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CONTENT - СОДРЖИНА

REVIEW

THERAPEUTIC OPTIONS IN THE TREATMENT OF CALCIFIED ROOT CANAL SYSTEMS

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Key words: endodontic therapy, calcified canals, obliterated canals, guided endodontic, 3D printed guides

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Abstract

Calcification of root canal systems presents one of the greatest challenges even in modern endodontics. Factors such as aging, trauma, dental intervention, auto-transplantation and genetic predispositions can lead to formation of calcifications in both the pulp chamber and root canals. Diagnostic procedures, including CBCT and AI-driven tools, have significantly improved the visualization and further management of calcified canals. Despite all advanced tools, the treatment of calcified canals still remains challenging. Obstructions caused by calcifications, which may vary in size, morphology and location make management much more difficult and compromising in many cases. This paper outlines the diagnostic approaches, therapeutic strategies and future directions in managing calcified root canals. The main emphasis is placed on the role of minimally invasive procedures, improved irrigation protocols and new technologies such as guided endodontics. The guided endodontic customized approach, which uses CBCT data and 3D printed templates, offers greater precision and reduces the risk of complications. All technological innovations hold a great potential for increasing the success rate of endodontic treatment while preserving natural tooth structures.

ПРЕГЛЕД НА ЛИТЕРАТУРА

ТЕРАПЕВСТСКИ ОПЦИИ ВО ТРЕТМАНОТ НА КАЛЦИФИЦИРАНИ КОРЕНСКИ КАНАЛНИ СИСТЕМИ

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Извадок

Калцификацијата на коренските канали претставува еден од најголемите предизвици дури и во модерната ендодонција. Факторите како стареење, траума, стоматолошки процедури, автотрансплантација и генетски предиспозиции можат да доведат до формирање на калцификати во пулпната комора и коренските канали. Дијагностичките процедури, вклучувајќи ги CBCT и алатките управувани од вештачка интелигенција, значително ја подобруваат визуелизацијата и понатамошниот третман на калцифицираните канали. И покрај сите овие напредни алатки, третманот на калцифицираните канали сè уште останува сложен. Опструкциите предизвикани од калцификати, кои можат да варираат во големината, морфологијата и локацијата, го прават справувањето многу потешко и во многу случаи компромитирачко. Овој труд ги прикажува дијагностичките пристапи, терапевтските стратегии и идните насоки во справувањето со калцифицираните коренски канали. Главниот акцент е ставен на улогата на минимално инвазивните процедури, подобрени протоколи за иригација и нови технологии како што е водена (насочена) ендодонција. Насочениот ендодонтски приспособен пристап, користејќи податоци од CBCT и 3D-печатени шаблони, нуди поголема прецизност и намалување на ризикот од компликации. Сите овие технолошки иновации имаат голем потенцијал за зголемување на стапката на успех на ендодонтскиот третман и зачувување на природните структури на забите.

Introduction

The aim of endodontic treatment is to eliminate infection, preserve the tooth and restore its function. For a successful outcome of endodontic therapy, it is essential to know the anatomy of the root canal system in detail, accompanied by a thorough understanding of the morphology of the pulp chamber and the root canal system. Attempting to treat the root canal system without a detailed anatomical description would be the equivalent of a doctor searching for an appendix without having read the Gray 's Anatomy[1].

With the advancement of technology and techniques, modern endodontic treatment is becoming much more efficient and predictable than ever before. Machine instrumentation as the basis for the processing of the canal system, supplemented by irrigation, laser sterilization of canals and the use of biological materials for obturation significantly improve the results in the final outcome of endodontic therapy. The use of modern diagnostic methods such as digital X-ray, CBCT, the inclusion of artificial intelligence (AI) and 3D models complement the precision and comfort of the patient during endodontic treatment. All of this contributes to minimizing the duration of endodontic therapy, increasing the success rate, ultimately enabling long-term preservation of natural teeth. This outcome would be ideal if there were no obstacles in the anatomy of the root canal system. Very often, root canals can be impassable, fibrotic, or obliterated by denticles, nodules, pulp stones, secondary or reactive dentin formation, diffuse calcifications, or anatomical obstructions that may prevent instrumentation[2].

There are several variations in the mineralization of pulp tissue, in structure, morphology, dimensions, or location. Within the pulp chamber, they have a nodular format, generally spherical or ovoid and sometimes they mimic the internal anatomy of the coronal aspect of the pulp chamber. In the root canal space, they have a more diffuse structure, with a tubular or cylindrical configuration, partly following the design of the root canal. The size varies from microscopic bodies to structures that occupy the entire space of the pulp chamber[3].

Pulpal canal calcification or sclerosis may be the result of physiological tooth aging, sequelae following dental trauma, autotransplants, carious lesions, excessive orthodontic treatment, iatrogenic dental treatment, or regenerative endodontic procedures[4]. Other factors, according to Beres *et al.*, could be: fluoride-rich supplements, D hypervitaminosis, or a possible genetic predisposition (dentinogenesis imperfecta and dental dysplasia which can be seen even in unerupted teeth[5].

Material and methods

To achieve the aim of this paper, a literature search was conducted using the databases PubMed, Google Scholar, ScienceDirect, Wiley, Scopus, Web of Knowledge, EBSCOhost to find published scientific papers and articles related to the therapy of calcified root canals.

The search was performed using the following keywords: endodontic therapy, calcified canals, obliterated canals, guided endodontics, artificial intelligence, 3D printed templates.

Symptoms

The symptomatology of calcified canals varies from the absence of symptoms, which is the most common finding, to minimal sensitivity. The most common complaint of patients is darkening of the teeth, which is due to reduced blood supply to the pulp tissue, which has a significantly reduced volume. Other symptoms that appear include brief pain during chewing, and the vitality test may show very low sensitivity, which may disappear over time.

McCabe *et al.* examining the impact of trauma on anterior teeth, concluded that 25% of the teeth in their cases developed calcifications, but 75% of them were asymptomatic[6]. Ogini *et al.* in their study of 168 traumatized teeth with discoloration, found that 47.6% had partial obliteration and 31.6% had complete obliteration[7].

Pulp sclerosis as a diagnosis is not a reason for endodontic treatment, but its presence may further worsen the prognosis of treatment. The presence of pathological changes in the periapical tissue is a common finding in teeth that have undergone calcific metamorphosis because of trauma and is an indication for initiating endodontic treatment. Accordingly, indications for pulp treatment are in cases of irreversible pulpitis or presence of apical periodontitis[4].

Diagnostics

Diagnosing the degree of calcification and patency of the root canals is an important aspect of endodontic treatment. Accurate diagnostics in daily routine usually include clinical examination, application of vitality test and X-ray diagnostics (Fig.1 and 2).

Clinical identification is usually based on various imaging methods, such as X-ray radiography (periapical, panoramic radiography, etc.) and cone-beam computed tomography (CBCT). Two-dimensional X-ray radiography offers advantages such as ease of use and low radiation dose. A partial disadvantage in the identification of calcifications on two-dimensional radiography is the limitation of the identification of calcifications smaller than 200 μm. Overlapping anatomical structures can also be an obstacle to the identification of calcifications in the root canals of multi-rooted teeth[3].

CBCT is a newer method used for diagnostic purposes. It provides high-resolution and three-dimensional spatial structural information (Fig. 3). It offers detailed visualization, showing the precise location, size, and extent of pulpal calcifications from axial, coronal, and sagittal perspectives[3].

Automated systems for root and root canal morphology detection have been developed, using advanced algorithms for analyzing dental images8. Artificial intelligence is used to successfully display the canal configuration, root morphology and overall tooth structure. This technology can be particularly useful in cases involving complex anatomical structures, where individual interpretation can make errors[9].

Artificial intelligence (AI) is enabling automated biomedical image analysis, decision support, and treatment planning[10]. It should be noted that artificial intelligence-driven software has shown its help in diagnosing complex cases such as periapical lesions, fractures, and calcifications, as well as in predicting treatment outcomes. Cutting-edge technology supported by artificial intelligence will increase the precision and efficiency of endodontic procedures[9].

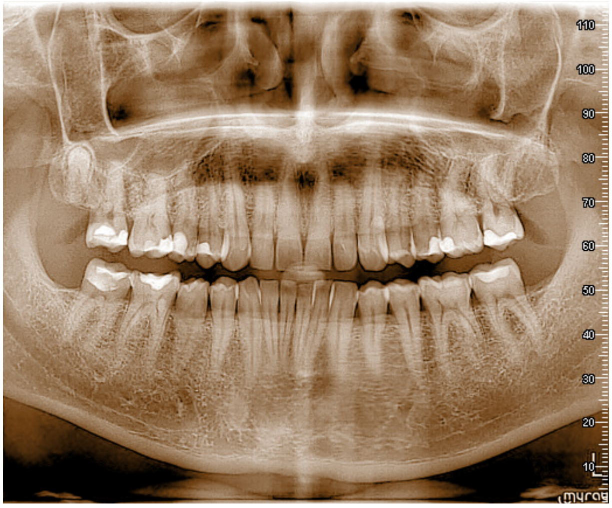

Figure1: Panoramic radiograph of a 31-year-old patient with a history of trauma to the upper anterior incisors several years ago, showing complete canal obliteration

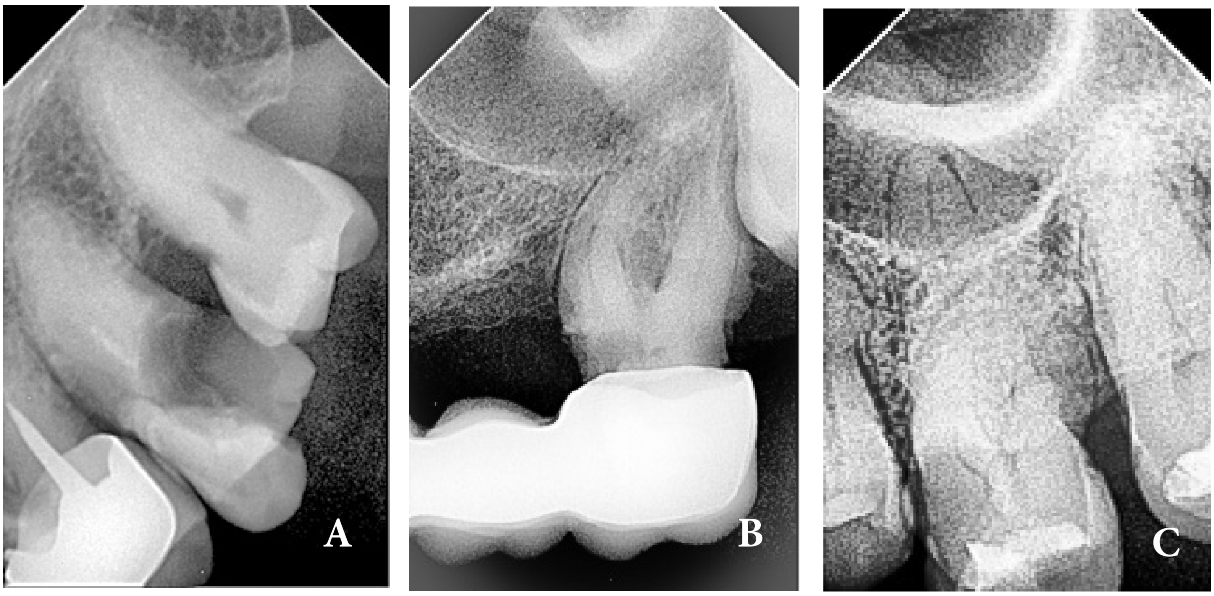

Figure2: Calcifications shown on intraoral radiographs. A) failed endodontic treatment of the upper left molar due to complete obliteration of the root canal system; B) presence of calcifications in the pulp chamber of the upper left molar, resulting from a mesial carious lesion; C) partial calcification in the pulp chamber, with a completely obliterated distal canal.

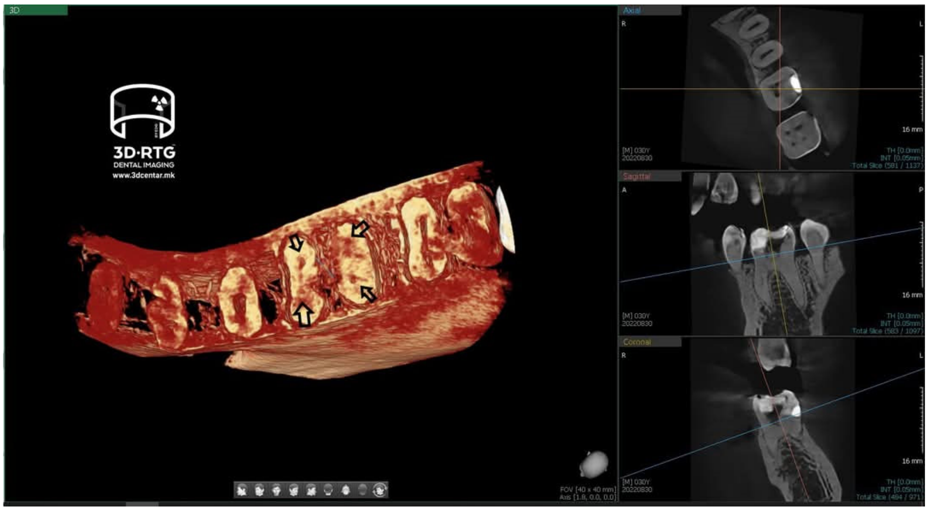

Figure3: 3D CBCT analysis of a lower left molar where horizontal cross-sections of segments show the presence of calcifications in the ventricular part, visible canal obliteration in the root canals

Management

The American Endodontic Association (AAE) classifies endodontic treatment of calcified canals as a high-risk treatment, due to the risk of complications and failure[4].

Treatment of calcified root canals requires time, patience, good skills and specialized equipment. The use of ultrasonic instruments and advanced irrigation techniques further increase the percentage of successfully completed treatments. Accurate diagnosis and careful work can prevent complications such as perforations and broken instruments.

Magnification and good illumination as an integral part of modern endodontic treatment are essential in the localization of the canals. With proper illumination and magnification, it is much easier to detect anatomical challenges and reduce the likelihood of making errors. The most commonly used devices are dental loupes and operating microscopes. Dental loupes offer magnification levels of 2.5x to 6x and are more suitable for routine procedures. Operating microscopes provide magnification levels of 6x to 30x and can be used in more complex situations, such as locating calcified root canals, better detecting broken instruments, or performing microsurgical procedures. Studies show that operating microscopes provide much improved visualization and precision in complex cases, compared to dental loupes[11,12].

Magnification combined with illumination can provide a better field of view for successful treatment of calcified canals, so that procedural errors can be minimized[13]. The operating microscope has integrated coaxial illumination and provides focused, shadow-free illumination of the surgical field. The dental loupes and microscopes use high-intensity LEDs that offer adjustable brightness levels to optimize visibility and precision[14].

Access cavity and course of endodontic treatment

Preparation of an adequate access cavity and removal of pulp tissue are important steps at the beginning of treatment.

The design of the conventional access cavity has remained unchanged for decades, as it allows adequate visibility and facilitates identification of the root canal entrances[15]. The “systematic respect for original tissues” means that in dentistry as a profession, original tissue is valued more than its replacement[15,16,18]. This approach has led to the avoidance of the preparation of the classical access cavity and the introduction of narrower and smaller access cavities that preserve the tooth tissue.

In their study, Falcon A. *et al.*[19] highlight the so-called chamberless endodontic approach (CEA) which can mitigate the risks of treating calcified canals. The integrity of the clinical crown is preserved, creating a minimal access to the root canal. CEA modifies the endodontic approach by using the apical foramen, instead of the foramen as the determinant for the straight-line approach. With this approach, the preservation of the coronal structure of the tooth is maximized, while at the same time it provides sufficient access to perform chemomechanical removal of debris from the canal system. The advantages of this approach are not yet sufficiently documented in the literature to confirm its contribution.

Accurate detection of root canal entrances can be challenging when dealing with calcified canals, given that calcified structures may be present in the pulp chamber, covering the canal entrances. Several methods have been recommended for accurate detection of root canal entrances. One of them is the use of ultrasonic extensions to prepare the pulp floor, as the use of turbine diamond chips can easily lead to pulp floor perforations. Ultrasonic treatment removes loosely attached calcified structures, revealing lines of developmental fusion leading to the root canal entrances[20].

Another aid in canal detection is the use of dyes, such as methylene blue, which penetrate the root canal entrances and makes them visible and easier to detect. The advantage of the dye is that it can also be used to locate potential fissures.

A liquid EDTA solution can be applied to the pulp chamber (with a pipette or cotton swab) and can be useful for identifying the canal openings, as bubbles begin to emerge from the pulp tissue. According to Hülsmann *et al.*, one to five minutes is sufficient for its action. The location of narrow canal entrances is checked using the DG16 endodontic probe. With its sharp and firm tip, any calcification present can be further removed[21].

Checking the patency of the root canals and creating a glide path are the next procedures in endodontic therapy. Patency is checked by selecting an appropriate instrument with a smaller diameter (pathfinder). Pathfinder in calcified canals is a critical step, since very often calcifications prevent patency. Mannual endodontic instruments, K-files, C Files+, D-finders with the smallest diameter varying from 0.06, 0.8 and 0.10 with 2% with tapers, are commonly used as pathfinding files. These instruments are employed to pre-shape the length of the root canal space prior to transitioning to larger taper endodontic instruments. Clockwise and counterclockwise movements are made to ensure safe navigation without damaging the canal walls. This is accompanied by irrigation with NaOCl, along with the use of EDTA gel at lower concentrations.

Regarding the efficacy of the pathfinder, Allen *et al.* cited several factors such as: design, helix density, taper, cross-sectional design, thermal tempering, type of metal, clinician skill, and clinical conditions[22].

Camps *et al.* pointed out the pathfinder cross-section as an important factor in endodontic treatment[23]. If the instrument occupies the entire endodontic volume during instrumentation, dentin scrapings are created and they cannot be removed coronally, as the space is limited by the instrument body. This leads to apical displacement of the debris, resulting in loss of working length and apical patency.

Baruwa *et al.* gave a comprehensive review of selected stainless steel dental instruments, providing valuable insights into their mechanical and physical properties. While similarities in cross-section design and metal wire composition were noted among the files, variations in the number of spirals and mechanical performance were observed. They analyzed characteristics such as the length of the active blade, which varied between 16 and 17 mm, and the number of spirals, which varied between 24 to 42 . The number of spirals in a file plays a crucial role in its performance during root canal procedures, since more spirals enhance the flexibility but decrease the cutting efficiency and rigidity. Conversely, a lower-pitch instrument, with fewer spirals, is more effective for filing but less effective for reaming[24]. Thus, all of these factors should be considered when selecting suitable files for an efficient root canal treatment.

When using these instruments in calcified canals, the choice of instrument according to hardness can be a problem. Choosing instruments with high flexibility, in addition to the fact that they are prone to deformation, may be a problem to penetrate the calcified canals. However, instruments that are too stiff with a strong bending resistance can lead to damage to the dentinal walls, i.e. create ledges and perforations, thus compromising clinical outcomes[20]. To eliminate such errors, a gradual increase in instrument size is recommended, starting from ISO size 06 to 10, using gentle clockwise and counterclockwise movements adapted to the specific clinical circumstances[24].

Instead of manual instrumentation, a patency of the root canals and glide path can be formed using NiTi rotary instruments with a small taper. But, despite the less effort, carelessness when using rotary NiTi instruments can easily lead to file fracture. Effective navigation through the complex anatomy of the canal and negotiation of tight curves relies heavily on the ability of the file to maintain centricity and prevent transport or ledging. Gambarini *et al.* present data on the use of thin stainless steel hand K-files applied to a reciprocally mounted instrument as a possible alternative for creating a glide path[25].

Once the glide path is established,

the use of rotary NiTi instruments becomes easily feasible. Almost 90% of the calcified canals can be negotiated to the apical third with the help of conventional techniques and the operating microscope. The success rate after a follow-up period of 3 years was found to be 80%[26].

An integral part of endodontic treatment is the use of irrigant, particularly in the treatment of calcified canals, where chelating agents play a significant role. Calcifications have an organic and inorganic component. The inorganic component is composed of calcium ions in the form of hydroxyapatite. For this reason, the use of chelating agents such as EDTA in gel form is necessary for their action[21].

Hulsman *et al.* emphasize that EDTA, in addition to calcium ions, also acts on the non-collagenous protein component of dentin. In combination with NaOCl, it significantly changes the calcium and phosphate content contained in the dentin of the canal. This combination improves demineralization, so that the irrigant can penetrate much more effectively[27]. The continuous chelation seems to be equally or more effective in all investigated outcomes when compared to the traditional sequential protocol. It refers to the combination of a soft chelator with NaOCl for simultaneous antimicrobial and proteolytic action with the smear layer removal. According to this protocol, NaOCl is added with the salt of a weak chelator, 1 hydroxyethylidene-1, 1-bisphosphonate or etidronate (HEBP or HEDP or etidronate), because the tetra-sodium HEDP salt is extremely compatible with NaOCl. This combination also acts on the organic component and provides an additional antibacterial effect. In particular, HEBP acts to reduce the smear layer, providing continuous chelation, minimizing dentin erosion compared to EDTA. In the tested group of chelates in the study by Zehnder *et al.* HEBP showed a three-fold lower calcium chelation capacity compared to the complexation ability of EDTA. This may limit its effectiveness in calcification, but this milder action may reduce the risk of excessive demineralization[28].

Maleic acid and peracetic acid can be used as alternatives for smear layer removal due to their stronger capabilities compared to NaOCl.

According to La Rosa *et al.*, a continuous chelation protocol maintains canal cleanliness and antimicrobial efficacy, demonstrating reduced dentin erosion. This can be achieved by using chelating agents and NaOCl simultaneously, ensuring consistent action throughout the procedure[27].

Figure 4 shows a case of a 76-year-old female patient requiring endodontic therapy and advanced pulp calcification. The patient had intraoral swelling localized to the area of the upper right lateral incisor, with old bridge construction. The examination revealed a fistula on the vestibular side. Endodontic treatment was performed without removal of the prosthetic restoration.

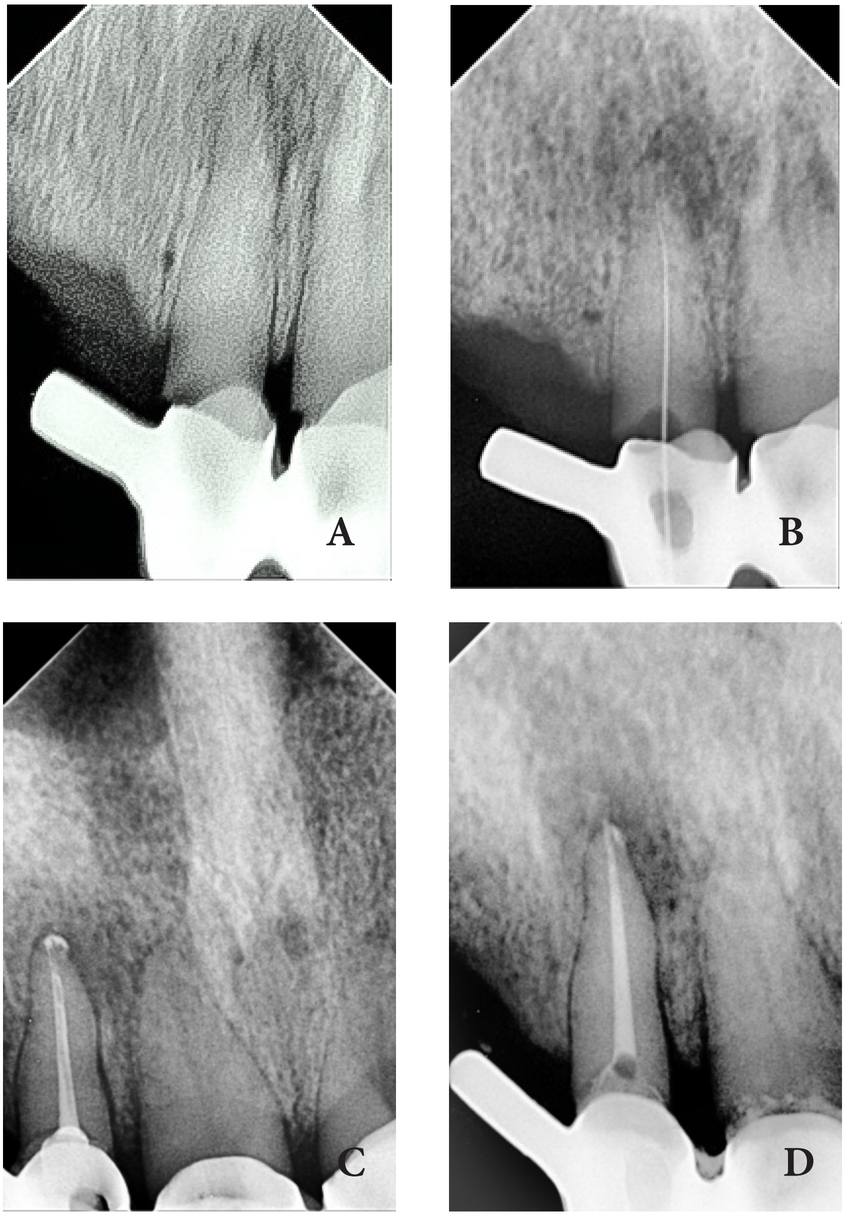

Figure4: A. Narrowing of the canal of tooth 12, accompanied by diffuse periapical change; B: Access cavity through the crown, formation of a glide path using a D-finder 0.8 hand instrument, interappointment Ca(OH) paste placed C: Control image of the filling with Ca(OH) , D: definitive obturation of the canal

Guided endodontics

The continued development of oral digital technology enables a new way to treat calcified root canals through guided endodontics. Guided endodontics is a technological approach that is not limited to finding pathways or accessing the cavity. It encompasses the entire procedure for treating calcified canals. The guided endodontic protocol involves combining oral scan data and CBCT data analysis to plan a path for opening the root canal from a three-dimensional perspective prior to the intervention, and then creating a digital guide using a 3D printing technique to guide the bur during the removal of the calcified segment of the root canal[29].

Conventional methods for treating calcified root canals rely solely on manual exploration, making treatment highly unpredictable. Guided endodontic therapy improves predictability by using a digitally planned approach. CAD-based treatment planning, a custom digital guide designed with 3D printing that guides the tooth precisely to the calcified segment of the root canal, allows for a minimally invasive approach.

Several *in vitro* and *in vivo* studies and case reports have shown that treatment of calcified canals using a guided endodontic technique has higher success rates, less tooth substance loss, and avoids complications in endodontic treatment compared to conventional endodontic treatment[30].

Kulinkovich-Levcuk *et al.* in their review described different types of guided endodontics, including static guided endodontics (SGE) and dynamic guided endodontics (DGE)[31].

SGE is performed as follows: first, a CBCT image is taken of the patient's upper or lower jaw (depending on the location of the tooth to be treated). At the same time, an impression is taken that will be scanned later, or an image is taken with an intraoral scanner. The two resulting images are superimposed using software, whereby a guide is easily designed to cover the tooth to be treated (and some adjacent teeth). In this guide, a place is determined where a drill with a specific appropriate diameter and angle is placed to allow direct access to the calcified canal. Cylinders or "sleeves" are then designed to allow a drill to reach into the root canal through the drilled cavity. The inner cylinder is smaller and made of metal. Once the designs are complete, the file is exported from the planning software and used for 3D printing of the guide. To proceed with the procedure, the guide is tried on to ensure it fits the patient's teeth. The inner metal cylinder guides the drill to access and remove the calcified tissue, and once the obstruction is removed, the root canal treatment is continued in the conventional manner. However, SGE has several clinical limitations: restricted applicability in posterior teeth, anatomical constraints in curved canals and insufficient cooling (guided burs lack continuous water jet cooling)[31].

Similar to the static navigation approach, the dynamic navigation technique begins with a high-resolution preoperative CBCT scan to plan the entry point, pathway, depth, and angle of the bur. The dynamic-guided technique uses a mobile unit equipped with a stereoscopic camera for motion tracking and a computer with planning software that uses CBCT data to guide a calibrated handpiece[20]. With the help of a stereo camera connected to a dynamic navigation system, the trajectory of the drills into the pulp chamber and root canal is coordinated in real time. This way, the operator can follow everything he/she does on a monitor and can correct or adjust the angulation of the instruments as needed. The operator can visually monitor the penetration of the root canal on a laptop screen in real time, with depth indicated by changes in the color of the depth gauge[32].

Figure 5 shows the diagram of all steps in the digital workflow for the creation of an endodontic guide.

However, the high cost of acquisition and the need for operator skills are significant disadvantages of dynamic navigation.

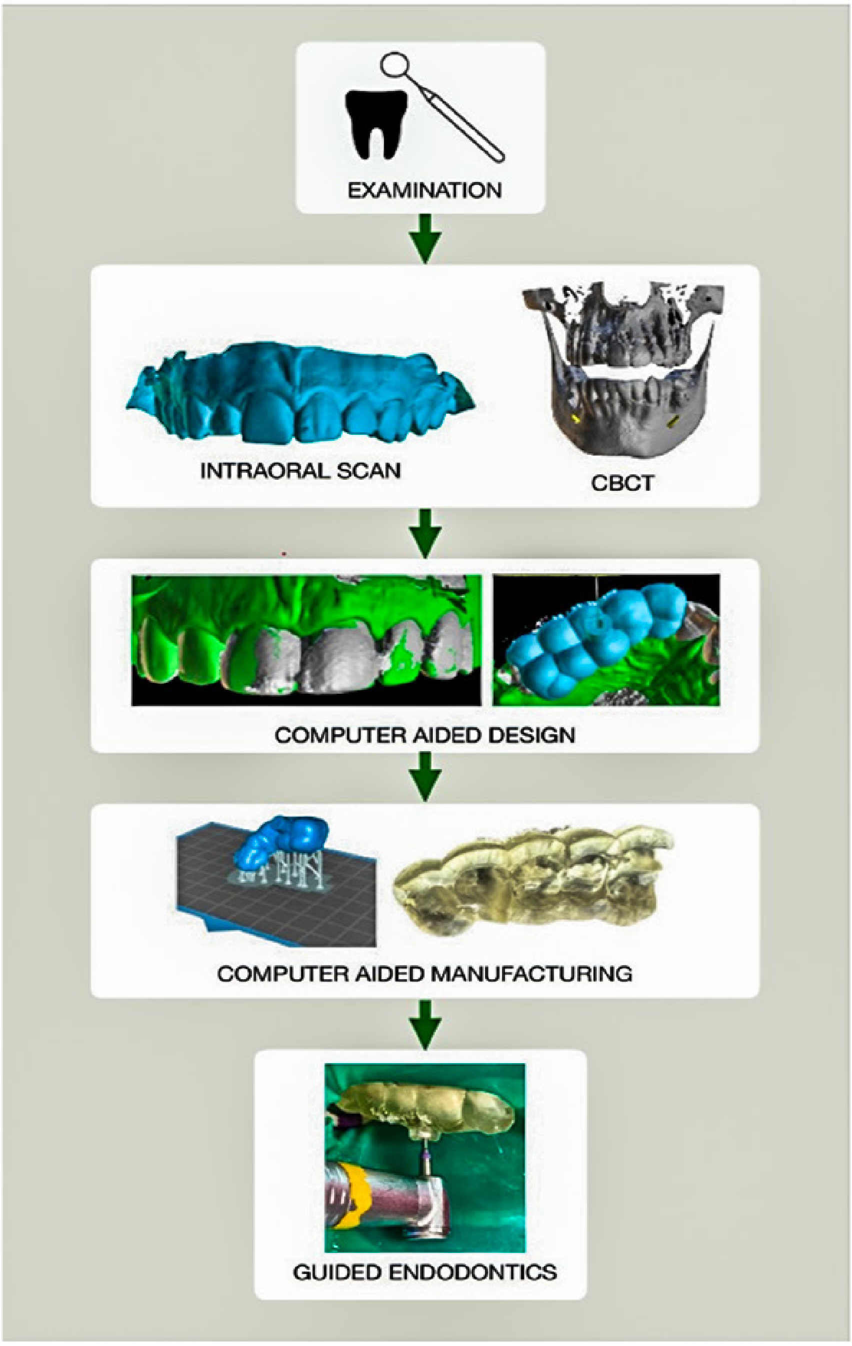

Figure4: Diagram of all steps in the digital workflow for the creation of an endodontic guide. Image reproduced from "Guided Endodontics as a Personalized Tool for Complicated Clinical Cases" by Wojciech Dabrowski, Wiesława Puhalska, Adam Zimlewski, and Ivona Ordinjec-Kwaśnica, published by MDPI under the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/). No modifications have been made to the original images.

Artificial Intelligence in Negotiating Calcified Canals

Artificial Intelligence (AI), with its technological advances, is also finding its place in the treatment of calcified root canals[33]. These technological advances improve diagnostic accuracy, treatment planning, and real-time navigation, significantly increasing efficiency in complex cases. Combining CBCT analysis, dynamic navigation, and adaptive tools, AI enables precise location and treatment of root canals, significantly reducing the likelihood of complications. Continued advances in machine learning and AI-driven robotics are expected to further revolutionize endodontic workflows, offering improved predictability and clinical efficiency in complex cases[34].

CBCT analysis as a significant part in identifying calcified canals has been improved in its interpretation by AI-driven algorithms. By employing machine learning models, clinicians can analyze canal trajectories, facilitate more accurate preoperative planning and enable the prediction of the optimal access pathway for negotiation[35].

AI also plays significant role in reducing the risk of iatrogenic errors including perforations or excessive dentin removal by the use of AI-powered dynamic navigation systems that enable real time guidance during endodontic treatment. They allow clinicians to modify the approach based on continuous feedback[36].

AI-based systems through predictive modelling can also assist in recommending an optimal file sequence ensuring a conservative approach. Also, AI can be incorporated in instrumentation strategies enabling adaptive refinements in rotational speed and torque, preventing instrument fractures[36].

Conclusion

Calcifications in the pulp and root canals are a challenge in conventional treatment, often resulting in prolonged treatment times, increased risks during the procedure, and unpredictable outcomes.

The application of diagnostic procedures with new modern methods in the treatment of calcified root canals aims to improve the accuracy, efficiency, and success rates of endodontic treatment. The minimally invasive approach through guided endodontics, which combines CBCT data and 3D printed guides, allows a high degree of precision in accessing the canal system, significantly reducing the risk of iatrogenic errors. The use of improved irrigant and chelating agents further facilitates the process of treating calcified canals. Similarly, artificial intelligence-driven treatment planning and navigation systems allow clinicians to overcome anatomical complexities, offering new possibilities for more successful endodontic procedures.

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