCS from the root canal is developed and proposed.

IV. RESULTS AND DISCUSSION

4.1. Research of the attitude of dentists from Plovdiv region to the application of bioceramic endodontic sealers in their clinical practice.

4.1.1. Characteristics of the surveyed persons by socio-demographic and professional characteristics

After processing the results, it was found that of the 164 dentists who participated in the study, 112 were women (68%) and 52 men (32%). The average age of the respondents is40.9 years. The results are presented in five age groups, with the largest share having the group from 31 to 40 years of age (38.4%), followed by the group of 41-60 years (22%), the group up to 30 years (18.9%), the group of 51-60 years (13.4) and the smallest share have persons over 60 years of age – 6.1% (Fig. 3).

A total of 39% of the respondents have acquired a specialty, and the distribution is presented in detail in fig. 4.

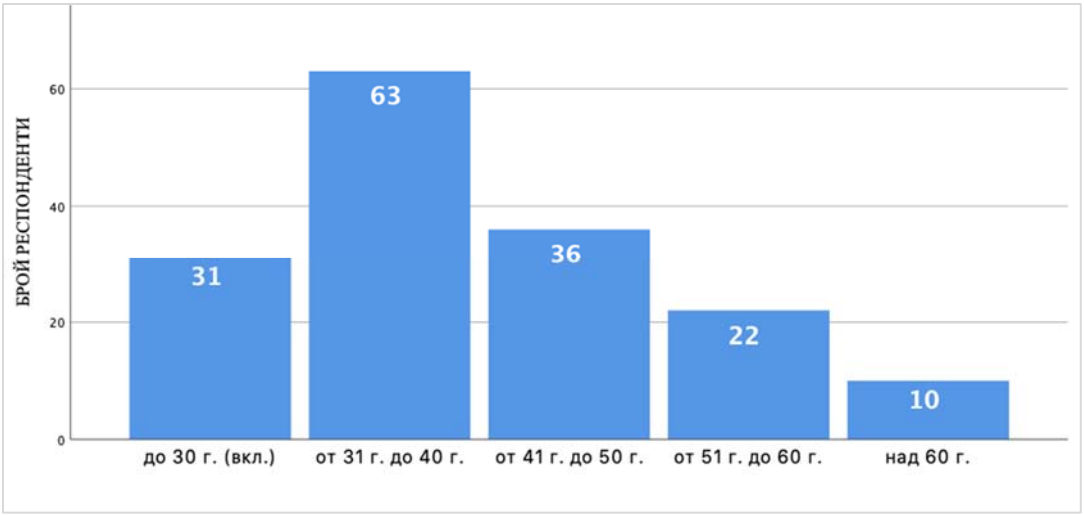


Figure 3. Age distribution.

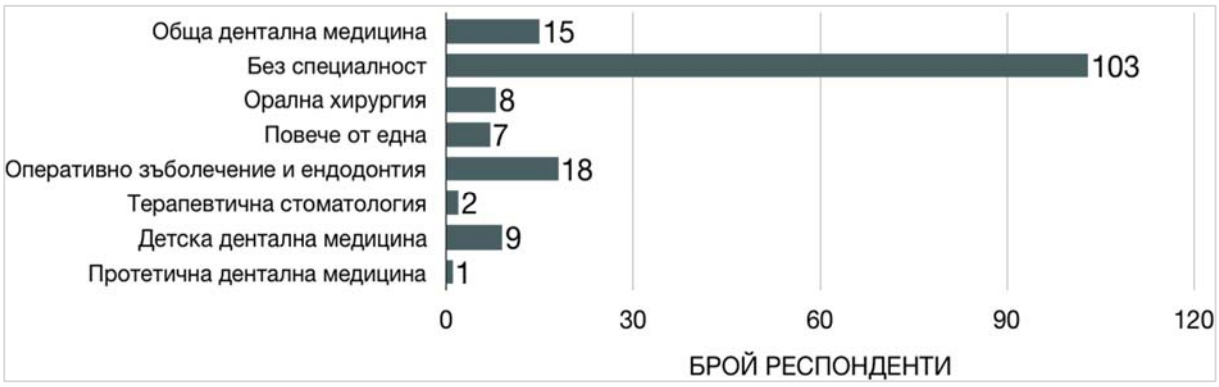


Figure 4. Distribution by acquired specialty.

The total length of service of the respondents is on average 16 years, with an average length of service in the specialty of 18.7 years. The distribution of the internship after acquiring the specialty is presented in Figure 5.

Graduates of the Faculty of Dental Medicine in Plovdiv are 89% and the rest are graduates in Sofia, as the majority of respondents practice in the city (91%), only 7% work in the countryside and 2% work in the countryside and in the city.

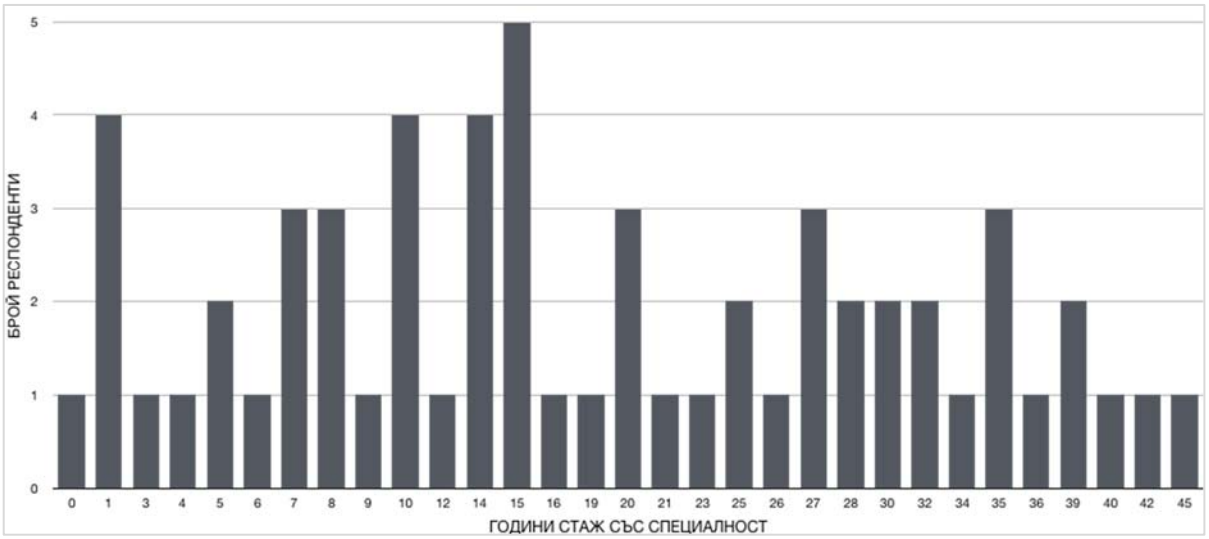


Figure 5. Distribution by years of experience with a specialty.

81% of all respondents have a contract with the National Health Insurance Fund (NHIF). The largest number indicate individual practice as a job (48%), followed by those in a group (26%), while only 3% work in the Faculty of Dental Medicine. Nearly a quarter of respondents (23%) say they work in more than one job.

The frequency of conducting a certain type of treatment procedures determines the professional orientation of a practice. Only 6% (n = 9) of the respondents do not perform endodontic treatment in their clinical practice. This shows the high frequency of endodontic treatment (EL), even by doctors without a specialty, as well as by those who have acquired a clinical specialty other than "Surgical dentistry and endodontics". The frequency of conducting EL by dentists from Plovdiv region is presented in Figure 6.

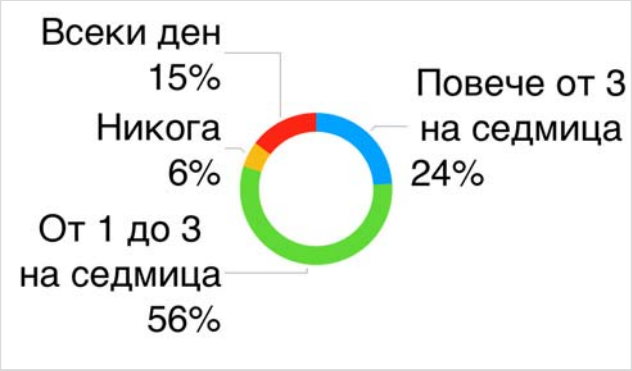


Figure 6. Frequency of endodontic treatment.

4.1.2. Analysis of the studied signs of the skills, knowledge and attitudes of dentists for the application of bioceramic endodontic sealers

When analyzing the data from the survey, significant differences were found between the age of the respondents and the frequency of application of bioceramic endodontic sealers ($p > 0.05$). The group of respondents over 60 years of age used

formalin-resorcinol pastes (FR) to fill the QC significantly more often than the group of 31-40 years ($p < 0.05$). Filling with paste only is again preferred by the group over 60 years of age (80%), which shows a statistical difference with all other groups ($p < 0.05$). Although the group of FR pastes and the technique of filling QC with paste alone are no longer recommended for clinical use, the results obtained are probably due to the long-term experience of clinicians with them, which led to building a professional stereotype of working with a solid foundation. Formalin-resorcinol preparations have strong antibacterial and mummifying properties, which make them a suitable tool of choice in the treatment of severely infected root canals. Botushanov considers separately the cases of infected and uninfected root canals, pointing out that COE endodontic pastes (sealers) are more suitable than FR in the absence of infection (vital inflamed dental pulp).

Analyzing the data reveals a difference in the frequency of endodontic treatment (EL) compared to the acquired specialty. The daily performance of EL is more common among specialists in "Operative Dentistry and Endodontics" (CEE) than among those without a specialty ($p < 0.05$). Specialists in Pediatric Dentistry (DDM), General Dentistry (ODM), as well as those without a specialty most often perform EL between one and three times a week, in contrast to specialists in PEE ($p < 0.05$). Practice without performing EL is more common among specialists in Oral Surgery (OX) than in the group without an acquired specialty ($p < 0.05$). No relationship was found between the type of specialty acquired and the choice of final irrigation solution ($p > 0.05$).

There is a difference with statistical reliability in the preferred obturation technique. Specialists in OZE use the technique of a single pin with paste in 95.24%, while specialists in OX use it only in 33.33% ($p < 0.05$). LDM with specialty ODM still practice filling the root canal only with paste, even more often than colleagues who do not have acquired specialty ($p < 0.05$). This is probably due to changes in the material taught in recent years. In modern endodontics, it is not recommended for definitive filling of the CC due to poor control of the level of obstruction and the high probability of resorption of the paste, but is used only in the application of a long-term medication agent. Modern BCS is not recommended for use as a stand-alone filler material,

We find a statistically significant difference in the type of sealer used in different groups of specialties. Those who have acquired the specialty ODM use FR pastes significantly more often than specialists in OZE ($p < 0.05$).

Bioceramic EUs are the newest type of EU that release non-toxic calcium hydroxide during the curing process. This plays a key role in determining their antimicrobial properties and partly in the mechanism of adhesion of the material to the root canal wall. The results of the statistical analysis show that the specialists in PEE prefer to use the new BCS significantly more often than those with a specialty ODM, DDM, as well as those who have not yet acquired a specialty ($p < 0.05$).

No statistical differences were found between the different specialties in the selection of cases requiring monitoring of the recovery process, nor in the average follow-up period ($p > 0.05$). Despite the high percentage of respondents who have a contract with the NHIF (81%), most clinicians who use BCS do not have a contractual relationship with it ($p < 0.05$).

No significant relationship was found between the frequency of EL and the presence of a contract with the box office ($p > 0.05$).

We find a connection with statistical reliability between the type of practice and the frequency of EL. From the analysis of the results it is clear that the practitioners in the Faculty of Dental Medicine conduct daily EL significantly more often than those working in individual practice ($p < 0.05$). This is probably due to the fact that the majority of the surveyed specialists are specialists in OZE.

We find a significant difference in the preferred obturation technique and the type of sealer used depending on the type of practice. The data show that workers in SPF more often apply BCS and the single pin technique in their endodontic practice, compared to individual practitioners ($p < 0.05$).

When analyzing the data on the frequency of EL, it was found that clinicians who perform EL more than 3 times a week use BCS more often than those who perform EL between 1 and 3 times a week ($p < 0.05$). The same relationship is found when comparing the applied obturation techniques. More often practitioners of EL (more than 3 times a week) prefer the technique of single pin and paste than less often performing EL (from 1 to 3 times a week) ($p < 0.05$). It is logical to conclude that the higher frequency of performing a manipulation leads to a perceived need for professional development. This is also confirmed by the fact that more often EL practitioners (more than 3 per week) are more informed about the incompatibility of combining BCS with warm root canal obturation techniques.

For the final irrigation solution, the largest number of respondents prefer alcohol (37%), followed by sodium hypochlorite (19%) and oxygenated water (16%). Few prefer to complete irrigation with saline (15%), and chelators (EDTA (8%) and citric acid (1%) and chlorhexidine (3%) are rarely used. When analyzing the data, it is impressive that the majority of BCS users in their endodontic practice prefer alcohol as an agent for final irrigation, instead of oxygenated water ($p < 0.05$). Saline solution is the best means of evacuating the irrigant present in the root canal, as it has no active properties and does not help to dry the canal. According to the data from the study, it can be stated with statistical reliability that those who use saline are more convinced that the price is the main factor limiting the use of BCS than those who use alcohol ($p < 0.05$).

From the conducted survey it is clear that a small number (20% in total) of LDM from Plovdiv region use hot obturation techniques, distributed almost equally between the obturator technique (9%) and the hot vertical condensation (11%). The largest number (57%) use the single pin technique, which is included in the indications for use with BCS. The second most commonly used technique

(13%) is student lateral condensation, and filling only with paste is the least commonly used (11%) by the group of cold techniques.

From the analysis of the relationships between the type of technique used and the endodontic sealer, we understand that the majority of clinicians using BCS apply it with the method of hot vertical condensation than with the technique of single pin and paste ($p < 0.05$).

Interestingly, to the question "What do you think limits the use of a bioceramic sealer", those who indicated "I do not have enough information" from practitioners of hot condensation are less than those who use the technique of cold lateral condensation ($p < 0.05$).

When asked what type of sealer you use in your clinical practice, the majority of respondents indicate more than one type. Only 6% use BCS, and a total of 16% have BCS in their arsenal, which they use only in certain clinical cases. The most widely used zinc oxide - eugenol (COE) sealers, and only 10% use materials based on formalin-resorcinol. The other types of sealers are distributed almost equally. Composite sealers are not preferred by LDM in Plovdiv region.

Unsurprisingly, we found that the question "Do you think that the use of a bioceramic sealer affects the healing process" those who use BCS significantly more answer "YES" than those who use COE sealer ($p < 0.05$). In unison with the latter, the users of COE who indicate "I cannot judge" are significantly less than the users of BCS ($p < 0.05$).

Nearly two thirds of the respondents (74%) believe that the specific clinical case requires a specific canal filling agent (CSF). A small proportion (18%) state that their choice is not influenced by the clinical case, and only 8% cannot judge. According to 47% of the surveyed LDM from Plovdiv region, BCS affect the healing process after endodontic treatment, while 15% do not think so. The remaining 37% state that they cannot judge. The high price of BCS (40%) and the lack of information (32%) are the two main reasons for LDM from Plovdiv region to refrain from their use. Only 9% are aware of the problems associated with the combined use of BCS and hot appliances, and 19% of respondents believe that further research is needed before adopting these new materials in their practice.

As the main reasons for the placement of an intermediate insert of calcium hydroxide preparation, 26% of the respondents indicated exudation, 23% - pain, 18% - odor and 15% - bleeding. Only 2% of the respondents state as a reason the subsequent use of BCS, and 4% will put the insert in each case. The remaining 12% do not put calcium hydroxide in the QC.

The majority of LDM (93%) report that they follow their endodontic treatments. More than half (54%) follow the treatment of chronic periodontitis, and reversible pulpitis is followed only in 26%. Irreversible pulpitis is followed in 12%, and the rest (7%) do not follow the cases they treat. The average follow-up period varies relatively evenly, respectively 23% for over 2 years, 35% between one and two years, 33% between half and one year. The rest of the respondents state that they do not follow their cases. Interestingly, those who

monitored their cases for more than 2 years would place a calcium hydroxide preparation in the root canal to raise the pH of the medium before using BCS, and not so much because of the odor present in the QC ($p < 0.05$).

Regarding the method for assessing the healing process, we received an almost unanimous answer - 94% rely on a clinical examination combined with anamnestic examination and conventional radiography. Some of the respondents believe that they do not need an X-ray examination and evaluate the results only clinically (3%), while others do not even conduct a clinical examination, but rely only on the anamnesis (2%).

Conclusions:

1. The high frequency of endodontic treatment by LDM in Plovdiv region necessitates the search for new and modern materials, such as bioceramic endodontic sealers, which must continue to be tested to prove or disprove their qualities by analyzing long-term results.
2. There is no need to change the technique of endodontic obturation, as the most commonly used techniques (single pin and lateral condensation) are included in the indications for use of BCS, but it may be necessary to make changes in other steps of EL, such as e.g. irrigation protocol.
3. LDM from Plovdiv region adhere to the activities typical for the acquired specialty, but there is a need for them to raise their awareness about the qualities of this new type of filling products.

4.2. Investigation of micropermeability in root canal obturation using the technique of hydraulic condensation and bioceramic sealer BioRoot RCS.

In determining the results of the present study, the solutions in the lower Eppendorf tube (C) were diluted 300-fold. The control group C + was equated to 100% at a dye concentration of 0.0066%. For the negative control group C-, a dye concentration of 0.0000004% (0.054%) was found. The test results are respectively (Fig. 7): for group C4 – 0.69%; for group BC4 – 0.39% and for group PT6 – 0.17%.

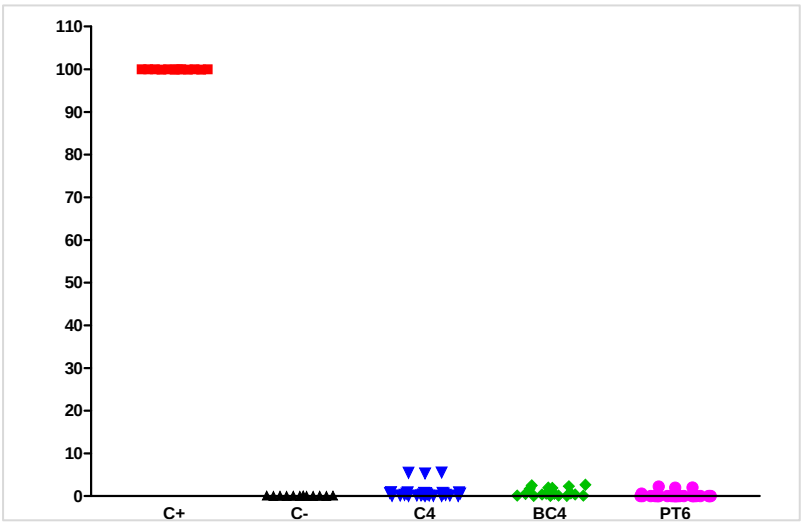


Figure 7. Graphical representation of the results of methylene blue filtration.

The relationships between the results of the methylene blue micro permeability study groups were assessed by variation analysis Kruskal-Wallis test and subsequent Dunn's Multiple Comparison test.

Reduced permeability of is reported MV for all samples, relative to the positive control (C +) ($p < 0.05$), as well as insignificant difference compared to the negative control (C-) ($p > 0.05$). All samples from the positive control missed 100% of the dye. Therefore, there is no retention of molecules MB in the parts of the root canal or in the lateral and dentinal tubules. The negative control group shows absolute dye resistance, as all samples show zero values. The group with unimpregnated 4% gutta-percha pins (C4) showed the strongest MB leakage. It is noteworthy that some of the samples missed more than the others in this group, which determines the higher value of the standard deviation in it. The arithmetic mean of the results from the group is 0.690, and the standard deviation is SD = 1.481. In group BC4 no high values of standard deviation were observed (SD = 0.853), and in group PT6, which showed the lowest transmission levels of all experimental groups (0.1672), the deviation had the lowest value SD = 0.6117.

Table 1. Tabular presentation of the results of Dunn's Multiple Comparison Test for methylene blue filtration.

Dunn's Multiple Comparison Test	Difference in rank sum	P value
Group C + vs group C-	61.71	P <0.001
Group C + vs group C4	51.47	P <0.001
Group C + vs group BC4	70.90	P <0.001
Group C + vs group PT6	77.06	P <0.001
Group C- vs group C4	-10.24	P> 0.05
Group C- vs group BC4	9,194 th most common	P> 0.05
Group C- vs group PT6	15.35	P> 0.05
Group C4 vs group BC4	19.43	P> 0.05
Group C4 vs group PT6	22.08	P> 0.05
Group BC4 vs group PT6	6,153 th most common	P> 0.05

After establishing the differences between the groups (Kruskal-Wallis) Dunn's Multiple Comparison test was applied to verify the statistical significance of these differences. Differences with statistical significance were found both between the positive (C +) and negative control (C-) and between each of the experimental groups and the positive control (C +). The variation analysis did not show an intergroup statistically significant difference in micro permeability for the experimental groups - 4% unimpregnated pin (C4), 4% bioceramically impregnated pin (BC4) and 6% unimpregnated gutta-percha pin. For all three groups, the results were less than 0.000005% and unreliable ($p > 0.05$), although

our expectations were that we would obtain a statistically significant difference between the group of the impregnated bioceramic pin BC Point (BC4) and the other two groups using a conventional (non-impregnated) gutta-percha pin (C4 and PT6). The differences between the negative control group (C-) with each of the experimental groups was without statistical significance ($p > 0.05$). Thanks to the analysis, it can be stated categorically that the tightness of the channel is ensured in all three techniques used for obturation of the CC (Table 1.).

Conclusions:

1. Bioceramic sealers, in particular the BioRoot RCS we used, showed a low degree of permeability in all samples in the experimental groups of the present study.
2. The preparation techniques used in the present study did not alter the degree of micro permeability of BCS
3. All three techniques of root canal obturation by bioceramic sealer (synchronized HC + non-impregnated gutta-percha pin; synchronized HC + impregnated gutta-percha pin; asynchronous HC + non-impregnated gutta-percha pin) did not show significant differences with each other. sealing ability of the three obturation techniques.
4. The presence of a connection between the gutta-percha pin and the endodontic sealer, as well as the different form of preparation do not significantly affect the degree of leakage of the endodontic obturation.

4.3. Research of the ability to perform re endodontic treatment and evaluation of residual canal filling material in root canals obstructed by hydraulic condensation and bioceramic endodontic sealer.

4.3.1. Research of the possibility of achieving apical patency in root canals obstructed by a bioceramic sealer and a gutta-percha pin positioned respectively on the RD and 2 mm shorter than the RD.

In order to study the possibility of achieving patency of the original apical opening, the samples prepared by us (n = 60, group 1) were purposefully obturated so that the gutta-percha pin did not reach the apical border of the preparation, but was 2 mm coronary from it. In this way we imitate a procedural error in the obturation protocol, in which the apical 2 mm of the prepared CC remain filled only with bioceramic endodontic sealer BioRoot RCS. The samples were subsequently divided into 3 groups, depending on the solvents used. In the control group (n = 10, group 0) the channels are completely filled with sealer, and in group 2 (n = 50) the gutta-percha pin is positioned at full working length.

The results are divided into 2 categories – without complication and with complication. Each of them includes 2 subcategories, respectively - achieved apical patency and lack of apical patency are possible results without the occurrence of a complication, and transport of the apical opening and separation of an instrument are possible results, including the occurrence of a complication.

The absence of an obturation core (gutta-percha pin) greatly complicates the procedure of preparation of the original root canal and the achievement of patency of the apical opening. In the control group (group 0) the root canals were obturated only with an endodontic sealer.

Group 0 (n = 10), in which the root canals are obturated only with a sealer, shows a 100% lack of apical patency. Due to the absence of a gutta-percha pin or other type of obturation core, the machine tools (D1, D2 and D3) barely manage to enter the duct filler before separating. Hand-held endodontic files fail to engage in the hardened sealer. In 8 out of 10 (80%) samples we register separation of an endodontic instrument, and in 2 of them (20%) an absolute lack of involvement.

When group 1-a the re-endodontic therapy (preparation of obturated KK) is performed without the use of solvents as aids, and the preparation is performed only by hand and machine endodontic files. The results show 30% achieved patency of the original apical opening. The highest share of the experimental samples from this group is occupied by the lack of apical patency – 40%. Transport of the apical opening is found in 25%, and separation of the instrument is observed in one of the samples – 5%.

In the re-preparation of the samples from group 1-bchloroform was used as a classic solvent. It is used in endodontics mainly as a solvent for gutta-percha, but no data have been found on its effect on penetration in our studied bioceramic endodontic sealer BioRoot RCS. The results for this group show the achievement of apical patency only in 20%, as the most common is the percentage of lack of apical patency – 55%. Transport of the apical opening is found in 4 of the experimental samples (20%), and separation of the instrument is established in a single sample – 5%.

In group 1-c we use 40% citric acid as an aid in the re-preparation process. Acids are used to dissolve cements in the construction industry, which gives us an opportunity to study the effect of acid when trying to pass through the apical part of the CC, filled only with an endodontic sealer, which is by nature hydraulic cement. The highest percentage of acid approved for intracanal use as an endodontic irrigant is 40% citric acid. The results show the achievement of patency of the original apical opening in 40% of the samples. Lack of patency was registered in 20%, and complications were observed in a total of 40%, with a distribution of 25% for apical opening and 15% for instrument separation.

Samples from group 2 (n = 50), in which the gutta-percha pin is located on the working length, show 100% achievement of apical patency. Without the use of solvents, the root canals were re-dissected to the apical foramen, with no complications such as instrument separation or apical opening. The gutta-percha pin "guides" the endodontic instruments by ensuring the engagement of their tips due to its semi-solid state.

The results were statistically processed using the Pearson Chi Square Test. The analysis shows no statistically significant differences between experimental groups ($p > 0.05$).

The results show the achievement of patency of the apical opening in 40% of the samples in the group with chelator (1-c). No other published studies have been found to evaluate the effect of chelators on the ability to walk KK obturated by bioceramic endodontic sealer and gutta-percha.

4.3.2. Tridimensional topographic characteristics of the residual material on the root canal wall after preparation of pre-obturated root canals by means of 3D cone-beam tomography (3D CBCT) and microscope.

The results of the conducted experiments on cleaning of the residual material, evaluated by two different methods - by 3D CBCT and digital optical microscopy (DOM), are presented in tabular form.

- **3D CBCT**

Table 2 presents the average volume of residual channel filler for each of the subgroups, as well as for group 2 in total, measured in cubic millimeters (mm^3).

Table 2. Quantity of residual channel filler for group 2, presented in cubic millimeters (mm3).

GROUP 2	Average volume (mm3)
Group 2 (PTR - control)	4.87144 mm3
Group 2-b (PTR + Pro Ultra)	0.11139 mm3
Group 2-in (PTR + SAF)	2.18957 mm3
Group 2-d (PTR + SAF + chloroform)	0.92138 mm3
Group 2-d (PTR + SAF + 40% lemon)	0.6755 mm3
Average volume for group 2	1.753856 mm3

In the control group (2-a) we observe the largest amount of residual channel filling material - average 4.87144 mm3, group 2-c, in which the innovative design and concept of operation SAF system is applied, is the second in terms of the amount of residual material - 2.18957 mm3. The addition of chloroform to the SAF system (group 2-d) improves the removal of KPS - 0.92138 mm3, as well as the addition of chelator (group 2-e) - 0.6755 mm3, but the lowest values are found in the group in which ultrasonic energy (2-b) was applied - 0.11139 mm3.

ANOVA and ANOVA were used for statistical processing of the results Pairwise Comparison Analysis.

In the control group (2-a) we observe the largest amount of residual channel filling material, and the smallest amount is found in group 2-b, in which ultrasonic energy is applied. The difference is with statistical significance ($p < 0.05$).

Group 2-c, in which the SAF system was applied, was second after the control group in terms of residual material. The file from the SAF system changes its shape according to the shape of the channel and thus helps to effectively remove KPS from the root canal wall. A significant difference was found between the SAF group (2-c) and the control group (2-a) ($p < 0.05$).

There is also a statistically significant difference between group 2-b, in which activation of the irrigation solution by ultrasonic energy was applied, and group 2-c, in which the SAF system without solvent addition was applied ($p < 0.05$).

No differences of statistical significance were found between groups 2-d and 2-e, nor between each of them and the control group ($p > 0.05$). The solvent chloroform (in group 2-d) and the citric acid chelator (group 2-e) used as excipients help to eliminate KPS, as the average values obtained are lower than those of the control group, but this difference is without statistical significance ($p > 0.05$).

The addition of a chelator (40% citric acid) also shows some advantage in removing KPS. The mean value of the residual material for the chelator group (2-e) is0.6755 mm3, which is less than the group with SAF only (2-b) as well as the group of SAF + chloroform (2-d). This difference can also be explained by the additional operating time of the SAF file, as well as by parts with the demineralizing action of the chelator. The obtained difference is without statistical significance ($p > 0.05$), which leads us to the conclusion that the chelators (in particular 40% citric acid) do not significantly help to remove the bioceramic sealer from the QC wall. This result supports Garrib's conclusion that chelators are not useful inthe removal of the bioceramic sealer from the QC wall.

- **Digital Optical Microscopy (DOM)**

Table 3. presents the mean values of residual endodontic sealer BioRoot RCS (in mm^2), relative to its location.

Table 3. Average values of residual endodontic sealer (in mm^2), according to its location.

Department\ Group	2-a	2-b	2nd century	2-d	2-d
Coronary	0.50743	0.30081	0.33105	0.26582	0.52919
Average	0.56442	0.23161	0.30175	0.64921	0.30219
Apical	0.28707	0.39821	0.42898	0.29822	0.28086

Bioceramic sealer residues are found in all sections of the root canals of all groups.

In the coronary third, the largest amount of sealer was found in the group of the SAF + chelator system (2-e) – 0.52919 mm^2, and the least in the group of SAF + chloroform (2-g) – 0.26582 mm^2. Control group 2-a, in which only the files of

the Pro Taper Retreatment + F3 system (Pro Taper Gold) were used, showed an average value of 0.50743 mm^2, and ranked second after group 2-e. Group 2-c, in which the SAF system (without the addition of solvent or chelator) is used in addition to the rotary files, shows an average value of 0.33105 mm^2. The results for group 2-b, in which, in addition to rotary files, ultrasonic energy was applied, show an average value of 0.30081 mm^2. The highest residual sealer is found in the middle third of the root canals of all groups. The largest amount of sealer in the samples from the group of SAF + chloroform (2-d) – 0, 64921 mm^2, which is followed by the control group (2-a) – 0.56442 mm^2 and the group of the SAF + chelator system (2-e) – 0.30219 mm^2. The smallest amount of sealer is found in the groups of the SAF system without the addition of solvent or chelator (2-c) – 0.30175 mm^2, and group 2-b, in which ultrasonic energy is applied – 0.23161 mm^2. The amount of residual sealer in the apical third of the root canals is the smallest. The group showing the largest amount is that of the SAF system without the addition of solvent or chelator (2-c) – 0.42898 mm^2, followed by the group in which, in addition to rotary files, ultrasonic energy (2-b) is applied – 0.39821 mm^2. The group of SAF + chloroform (2-d) shows an average value of 0.29822 mm^2, which is more than the control group (2-a) – 0.28707 mm^2, and the group of SAF + chelator (2-e) shows the lowest values in this department – 0.28086 mm^2. Comparing the total average area, the lowest average values for residual sealer are in the control group (2-a) – 0.45297 mm^2, followed by the group of SAF + chloroform (2-g) – 0.40441 mm^2 and SAF + chelator e) 0.37074 mm^2. Groups 2-c (SAF system, without addition of solvent or chelator) and 2-b, in which ultrasonic energy was applied, show the lowest average values of residual bioceramic sealer after re-preparation, respectively – 0.35392 mm^2 and 0.31021 mm^2. Table 4 presents the mean values of residual gutta-percha (in mm^2), relative to its location in the root canal.

Table 4. Average values of residual gutta-percha (in mm2), relative to its location.

Department \ Group	2-a	2-b	2nd century	2-d	2-d
Coronary	0.1585	0	0.0551	0	0
Average	1.1360	0.39325	0.4172	0	0
Apical	0.24045	0.2227	0.36853	0.0658	0.1320

The results show that gutta-percha is removed more effectively than the bioceramic sealer BioRoot RCS.

No residual gutta-percha was found in the coronary department in most of the experimental groups. Residues of the calibrated gutta-percha pin are found only in the control group (2-a) – 0.1585 mm^2 and less in that of the SAF system, without the addition of solvent or chelator (2-c) – 0.0551 mm^2. In the other groups there are no perceptible remnants of gutta-percha.

In the middle section we find gutta-percha residues in three of the experimental groups, and the amount is again the largest in the control group (2-a) – 1.1360 mm^2. This is followed by the SAF group, without the addition of solvent or chelator (2-c) – 0.4172 mm^2 and the ultrasound group – 0.39325 mm^2.

In the apical department, gutta-percha is found in each of the groups, with the largest amount in the SAF group, without the addition of solvent or chelator (2-c) – 0.36853 mm^2. In second place is the control group (2-a) – 0.24045mm^2, followed by the group of ultrasound (2-b) – 0.2227mm^2 and the system SAF + chelator (2-e) – 0.1320 mm^2. The smallest amount of gutta-percha for the apical zone was found in the group of SAF + chloroform (2-g) – 0.0658 mm^2.

The total amount of residual gutta-percha is the largest in the control group (2-a) – 0.51165 mm^2, followed by the group of ultrasound (2-b) – 0.30797 mm^2 and the group of the SAF system, without the addition of solvent or chelator (2-c) – 0.28027 mm^2. The groups of SAF + chelator (2-e) and SAF + chloroform (2-d) show the lowest values, 0.1320 mm^2 and 0.0658 mm^2, respectively.

To process the results, we use various statistical analyzes to determine the type of distribution of results and the presence or absence of differences of statistical significance. Normal distribution of results (Kolmogorov-Smirnov Z.test) for residual sealer was observed in all three departments of the QC, while the results obtained for residual gutta-percha showed a lack of normal distribution. The total area of residual channel filler (sealer + gutta-percha) also shows a normal distribution of results ($p > 0.05$).

- **Analysis of residual sealer results**

To determine whether there were intragroup and intergroup statistically significant differences between data from three or more independent groups, a nonparametric ANOVA analysis was applied. It revealed intergroup differences in the coronary and middle third ($p < 0.05$), and in the apical third and the total volume of the sealer intergroup differences with statistical significance were not observed.

To find out which groups are statistically different from each other, we apply Post Hoc Test for dependent samples, which detects differences with statistical significance in terms of the amount of residual sealer for coronary, middle and apical third, respectively.

In the coronary third the root canal has the largest number of statistically significant differences.

A statistical difference ($p < 0.05$) was found between the control group (2-a), in which only rotary files (PTR) were used, and the ultrasound group (2-b), in which the ultrasonic tips Pro Ultra (Densply) were used. Another difference with statistical significance exists between the control group (2-a) and the group of the SAF + chloroform system (2-d). Another difference with statistical significance was found between the group of the SAF + chelator system (2-e) and the group in which ultrasound (2-b) was applied.

The addition of a chelator to the SAF protocol in the endodontic treatment procedure is an original technique that has not been tested so far. Interestingly, in this group we found more residual sealer in the coronary department of the CC than in the group of ultrasound (2-b). Although the SAF file worked an additional minute more in the CC after the chelator was placed, the amount of residual sealer in this area was higher compared to the UL group ($p < 0.05$). In the other departments of the CC - middle and apical, such a difference in the amount of sealer is not observed ($p > 0.05$). We attribute these results to the high efficiency of ultrasound in the coronary section of the CC, which is usually straight and accessible to the ultrasound nozzles.

A difference with statistical significance ($p < 0.05$) was found between the group of the SAF + chelator system (2-e) and the group in which the SAF system was applied, without the addition of solvent or chelator (2-c).It's surprising the larger amount of bioceramic sealer in the chelator group (2-e), as we think it should help remove the material.

A statistical difference was found between the groups of the SAF + chelator (2-e) and SAF + chloroform (2-d) systems.

In both groups, the SAF file runs for an additional minute after the 2 minutes set out in the operating protocol have elapsed. The lower values of residual sealer in the coronary third of the CC for the chloroform group are probably due to the more easily removed gutta-percha and subsequent reaching of the SAF file to the endodontic sealer ($p < 0.05$).

When analyzing the residual sealer in the middle third, the data show a statistical difference only between group 2-b, in which ultrasonic energy was applied, and group 2-d, in which chloroform was applied in combination with the SAF system ($p < 0.05$).

In the apical department no significant differences between the groups were found. The results obtained on the amount of residual bioceramic sealer are close in absolute values, with the least material found in the group of SAF + chelator (2-e), and the most in the group of SAF, without the addition of chelator or solvent (2- in). The differences are without statistical significance ($p > 0.05$).

When comparing the total area of the residual sealer, no significant differences were found between the three departments of the QC ($p > 0.05$).

- **Analysis of the results for residual gutta-percha**

The comparison test between data from three or more independent ANOVA groups showed no statistically significant intergroup differences in the three CC departments regarding the amount of residual gutta-percha ($p > 0.05$). The test of Kruskal-Wallis for independent samples also did not show statistically significant differences in the amount of residual gutta-percha between the groups for any of the three QC departments. ($p > 0.05$).

Our working hypothesis is that endodontic solvents have an effect on the physical and mechanical properties of the hardened sealer and would facilitate the

procedure of non-surgical re-endodontic treatment. Chloroform dissolves gutta-percha, which according to the instructions for use of BKS is always available in KK. This facilitates the passage of that part of the root canal in which gutta-percha is present, but has no effect on the bioceramic sealer itself. Therefore, based on the conducted experiment and the obtained results, we have to reject the working hypothesis formulated by us that the applied solvents have an effect on the physical and mechanical properties of the hardened sealer.

Conclusions:

1. The methodology for obturation of root canals by hydraulic condensation and bioceramic sealer BioRoot RCS is fully applicable in in-vitro studies.
2. In root canals obstructed by hydraulic condensation and BCS, the achievement of patency of the apical opening is directly related to the position of the obturation core (gutta-percha pin) relative to the apical opening.
3. Endodontic solvents (chloroform) and chelators (40% citric acid) did not significantly affect the degree of removal of BCS from the root canal wall during non-surgical re-endodontic treatment.
4. The SAF system, as well as the application of ultrasonic energy, have a significant influence on the degree of removal of BCS from the root canal wall.
5. Three-dimensional cone-beam examination (3D CBCT) and digital optical microscopy (DOM) are suitable methods for measuring the amount of residual channel filler in in vitro studies.

4.4. Clinical study of the healing process after root canal obstruction by hydraulic condensation and BioRoot RCS.

The design of the clinical trial and patient flow was compiled according to the reporting requirements of the Consort cohort studies.

The healing process was assessed in 37 patients. 66 clinical cases were subjected to endodontic treatment and the data from the respective clinical maps (n = 66) were subjected to statistical processing. The average age is 41.83 years and the gender distribution shows a larger share of women – 55% (n = 36) and men occupy 45% (n = 30). The mean age in women was 42.58 and in men 40.93. Half (50%) of the teeth treated were maxillary (n = 33), with 27% of the first quadrant (n = 18), and of the second quadrant is 23% (n = 15). The remaining 33 cases (50%) were respectively mandibular, with 21% (n = 14) being from the third and 29% (n = 19) being from the fourth quadrant (Fig. 8).

Figure 8. Distribution by groups of teeth.

The study treated irreversible diseases of the dental pulp and chronic inflammatory processes of the periodontium, with acute conditions occupying only 5% (n = 3) and the majority being chronic (95%, n = 63). The largest share is occupied by cases of chronic localized periodontitis -Periodontitis chronica granulomatosa localisata (32%, n = 21), followed by chronic ulcerative pulpitis - Pulpitis chronica ulcerosa (26%, n = 17). The cases of chronic diffuse periodontitis - Periodontitis chronica granulomatosa diffusa and chronic fibrous periodontitis - Periodontitis chronica fibrosa are equally common in the sample (18%, n = 12). The study also included one case of chronic concremental pulpitis - Pulpitis chronica concrementosa (2%, n = 1) (Fig. 9).

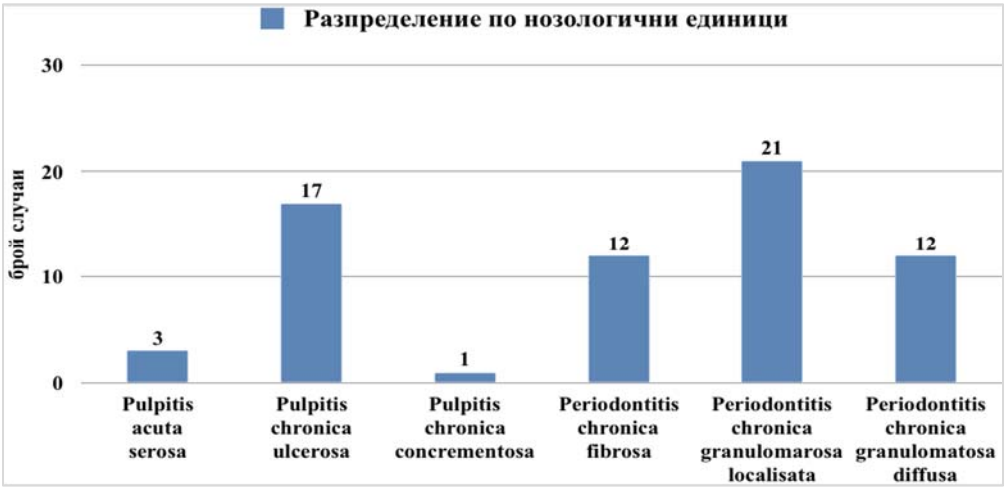


Figure 9. Distribution by nosological units.

The result of the treatment was evaluated in two stages - once in the 6th month and once in the 12th month. The assessment is performed by performing a clinical examination and paraclinical examination. The evaluation criteria from the clinical examination are filled in the clinical map and include two sections - clinical signs and radiological signs. The clinical signs are respectively: presence

of spontaneous pain, reaction to vertical percussion, pain from temperature stimulus and mobility. Paraclinical examination involves the imaging of sectoral parallel two-dimensional radiography. The radiological signs for evaluation are: adaptation of the canal filling material to the walls of the root canal, level of the root canal obturation to the radiological apex and periapical index.

- **Clinical signs**

Data processing showed that spontaneous pain was present in 6 of the clinical cases (9%) before seeking dental care. Two of them have chronic ulcerative pulpitis in the exacerbation stage (classes 4 and 5), three of them have acute serous pulpitis (classes 16, 33 and 52) and one has chronic concremental pulpitis. in the exacerbation stage. In all of them, the spontaneous pain disappeared immediately after the procedure and there is no evidence of such either at 6 or 12 months.

A positive response to vertical percussion was observed in 61% (n = 40) of clinical cases. At the 6th month, total elimination of this symptom is established, which is confirmed at the next control examination, respectively at the 12th month.

The response to a cold stimulus, in which the pain does not pass immediately after interception of the stimulus, was found anamnestic and was positive in 36% of clinical cases (n = 24) at the initial examination. These are both cases of inflamed pulp and some borderline conditions in which, due to the available changes on radiography, chronic periodontitis has been diagnosed, but they have preserved vitality in some parts of the pulp. In 100% of them, the complaint disappeared immediately after the endodontic procedure and did not appear within a year. These data were confirmed during follow-up examinations, and there was no such complaint in all patients at both 6th and 12th month.

Tooth motility was not observed in any of the clinical cases before treatment or follow-up.

- **Radiological signs**

The degrees for assessing the adaptation of the canal filler to the root canal wall, the level of the root canal obturation relative to the radiological apex and the periapical index are presented in.

In 95% of the monitored cases (n = 63) we report a good adaptation of KPS in both the coronary and apical ½ of the root canal - grade "1". In two of the cases (№15 and 18) we report good adaptation in coronary ½ and poor in apical ½ - grade “2”, and in only one case (№25) we give grade “3” - poor adaptation in coronary ½ and good in apical ½. The adaptation of the KPS to the QC wall does not change over time. This is confirmed by the control examinations, in which we make an assessment similar to the one placed immediately after filling the root canals.

Although BioRoot RCS extends to 28 days after mixing, which also results in improved adaptation to the QC wall, we do not report a difference in adaptation at either 6th or 12th month.

The level of root canal obstruction coincides with the radiological apex of the root canal in 80% (n = 53) of the observed cases. In all of them we do not

report a difference in the level of the control examinations and we set the same assessment to 6-you and 12th month.

In 5 of the cases (7.88%) we report a shorter filling of the root canal up to 3 mm from the radiological apex. Despite suboptimal obstruction, in 3 of these 5 cases we report complete recovery of the periapical tissues (№14, 21 and 52). In the other 2 (№12 and 18) we report a reduction in the size of the periapical lesion - in the case of №12 the localized granulomatous periodontitis becomes fibrous as early as the 6th month, and in the case of № 18 the diffuse granulomatous periodontitis acquires clear boundaries at 6- month and 12th month was diagnosed as localized granulomatous periodontitis. In 12.12% of cases (n = 8) the root filling is after the radiological apex on the tooth. It is important to note that in all of them only a bioceramic sealer was extruded, and the gutta-percha pin coincided with the apical border of KK preparation. In 7 of them the level does not change during the control examinations. In one of them we observe resorption of the extruded sealer at the first control examination (6th month) and coincidence of the level of the root filling with the radiological apex of the tooth at the 6th and 12th month.

Extrusion of an endodontic sealer outside the root canal can affect the healing process. In 8 (12.12%) of the monitored cases we register "canal filling after the radiological apex", which is a bioceramic endodontic sealer BioRoot RCS. Only in one of them (1.6%) we register resorption (dissolution) of the extruded material as early as the 6th month, while in the remaining 7 volumes the extruded material does not change even at the control at the 12th month. In all cases of extrusion, there is a registered healing process at 12 months, and only one of them remains incomplete (PAI-3). The exceptional properties of bioceramic materials determine the lack of inflammatory reaction after their extrusion.

The periapical index (PAI) was proposed by Orstavik in 1986 as a simplified version of the radiographic method for interpreting Brynolf from 1967 and consists of 5 categories numbered from 1 to 5. The assessments of the PAI system are not tied to specific nosological units of the classification of Svrakov-Dachev and the search for such compliance we consider inappropriate.

Immediately after endodontic treatment, we found healthy periapical tissues (PAI-1) in 32% of cases (n = 21). A PAI-2 score was found in 17% of cases (n = 11), a PAI-3 score in 3% (n = 2), and a PAI-4 and PAI-5 score in 30% (n = 20) and 18%, respectively. (n = 12). When performing a control examination at 6 months after root canal obturation, we report an increase in PAI-1 (70%, n = 46) and a decrease in PAI-2 (11%, n = 7). We registered a slight increase in PAI-3 (20%, n = 13) compared to baseline. There are no clinical cases evaluated with PAI-4 and PAI-5. At the follow-up examination at 12 months, we again report an increase in cases with PAI-1 score, which reached 92% (n = 61) of the monitored cases. The incidence of PAI-2 and PAI-3 decreased - 5% (n = 3) and 3% (n = 2), respectively, both compared to both the initial condition and the follow-up examination at 6 months.

We consider successful the cases in which a reduction in the size of the periapical lesion is observed. Estimates of PAI-1 and PAI-2 correspond to the healing process that has taken place. When reducing the size from PAI-5 to PAI-4 or PAI-3, or from PAI-4 to PAI-3, we believe that the healing process is not over, but is still underway. In the absence of a reduction in size, as well as an increase in the size of the lesion during follow-up examinations, the case is considered unsuccessful.

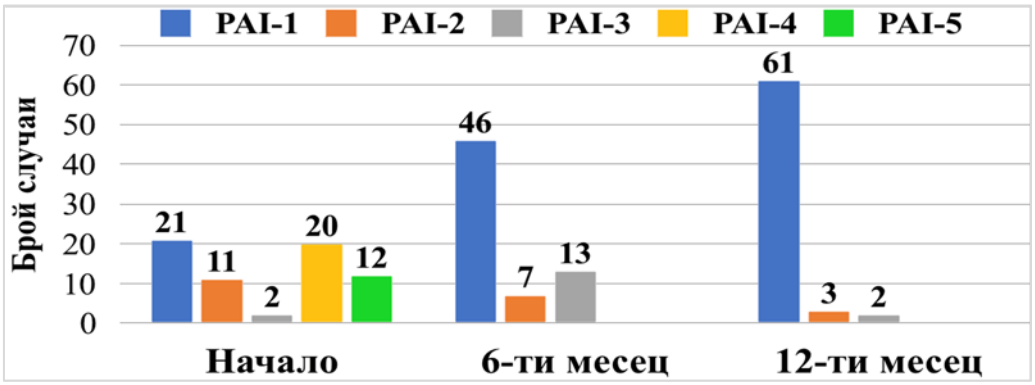


Figure 10. Dynamics of the periapical index (PAI) in the course of the clinical study.

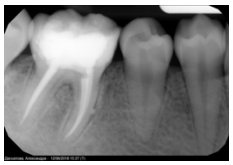
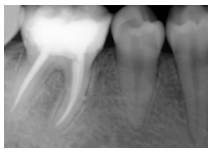
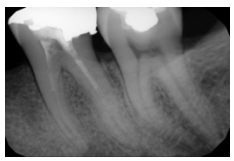
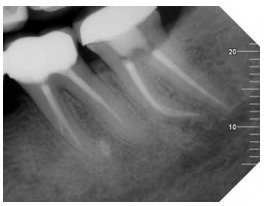
Tooth №	Before treatment	During treatment	6th month	12th month
46				
	PAI-5	**PAI-5**	**PAI-1**	**PAI-1**
37				
	PAI-1	**PAI-1**	**PAI-1**	**PAI-1**

Figure 11. X-rays from the clinical trial.

The average success rate in the treatment of the clinical cases we followed was 100%. In the treated acute and chronic pulpitis (n = 21) the condition of the periapical tissues remains unchanged after the endodontic treatment - periapical lesion does not develop and the assessment of PAI remains PAI-1, both before treatment and at follow-up examinations on the 6th and 12th month. In the treatment of chronic periodontitis, we observe a reduction in the size of the periapical lesion in all clinical cases (n = 45). In them, we observed an increase in PAI-1 from 0% before treatment

to 44% (n = 20) at 6 months and up to 82% (n = 37) at follow-up at 12 months. In 13% (n = 6) the assessment at 12 months was PAI-2, and in 4% (n = 2) a PAI-3 assessment was given and the healing process was considered incomplete.

In 27% (n = 12) of the chronic periodontitis group, the pre-treatment PAI score was PAI-5. In 5 of them, a reduction to PAI-3 was observed at 6 months, and a complete recovery of the periapical space was reported at 12 months. At one month, no reduction (PAI-5) was observed, while at 12 months we reported a reduction in lesion size (PAI-2). In another, the reduction in size (PAI-2) occurred as early as 6 months and did not change on follow-up at 12 months (PAI-2). Although the recovery of the periapical tissues is not complete, these cases have been reported as successful with a completed healing process.

In 2 of the clinical cases with a PAI-5 score before treatment, we set a PAI-3 score on follow-up examinations at 6 and 12 months. Due to the fact that the size of the lesion in these cases does not increase, they are assessed as successful, in which the healing process is still ongoing.

In 44% (n = 20) of the cases of periodontitis, the assessment of PAI before treatment is PAI-4, and in 90% of them (n = 18) at 12 months we report complete recovery of the periapical area (PAI-1). At 10% (n = 2), the healing process is again considered complete, although the periodontal fissure remains dilated in the apical area (PAI-2).

Only 2 cases (4% of periodontitis) were evaluated with PAI-3 before treatment. In both cases, we report a reduction in the size of the lesion at 6 months, while at 12 months the healing process is complete (PAI-1). In 11 clinical cases (24% of periodontitis) the PAI score before treatment was PAI-2, and in 10 of them we found a reduction in the size of the lesion to complete recovery (PAI-1). In 8 of these 10 the recovery was completed in the 6th month, and in 2 of them a change is observed only in the 12th month.

Conclusions:

1. The technique of obturation of the root canal by hydraulic condensation and bioceramic sealer BioRoot RCS is fully applicable in clinical conditions and shows good adaptation to the walls of the root canal.
2. Drying the root canal with a single calibrated paper pin, without the use of alcohol in clinical conditions, provides suitable conditions for the manifestation of the properties of the bioactive material.
3. The placement of a bioceramic sealer (BioRoot RCS) in the root canal by a Lentulo-type canal filler in clinical conditions leads to good adaptation to the walls of the root canal and does not lead to excessive extrusion of material.
4. BioRoot RCS bioceramic endodontic sealer has a positive effect on the healing process in the treatment of irreversible inflammatory diseases of the pulp and periodontium, without leading to clinically and/ or radiologically detectable inflammation of the periapical tissues for a period of 12 months.

4.5. Development of clinical protocols for optimization of the application and removal of bioceramic endodontic sealers.

4.5.1. Root canal obturation protocol by hydraulic condensation and bioceramic endodontic sealer

Our proposed clinical protocol is supported by clinical and laboratory studies on the quality of endodontic obstruction, as well as clinical data on a quality healing process (table 5).

1. Choice of material. Bioceramic endodontic sealers are available in two possible commercial forms - pre-mixed and requiring mixing. In passable root canals (patency of the foramen apicale is uncompromised) both forms are fully applicable. In root canals where the patency of the apical opening is compromised - for example during repeated endodontic therapy and inability to reach the foramen apicale, or iatrogenic blockage of the canal lumen with dentin filings, separated instruments or others, we recommend the use of BCS from the group of those requiring mixing, in which the risk of insufficient moisture in the root canal leading to doubtful or suboptimal hardening is minimized.

2. Final irrigation protocol. Final treatment of the root canal with saline is recommended to assist in the evacuation of active irrigants used in endodontic treatment and to rehydrate the root dentin. Alcohol should not be used due to the risk of canal dehydration.

3. Drying of the root canal. The final irrigation solution is aspirated by back pressure of the irrigation syringe. A single calibrated paper pin is used to dry the root canal.

4. Method of placement in the root canal. Representatives of the group requiring mixing are applied in a thin layer along the root canal wall using a paper or gutta-percha pin, while pre-mixed can also be injected into the root canal through a plastic cannula. Applying a hygroscopic material, such as all BCS, with a paper pin carries risks of dehydration of the already mixed (or ready to use) material. There is also the possibility of incomplete coverage of all areas of the root canal wall by the bioceramic sealer. The method of injecting premixes also carries risks, such as the formation of a balloon in the apical area or the unwanted extrusion of a large amount of material beyond the apical opening.

We offer an alternative to the described BCS application techniques, which eliminates most of the possible errors and complications, and which is also applicable to each of the two BCS groups. After mixing the material, a small amount of material is taken with a Lentulo-type duct filler mounted on a return tip to the endodontic micromotor. The tip of the channel filler is positioned 1-2 mm coronally from the apical opening and is driven in constant rotation at 600 rpm. If a pre-mixed BCS is used, a small portion is injected from the syringe into the plastic cannula, then the latter is removed from the syringe and the required amount of material is taken from its coronary end by means of the duct filler itself. It is not recommended to apply directly on the cartridge from the syringe itself due to the risk of contamination of the syringe!

5. Inserting a gutta-percha pin. A calibrated gutta-percha pin is used, which is inserted slowly up to the specified working length. Due to the high hardness that BCS reach after hardening and the lack of a known solvent for them, the gutta-percha pin must reach the apical limit of preparation.

6. Remove excess. BCS are relatively easily removed from the cavity before they have hardened. The working time of BioRoot RCS is 12 minutes, but its hardening time exceeds 4 hours, so there is no risk of the material in the pulp chamber hardening before the obturation of all canals in multi-rooted teeth is completed. For wider cavities, it is sufficient to flush the cavity with a water-air spray from the unit, and for narrower ones, it is recommended to include an ultrasonic nozzle (water-cooled) held centrally (passively) in the pulp chamber, whose vibrations, similar to assisted irrigation of QC, help to completely remove excess material. In cases where there is a hardened BCS in the pulp chamber, the approach for its removal is again through an ultrasonic nozzle with water cooling, which comes into contact with the material.

Table 5. Protocol for clinical use of BCS.

Type of BCS / Stage	One-component (pre-mixed)	Two-component (requiring mixing)
1. Choice of material	Passable QC	Passable QC Impassable QC
2. Final irrigation solution	Saline	
3. Drying	Single calibrated paper pin	
4. Method of placement	1. Paper/ gutta-percha pin 2. Injection 3. Lentulo	1. Paper/ gutta-percha pin 2. Lentulo
5. Introduction of GP pin	Slow to working length	
6. Remove excess	Water-air spray (± ultrasound)	

4.5.2. Protocol for removal of bioceramic endodontic sealer BioRoot RCS from the root canal

Bioceramic endodontic sealers are a relatively new type of material that reaches high hardness after hardening. Their removal from the root canal is a problem for which no clinical protocol has been established. Based on an experiment, we make recommendations to dentists about the steps and methods for optimal removal of a bioceramic sealer (BioRoot RCS) from the root canal (Table 6.).

1. The removal of the canal filling material begins with the removal of the gutta-percha available in the root canal using a technique chosen by the operator. In our experiment, we used files from the Pro Taper Retreatment (PTR) system.
2. In the absence of gutta-percha in any department (or departments) of the root canal, the PTR system is not indicated. In these cases, manual K-files are used, attempting to reach the apical opening.
3. In the absence of involvement at the tip of the manual K-files, with straight root canals, an attempt is made for ultrasound preparation under visual control (dental operating microscope). The ultrasonic tips must have a thin and long working part, which allows to work in the root floor magnification. In our experiment we use Pro Ultra tips (Densply) with numbers 6, 7 and 8.
4. In the absence of visual control (curved root canals) there is no possibility for the application of ultrasonic tips. In these cases, after drying the KK with paper pins, a solvent (0.1 ml) of chloroform is applied to the prepared part of the KK or to the coronary reservoir of the irrigator (pulp chamber) and attempts are made again to engage the tip of the hand file. If a lack of involvement is found, the canal is dissected to the appropriate level and the need for endodontic surgery is assessed.
5. After the passage of the root canal (reaching the apical opening) and measuring the working length, the formation of the QC with the preferred machine system for preparation is started. Criteria for completed preparation include:
   a. Lack of residual channel filling agent on the tool;
   b. Lack of residual canal filler in the root canal.
6. The use of the self-adjusting file from the SAF system (ReDent Nova) is recommended for optimal removal of bioceramic endodontic sealer residues from the root canal details. The file is applied for 2 minutes in each root canal, and the activation time is strictly monitored by the built-in timer in the endomotor.
7. If gutta-percha residues are observed on the instrument, an organic solvent - chloroform is applied. A drop (0.1 ml) of the solvent is placed in the root canal and the SAF file is activated for an additional minute in a completely similar manner, the only difference being that the simultaneous irrigation pump is switched off in advance. After an additional minute, the chloroform was removed by washing with saline.
8. After the preparation of the root canal is completed, assisted irrigation is performed. Ultrasonic energy is applied to activate the irrigation solution through the Pro Ultra (Densply) nozzles. The kinetic energy from the ultrasonic tip is transmitted to the remains of the BCS and helps their dislocation and evacuation.

Table 6. BioRoot RCS bioceramic endodontic sealer removal protocol.

Legend:

- **Poor** efficiency

- **Moderate** efficiency

- **Good** efficiency

Means \ Material		Gutta-percha	Bioceramic sealer (BioRoot)
Mechanical means	Gates Glidden		
	Pro Taper Retreatment (PRT)		
	K-saws, H-saws		
	Pro taper Gold/ Next; WaveOne		
	Ultrasound		
	SAF system		
Chemical funds	Solvent (chloroform)		
	Chelator (40% citric acid)		

V. CONCLUSION

Bioceramic sealers (BCS) are the newest type of endodontic sealers presented in clinical practice. They differ from their predecessors in a number of indicators, but the main difference lies in their reaction to hardening. There is no other member of the family of endodontic obturation materials that hardens when reacted with water (hydration). Based mainly on calcium silicates, these materials react with water molecules to form a gel of calcium silicate hydrate, which under appropriate conditions turns into hydroxyapatite - the main building block of hard dental tissues. During their hardening reaction, a large amount of calcium hydroxide is released, which raises the pH and determines their biological effect.

There are endodontic sealers that do not have the properties characteristic of BCS, but are marked as "bioceramic". They do not cure on the basis of the reaction of the components with water, but contain reacted particles of bioceramic material (MTA) in a matrix of epoxy resin or salicylate. This creates confusion not only among clinicians but also among researchers. The definition created by us specifies the term bioceramic endodontic sealer, and the classification proposed on this basis brings clarity about the composition and form of offering the most commonly used representatives.

Cold techniques have evolved naturally to simplify the clinical protocol. Thanks to modern calibrated gutta-percha pins, today the technique of hydraulic condensation and BCS offers an easy, fast and effective method for three-dimensional obturation of the root canal system, without the need for expensive equipment, complex clinical protocol or risk of thermal trauma. Most of the dentists from Plovdiv region prefer the technique of a single pin for root canal obturation. Bioceramic sealers are still entering the individual practice of clinicians, and the main reason for refraining from their use is the relatively high cost of the material. It is necessary to raise the awareness of LDM from Plovdiv region about the peculiarities of this type of materials,

BCS manufacturers recommend that they be used in combination with gutta-percha impregnated with bioceramic particles to obtain a bioceramic monoblock endodontic obturation. However, our experiment on a bioceramic monoblock concept shows that the use of impregnated gutta-percha pins does not significantly increase the degree of root canal sealing. The different conicity (4% and 6%) of the preparation also does not significantly affect the degree of leakage of the endodontic obturation when using the technique of hydraulic condensation and BCS.

Achieving patency of the apical opening is an important condition for success in non-surgical re-endodontic treatment. Due to the high hardness that BCS acquire after hardening, and since there is no proposed specific solvent for them, the passage of QC is not a completely predictable procedure. Chloroform is a standard solvent used in endodontics to remove gutta-percha and some sealers, but we confirm the lack of effect on bioceramic endodontic sealers. Chelators are compounds that bind to calcium ions and help remove the smeared layer while conditioning the root canal dentin. However,

they are ineffective in binding calcium ions from BCS and therefore do not help to remove them.

The mechanical impact on the BCS through ultrasonic tips is effective in the right part of the root canal, but is inapplicable after the curvature, which severely limits their use, especially in the apical departments. The self-adjusting file (SAF) successfully removes BCS from the root canal wall, but is not effective in achieving apical patency. To increase the predictability of their removal, the gutta-percha pin should reach the apical border of the preparation, and serve as a pathway for the obstructed root canal. If this condition is met, the root canals obstructed with BCS and gutta-percha pin pass smoothly and achieving patency of the apical opening is a predictable procedure.

Complete removal of canal filling material from the root canal walls is another important condition for success in non-surgical re-endodontic treatment. Microtomography (micro CT) is most commonly used as a method for measuring the amount of residual channel filler in laboratory experiments. As it is not applicable in in vivo conditions, we investigate the possibilities of cone-beam computed tomography (CBCT) as a method for determining and measuring the amount of residual channel filler, after an attempt to remove it. We find that it is applicable in both vitro and in vivo conditions, which gives us reason to recommend it as a means of quantitative measurement of residual CPS in clinical conditions.

Our clinical study on the healing process after endodontic treatment supports the results of laboratory experiments. Success was found in 100% of the treated patients, with a reduction in the size of the periapical lesion in all chronic periodontitis, and no periapical lesion in the treated acute and chronic pulpitis at either the 6th or 12th month. All treated teeth are asymptomatic, functionally and aesthetically fit.

The transition to the use of hydrophilic endodontic sealers (in particular BCS) determines some features of the work protocol, compliance with which is an important prerequisite for achieving predictable clinical results. For this purpose, we offer an original protocol for clinical use of bioceramic endodontic sealers, which minimizes the risks of formation of voids and pores in the filling, suboptimal hardening of the material, and also ensures the possibility of subsequent non-surgical (orthograde) re-endodontic treatment.

If not applied optimally, BCS are difficult to remove from the root canal. Agents that help remove other types of endodontic filling materials do not have the desired effect on BCS. Based on our laboratory experiments, we offer an original protocol for removal of BCS from the root canal, in cases of repeated endodontic treatment.

The protocols proposed by us for work with bioceramic endodontic sealers are created on the basis of conducted laboratory and clinical studies. The recommendations should facilitate dental practitioners, both in choosing the appropriate material for the specific clinical case, and to clarify the specifics of the implementation of specific steps of endodontic treatment related to the use of BCS. Although relatively new materials, BCSs promote a simplified clinical protocol characterized by ease and speed of execution, making it accessible and increasingly popular.

VI. GENERAL CONCLUSIONS

1. Bioceramic sealers are not often used by dentists from Plovdiv region, although their preferred obturation techniques are included in the indications for use of these materials, requiring a change only in the technique of the final irrigation protocol.

2. Obstruction by hydraulic condensation and BioRoot RCS showed a low degree of permeability, which did not depend on the conicity of the preparation (4% or 6%) or on the type of gutta-percha pin (impregnated/ non-impregnated).

3. BioRoot RCS cannot be completely removed from the root canal during repeated endodontic treatment, and neither chloroform nor citric acid help to remove it.

4. The effective removal of gutta-percha and bioceramic sealer (BioRoot RCS) from the root canal wall, applied by the technique of hydraulic condensation is achieved through the use of ultrasonic nozzles Pro Ultra and the SAF system.

5. The application of bioceramic sealer BioRoot RCS with the technique of hydraulic condensation, in the treatment of diseases of the dental pulp and periodontium, provides an excellent healing process.

VII. CONTRIBUTIONS

Contributions of original character:

1. Created is an original definition and author's classification of bioceramic endodontic sealers based on the original product and form of supply of the preparation.
2. For the first time a survey was conducted on the attitude of dentists from Plovdiv region to the use of bioceramic endodontic sealers in their clinical practice.
3. The difference in the micropermeability of dye between two different conicities of preparation (4% and 6%) in obturation of the root canal system with hydraulic condensation and the application of bioceramic monoblock concept - impregnated gutta-percha pins (BC Points) and bioceramic endodontic sealer was evaluated. RCS)
4. The effect of the SAF system on the removal of a bioceramic sealer (BioRoot RCS) from the root canal wall was studied.
5. The effect of 40% citric acid on the removal of BioRoot RCS from the root canal wall and the apical opening (achieving apical patency) was studied when used not as an endodontic sealer but as a stand-alone filling material.
6. The volume (by CBCT) and the area (by digital optical microscopy) of the residual bioceramic sealer BioRoot RCS in the root canal were measured after non-surgical re-endodontic treatment.
7. Clinical protocols for application and removal of BioRoot RCS bioceramic sealer have been developed.

Confirmatory contributions:

1. The low degree of micropermeability at obturation of the root canal system with hydraulic condensation and bioceramic endodontic sealer BioRoot RCS has been proven.
2. The absence of a statistically significant difference in obturation with bioceramic sealer in combination with bioceramically impregnated and unimpregnated gutta-percha pin.
3. The good adaptation of the bioceramic endodontic sealer to the root canal wall in clinical conditions has been confirmed.
4. A clinical study of the effect of the BioRoot RCS bioceramic sealer on the healing process after endodontic treatment for a period of 6 and 12 months was performed.

VIII. PUBLICATIONS

Publications:

1. Zhekov K, Stefanova V. Healing of Chronic Apical Periodontitis Using Novel Bioceramic Sealer BioRoot RCS. J of IMAB. 2020; 26 (2): 3081-3086.
2. Zhekov K, Stefanova V. Retreatability of Bioceramic Endodontic Sealers: a Review. Folia Medica 2020; 62 (2): 258-264.
3. Zhekov K, Stefanova V. Study of the attitude of dentists from Plovdiv region to the use of bioceramic endodontic sealers. Scientific works of the Union of Scientists in Bulgaria-Plovdiv. Series D. Medicine, pharmacy and dentistry. 2020; 15: 364-7.

Scientific communications:

1. Kostadin Zhekov, Vesela Stefanova. Healing of Chronic Apical Periodontitis Using Novel Bioceramic Sealer BioRoot RCS. 29th Annual Assembly of IMAB, Varna, 9 - 12 May 2019 (poster)
2. Zhekov K, Stefanova V, Nicheva S. Study of the attitude of dentists from Plovdiv region to the use of bioceramic endodontic sealers. VIII International Conference of Young Scientists - Plovdiv, July 23-26, 2020 (oral presentation)
3. Kostadin Zhekov, Vesela Stefanova, Plamen Zagorchev, Elena Boyadzhieva. Microleakage assessment of bioceramic monoblock endodontic obturation. IADR Oral Health Research Congress. Brussels, Belgium. 16-18 September 2021 (oral presentation)