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Title picture: From the review of Till Dammaschke, here Figure 2: Example of a two-component calcium silicate-based sealer consisting of powder and water (BioRoot RCS; Septodont, Saint-Maur-des-Fossés, France). For powder and water-based sealers, the consistency can be adjusted to match the clinical situation, p. 71–79; (Fig. 2: T. Dammaschke)

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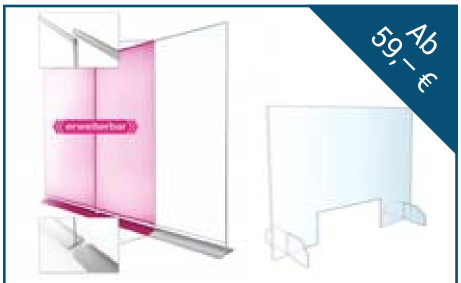

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The deglutition act/ swallowing reflex

Question:

What is the importance of the deglutition act/swallowing reflex with regard to the regulation and feedback mechanisms of the stomatognathic system?

Background

The deglutition act represents one of the most frequent motor functional processes in our body, which coordinates more than 50 pairs of muscles. It can be understood as a complex reflux event. In the wake state, we swallow around 0.5–1.5 ml of saliva per minute, mostly unconsciously. During deep sleep, salivation and swallowing activities are largely at rest [1]. In addition to regulating salivary flow, the deglutition act also appears to have an important influence on the regulatory and feedback mechanisms of the entire stomatognathic system. Since the lower jaw usually moves dorsally and the dental arches of the maxilla and mandible come into brief contact during the swallowing act [2, 4, 7], a physiological sequence of the swallowing activity is essential for controlling the masticatory muscles. During the physiological deglutition act, feedback is provided via the receptors in the periodontal attachment apparatus, as well as, those in the masticatory muscles and temporomandibular joint; this feedback is responsible for establishing important control variables of the stomatognathic system, such as the rest position of the mandible when the masticatory muscles are relaxed. Each muscle works by shortening itself. However, a muscle which is constantly shortening (working) also requires information about what "length" it should maintain or set in the relaxed rest mode. Skeletal

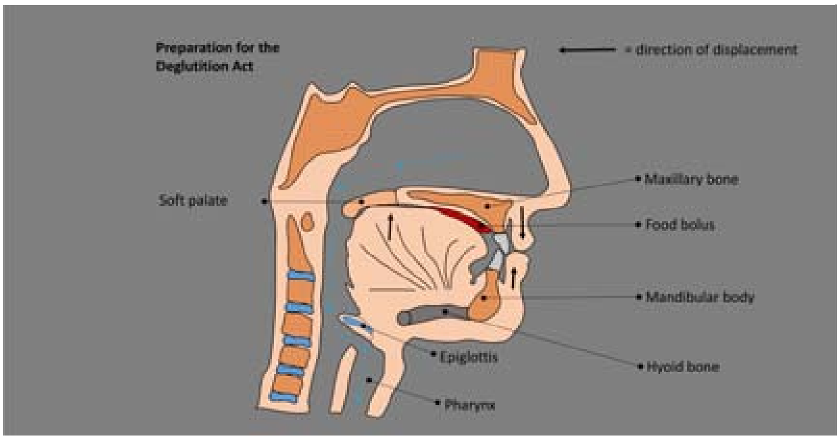
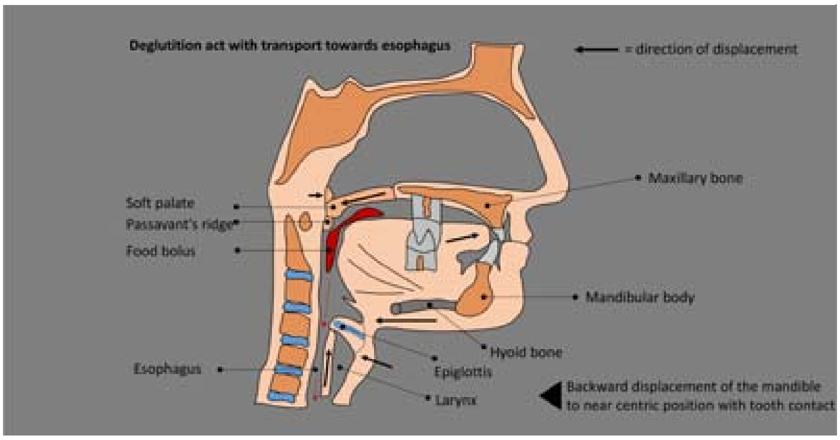


Figure 1 Shortly before the deglutition act: the back of the tongue closes off the oral cavity from the pharynx. The respiratory air can still flow into the trachea via the nose (redrawing according to [6]).



(Fig. 1 and 2: M. Behr)

Figure 2 During the deglutition act: The tongue is displaced dorsally. The soft palate is raised and together with Passavant's ridge, it closes off the upper respiratory tract. Through the backward displacement of the hyoid bone and tongue, the epiglottis is pushed over the trachea. The food bolus can be transported into the esophagus (redrawing after [6]).

Translation from German: Cristian Miron
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muscles, for example, use feedback from their direct antagonists' activity for establishing their "length" at rest; hence, an interplay between "flexors" and "extensors" is involved. In the stomatognathic system, this simple interplay as it occurs in the extremities is not so obvious. It is also necessary to consider that the stomatognathic system has to serve two functions. On the one hand, it performs the function of mastication, while on the other hand, it is a part of the organ of speech, so that, different centers in the brain – which partially compete with each other – exert their control functions on the stomatognathic system [3]. In this manner, a "reset" through which the stomatognathic system always finds its physiological rest position represents a necessary set of rules for the undisturbed function of the stomatognathic system. The fact that the mandible can reliably and reproducibly be brought into the centric position during swallowing, and because this happens very frequently and unconsciously in the waking state, suggests that swallowing activity has an important control function. The occlusal contact which takes place between the upper and lower dental arches during the swallowing cycle generates a vertically acting force of approximately 30 N [7]. The occlusal forces that are elicited during swallowing can modify the resulting force system. The force is thus not constant meaning that there is a continuous increase and decrease.

Sequence of the deglutition act

The deglutition act is characterized by 3 partial processes [5, 8]:

- preparation and transport of food from the oral cavity through the pharynx into the esophagus,
- closure of the nasopharynx,
- closure of the laryngeal inlet.

After food is mechanically broken down and moistened with saliva, the deglutition act is triggered. The deglutition act is divided into a preoral, oral, pharyngeal and esophageal phase. All phases transition smoothly into one another [1, 5]. The food bolus which is prepared in the pre-

Figure 3 Schematic overview of the muscles involved in the deglutition act (from [5]).

(Fig. 3: with friendly permission DeGruyter)

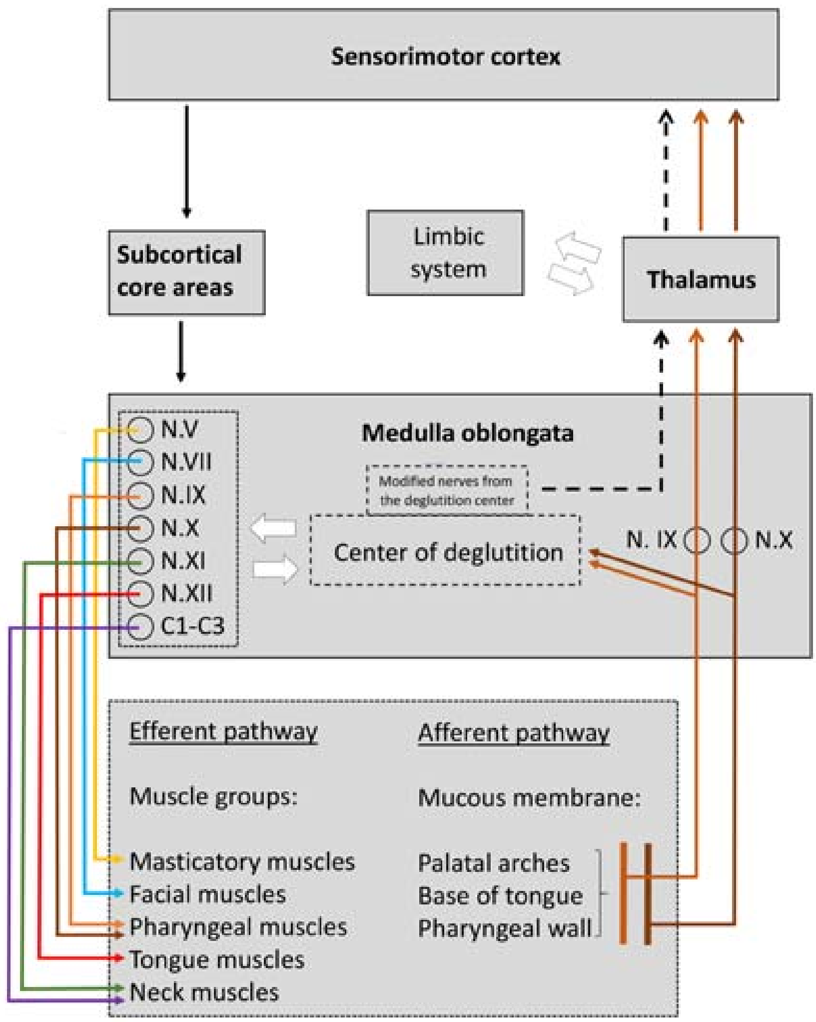

Figure 4 Schema of the neuromuscular control of the deglutition act.

(Fig. 4: J. Fanghänel)

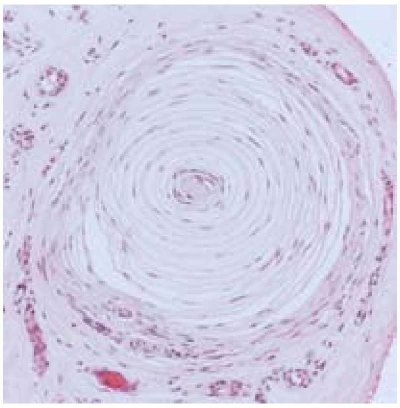

Figure 5 Pacinian corpuscles, H&E staining, magnification 20x.

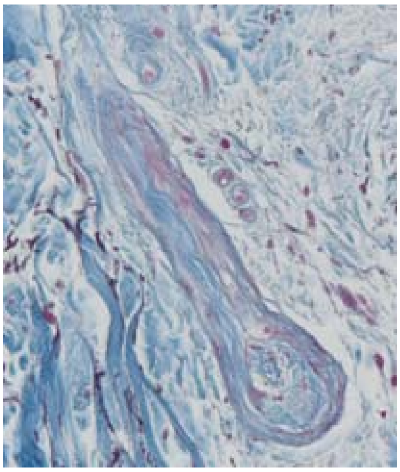

Figure 6 Ruffini-corpuscles, Kresazan staining, magnification 40x.

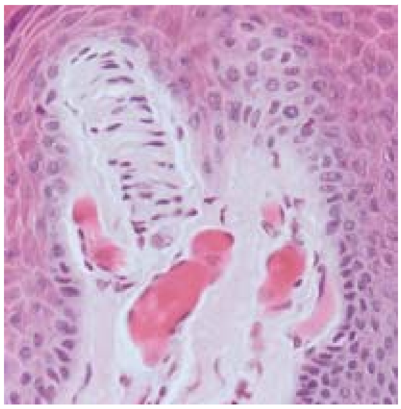

Figure 7 Meissner tactile corpuscle, H&E staining, magnification 40x.

(Fig. 5–7: B. Miehe, J. Fanghänel)

oral phase (women 14–20 ml, men 20–25 ml) [6] is positioned on the back of the tongue. The tip of the tongue positions itself against the upper anterior teeth and anteriorly against the hard palate. The lateral areas of the tongue lift up and form a spoon-shaped depression for the bolus. The posterior pharyngeal part of the tongue arches up and comes into contact with the soft palate. This initially keeps the bolus in place and prevents it from sliding into the pharynx (so-called glossopharyngeal sphincter) (Fig. 1).

The lips close and the mandibular incisors approach the maxillary incisors. The anterior two-thirds of the tongue pushes the bolus toward the pharynx using peristaltic movements. The hyoglossus and styloglossus muscles lift the tongue cranially and the palatoglossus muscles pull the back of the tongue dorsally (Fig. 2, Fig. 3). The dental arches come into contact. The soft palate is lifted by the tensor veli palatini and levator veli palatini muscles and pressed against the Passavant‘s ridge. This opens the auditory tube. The Passavant‘s ridge is formed by the contraction of the superior pharyngeal constrictor muscle. Together, the soft palate, Passavant‘s ridge and the posterior dorsum of the tongue seal the upper airway and prevent the bolus from passing prematurely into the pharynx. The anterior two-thirds of the tongue now generate peristaltic movements that briefly open the oropharyngeal isthmus and transport the bolus toward the pharynx (Fig. 2). In this phase, the floor of the mouth is lifted by the suprahyoid muscles. This causes the hyoid bone and larynx to be displaced cranially. The epiglottis is passively displaced over the laryngeal inlet. Reflex closure of the glottis and inhibition of the respiratory muscles follows. Further transport is achieved by rhythmic contractions of the pharyngeal constrictor muscles, especially the inferior pharyngeal constrictor muscle. In the esophagus, peristaltic waves that are generated by the esophageal muscles transport the bolus further on toward the stomach [5].

The entire mechanism of deglutition represents a regulatory feedback system (Fig. 4) with an afferent and efferent pathway. The former begins in the mucosa of the palatal arches, the base of the tongue and the posterior pharyngeal wall. This is where free nerve endings and nerve ending corpuscles are located in the mucosa. While the free nerve endings register the sensation of pain, the nerve ending corpuscles, Pacinian corpuscles (Fig. 5), Ruffini corpuscles (Fig. 6), Meissner tactile corpuscles (Fig. 7), among others, register the sensations of pressure, shock and tension. The structures made from glial tissue (lamellae, spheres, cylinders, branches, etc.) serve to enlarge the receptive surface [8] (like antennas) for the received stimuli. The afferent fibers of nerves IX and X are relayed in the medulla oblongata and run via the thalamus (center of sensation) to the sensorimotor cortex (region behind the central sulcus) of the cerebrum. The reticular formation of the medulla oblongata also contains the center of deglutition (Fig. 4), which regulates vegetative processes.

After being further relayed in the central nervous system, the efferent pathways (as pyramidal and extrapyramidal pathways) reach the muscles of the effector organs, including the pharynx, base of tongue, larynx, esophagus as well as the neck muscles, via the nuclei of the cranial nerves V, VII, IX, X, XI, XII and the cervical segments C1-C3 [5]. The deglutition act can therefore take place cortically or subcortically depending on whether it occurs consciously or unconsciously. The causes of swallowing disorders (dysphagia) are varied and correspond to the phases of swallowing. For example, in functional disorders of the medulla oblongata such as bulbar palsy, dysphagia is one of the cardinal symptoms [8].

Statement

The deglutition act is a highly complex reflux event in which we distinguish a preoral, oral, pharyngeal and esophageal phase. In total, swallowing involves more than 50 pairs of muscles, 6 cranial nerves as well as nerves of the cervical segments C1-C3. With approximately 1000–2000 swallowing cycles taking place every day, swallowing represents one of the most frequent motor functional processes in the body. The act of deglutition not only serves the purpose of food intake and the reduction of the amount of saliva in the oral cavity, but it also plays an obvious and important role in the self-regulatory processes of the stomatognathic system such as the (re)setting of the rest position of the mandible.

Conflicts of interest

The authors declare that there is no conflict of interest as defined by the guidelines of the International Committee of Medical Journal Editors.

Michael Behr, Jochen Fanghänel, Regensburg

References

1. Bartolome G: Physiologie des Schluckvorgangs. In: Bartolome G, Schröter-Morasch H (Hrsg): Schluckstörungen. Interdisziplinäre Diagnostik und Rehabilitation. Urban & Fischer, Elsevier, München 2018, 23–46

2. Bartow K: Physiotherapie am Kiefergelenk. Untersuchung, Therapie, Fallbeispiele. Kap. 8.1.3, S104. Thieme, Stuttgart, New York 2019

3. Behr M, Fanghänel J: Der Einfluss des stomatognathen Systems auf die Entwicklung des Menschen. Dtsch Zahnärztl Z 2019; 74: 295–299

4. Bradley RM: Physiologie des stomatognathen Systems. Ulstein-Mosby, Berlin, Wiesbaden 1996

5. Fanghänel J: Schluckakt. In: Fanghänel J, Pera F, Anderhuber F, Nitsch R (Hrsg): Waldeyer. Anatomie des Menschen. Lehrbuch und Atlas in einem Band. De Gruyter, Berlin 2009, 309

6. Lawless HT, Bender S, Oman C, Pelletier C: Gender, age, vessel size, cup vs. straw sipping, and sequence effects on sip volume. Dysphagia 2003; 18: 196–202

7. Proffit WR, Fields HN, Nixon WL: Occlusal forces in normal and long-face adults. J Dent Res 1983; 62: 566–570

8. Schiebler TH, Schmidt W (Hrsg): Anatomie. Springer, Berlin, Heidelberg, New York 1991

(Photo: UKR)

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CBCT in surgical endodontics – a must-have?!

Abstract: 3D diagnostics – i.e. CBCT – has become indispensable in endodontic and endosurgical diagnostics, treatment and control (follow-up) and has become a real "gamechanger" not only for experienced colleagues and specialists. With the increasing complexity of cases, the superimposition-free and dimensionally accurate display of even the smallest details is gaining in importance and offers an excellent assessment of the prognosis of the teeth to be treated, thus allowing a high degree of certainty in treatment planning as well as (evidence-based) patient education. This is especially relevant for endosurgical procedures with their close relationships to anatomically significant structures (e.g.: maxillary sinus or nervous structures). Nevertheless, CBCT requires a high degree of responsibility with regard to the use of ionizing radiation. The ALARA principle ("As Low As Reasonably Achievable") is more and more replaced by ALADA ("As Low As Diagnostically Acceptable"). It is always necessary to decide whether the patient's well-being is more compromised by not taking the X-ray than by the ionizing radiation and its consequences. Even though there is current evidence that exposure to low-dose radiation with a cumulative dose of up to 100 mSv does not appear to increase the risk of cancer, each CBCT-scan is a justifiable, indication-based, case-by-case decision that must always be made on the basis of a thorough history and clinical examination, taking into account any previous images that may be available.

Keywords: apical surgery; CBCT; endodontics; microsurgery; radiation exposure; surgical; endodontics; treatment outcome; radiography

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Figure 1 A = preoperative X-ray (tooth 26) after root canal treatment and root filling with iatrogenic ledge formation and complex root canal morphology. **B1,2** = coronal and sagittal view (CBCT) with an apical periodontitis. **C** = annual follow-up in (X-ray) with no evidence of a pathological finding. **D1,2** = coronal and sagittal view (tooth 26) with complete osseous regeneration.

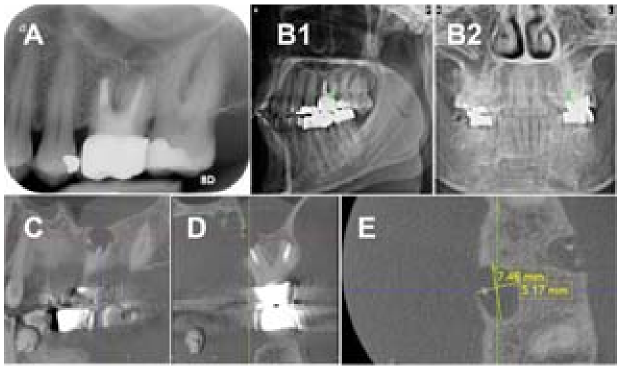

Figure 2 A = periapical X-ray (tooth 26) after multiple orthograde retreatment and surgical preservation attempts performed alio loco. **B1,2** = pre-shot-image in 2 planes to set the ROI (region of interest). **C,D** = CBCT (sagittal and coronal view) through the palatal root with involvement of the maxillary sinus (perforation) and reactive mucosal swelling. **E** = maximum extent of osteolysis at the palatal root in the axial section.

1. Introduction

Endodontic treatment aims at prevention or treatment of pulpal/periradicular pathology with the overarching goal of tooth preservation. Endodontic failures usually result from the failure to achieve this primary goal, and revision is intended to correct the inadequacies of the initial treatment. In this context, revision is defined as a treatment on a tooth that has received previously attempted definitive treatment, with a condition that requires further endodontic treatment to preserve the tooth.

Non-surgical endodontic retreatment should always be the first treatment choice when failed endodontic treatment is identified. In principle, there are four possible procedures about which the patient must be informed in order to give consent:

- non-surgical endodontic retreatment,
- apical surgery (root tip resection),
- extraction (with or without replacement; transplantation if necessary),
- no treatment (this choice requires proper documentation),

The decision on the alternative therapy is usually relatively simple if an obvious reason for the pathological finding can be established.

2. Indications for an apicoectomy

Endosurgical intervention may be considered in the following cases when clinical and/or radiographic signs of apical periodontitis are present:

- teeth with obliterated and/or no longer instrumentable root canal (Fig. 1),
- indicated, but orthograde not feasible root canal treatment or in case of significant morphological variations of the roots (Fig. 1),
- persistent apical periodontitis with clinical symptoms or increasing radiographic osteolysis after complete or incomplete root canal filling or revision treatment, if this cannot be removed or improved only at disproportionate risk (Fig. 2),
- fracture of a root canal instrument near the apex which cannot be removed orthogradically (Fig. 3),
- apical perforations that can no longer be corrected orthogradically and were caused iatrogenically during primary treatment (Fig. 3 and 4),
- extruded root canal filling material with clinical symptoms or involvement of neighboring structures (maxillary sinus, mandibular canal) (Fig. 1–4),
- horizontal root fractures in the apical root third with infection of the apical fragment,
- already resected teeth – as an alternative to or in addition to orthograde revision, e.g. suspected apical in/fractures (Fig. 2),
- iatrogenic injury of root tips caused by preceding surgical procedures (e.g. cyst removal, biopsy),
- teeth with complex prosthetic restoration or large-volume post build-up (Fig. 5).

A thorough general and specific medical history as well as a comprehensive clinical diagnosis in combination with appropriate imaging techniques are always obligatory for the decision regarding the choice of therapy.

3. Imaging techniques

In endodontic treatment, the intraoral dental X-ray is still the most important tool for radiographic imaging of the teeth. X-rays penetrate the tissue and are diminished by absorption and scattering as they pass through the tissues. Absorption is element dependent – structures with elements of high atomic numbers absorb X-rays more than those with lower atomic numbers. This produces the typical grayscale image, which either must be developed (analog radiographs) or made visible by digital processing of an image receiver. In conventional X-ray technology, a spatial object is displayed two-dimensionally on the dental X-ray or monitor. Superimpositions, distortions, addition and subtraction effects as well as hardening artefacts can occasionally result in individual objects no longer being differentiable. If, for example, a projection

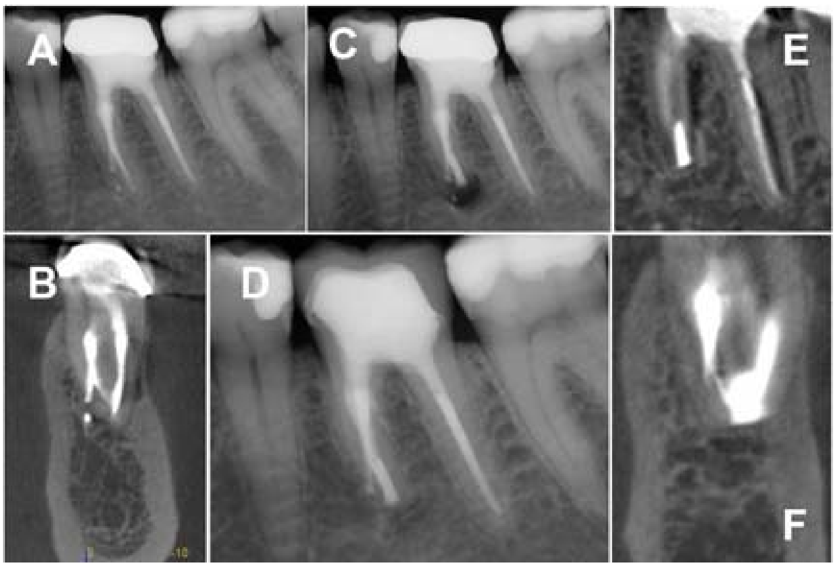

Figure 3 A = persistent complaints occurred in regio 36 after multiple retreatments and a perforation repair. **B** = coronal view (CBCT) with extruded root canal filling material in the area of perforation repair. **C** = situation after microsurgical apicoectomy. **D** = 1-year follow-up (periapical X-ray) with no evidence of pathology. **E,F** = sagittal and coronal view (CBCT) with complete bony regeneration and perfect bevel angle.

Figure 4 Iatrogenically fractured and displaced instrument over the apex, which was orthograde and no longer removable. **Bottom:** Two-year follow-up (periapical X-ray 16) with almost complete osseous regeneration (root end filling with Biodentine (Septodont, Saint-Maur-des-Fossés, France).

of the roots without superimposition and their differentiation is not possible when assessing periapical structures, it may be indicated to take additional eccentric images (approximately 30 ° mesially or distally eccentric from the orthogonal setting). The additional information makes it possible to infer the three-dimensional reality. However, when comparing single tooth X-rays (e.g. follow-up radiographs), the same exposure angles, exposure times, amperage (mA), voltage (kV) and sensors are always required in the sense of standardized radiographs.

4. CBCT

CBCT images are created from multiple two-dimensional projection images from different directions during the defined orbit of the radiation source and detector around the object. These individual projections are then combined by mathematical algorithms to form 3D data (primary reconstruction). Based on the absorption values in the tissue, gray values are assigned to the irradiated object with respect to the voxels (= volumetric pixels) by means of mathematical algorithms. In imaging, a gray level distribution can be viewed as a mathematical function and each function can be fully recovered from integrals over an infinite number of lines passing through the function [40]. The underlying reconstruction principle itself is called “back projection”. Nowadays, for easy and fast implementation, the well-known Feldkamp algorithm is used in its original form or in various modifications to create the primary reconstruction. On the PC, all desired slice directions of the FOV (Field of View) can then be created in the secondary reconstruction. The major advantage of the images is the isometry of the voxel. It is the same in length, width and height (isometry), therefore length and angle measurements can also be made in the CBCT, which are free of any superimpositions.

4.1 CBCT-associated artefacts

If differences occur between the image and reality, these are referred to artefacts, which must always be taken into account when making findings. The following typical artefacts are distinguished:

• Metal artefacts

Caused by scattering: photons that are diffracted from their original path after interaction with matter contribute to increased measured primary intensities.

• Extinction artefacts

Particularly thick and dense materials (e.g. gold restorations) lead to an incident intensity of “zero” on the detector (= complete absorption), which means that no absorption can be calculated [38].

• Beam hardening artefacts

Beam hardening is one of the best known sources of artefacts [13]. When the beam spectrum passes through dense objects, lower energy beams are significantly absorbed. The denser the object and the higher the atomic number, the greater the fraction of absorbed wavelengths. Consequently, the object acts like a filter and relatively more high-energy radiation hits the detector resulting in dark fringes. This effect is more pronounced in lower radiation energy spectrum. Even light metal such as titanium leads to beam hardening with the common used voltage values (KV).

• Motion artefacts (Fig. 6)

Breathing, heartbeat (pulse), blinking and muscle tone lead to movements

(Fig. 1, 3 and 5: Tom Schloss)

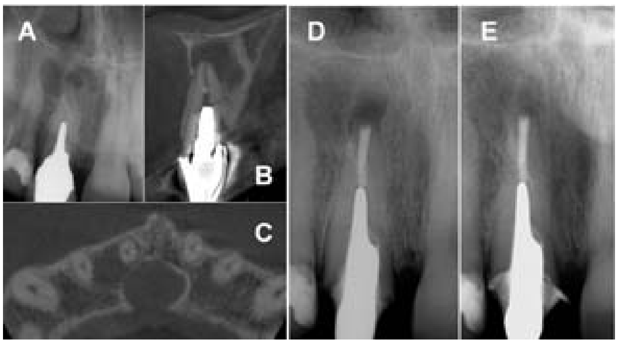

Figure 5 A = tooth 11 with an intact individual root post (orthograde only removable with a high risk), but without an appropriate root canal filling and an apical periodontitis. **B,C** = sagittal and axial section through the ROI. Note: a large incisive canal is visible directly adjacent to the apical periodontitis. **D** = postoperative X-ray (tooth 11) after microsurgical apicoectomy with axial retrograde preparation and root canal filling. **E** = 1-year follow-up with a complete osseous healing (periapical radiograph tooth 11).

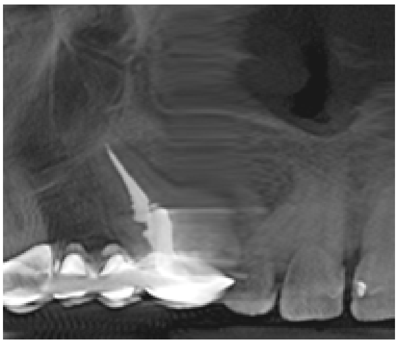

Figure 6 Detail out of the "implant view" in a CBCT. Considerable blurring due to patient movement

of the object points during the exposure time, which are, however, considered to be stationary/immobile. Consequently, details in the reconstruction may be assigned to several voxels. This causes so-called "motion blurs" – especially at higher exposure times. The sum of motion blurs (up to 1400 µm) can be a multiple of a voxel size (70–400 µm). Thus, the exposure time and the fixation of the patient are important factors for the expected image quality.

• Exponential Edge Gradient Effect (EEGE)

This effect occurs at sharp edges (e.g. crown edges) with high contrast to neighboring structures and consists of delicate stripes or thin, alternating dark and light lines behind the objects. It arises due to the difference between the finite beam and focal spot width when mathematically assuming a width of "zero". It can be compared to the penumbra of a light source.

• Aliasing artefacts

To be able to reconstruct a detail completely, the sampling frequency (here pixel size of the detector) must be twice as large as the object (Nyquist theorem). A so-called "undersampling" and the divergence of the cone beam cause the aliasing artifacts, which appear as a fine line pattern (moiré pattern), which diverge towards the periphery of the irradiated volume [12].

Noise

Noise does not belong to the artifacts themselves, but it affects CBCT image quality by reducing the contrast resolution of low-density object details, which are consequently more difficult to differentiate – similar to a digital camera providing lower quality images in low light conditions. This is because the current intensity (mA) is matched to that of conventional CT devices for dose reduction reasons, but this is associated with a lower signal-to-noise ratio in CBCT [49].

4.2 Cone beam volume tomo-graphy (CBCT): forensic basics

Today, imaging diagnostics in endodontics is essentially supplemented by the possibilities of digital volume tomography. For the justifying indication, a comprehensive basic diagnosis should always have been performed prior to taking a CBCT image [17]. Furthermore, the FOV should be limited to the region of interest and the highest possible nominal resolution should be aimed for, in terms of a voxel size of ≤ 125 µm [46], although the spatial resolution that can actually be achieved is significantly higher than the nominal size of the voxel [7, 49].

It is acknowledged that CBCT has a higher sensitivity than conventional diagnostics in a large number of indications in the field of endodontics [36]. With regard to the benefits for patients and the evidence for modifying treatment plans, there are contradictory statements. While some authors in systematic reviews are very critical of CBCT use and its potential advantages and disadvantages [27, 44], others describe a broad impact on treatment decisions for specific indications – especially for endodontic surgery [14, 32, 42, 43, 57].

The fundamental question is therefore: when is the ideal time to obtain a CBCT in addition to the single-tooth radiograph (signs and symptoms => treatment needs => indication)? In order to detect iatrogenic problems caused by previous treatments (e.g. canal displacements in bucco-lingual alignment, perforations), which may have an influence on the outcome of the planned therapy [21], superimposition-free 3D diagnostics may already be indicated when deciding between surgical or nonsurgical intervention. Regardless of this, the patient's consent must be obtained before any dental intervention, and only after comprehensive (evidence-based) information has been provided on therapy, alternatives, risks and side effects, as well as prognosis.

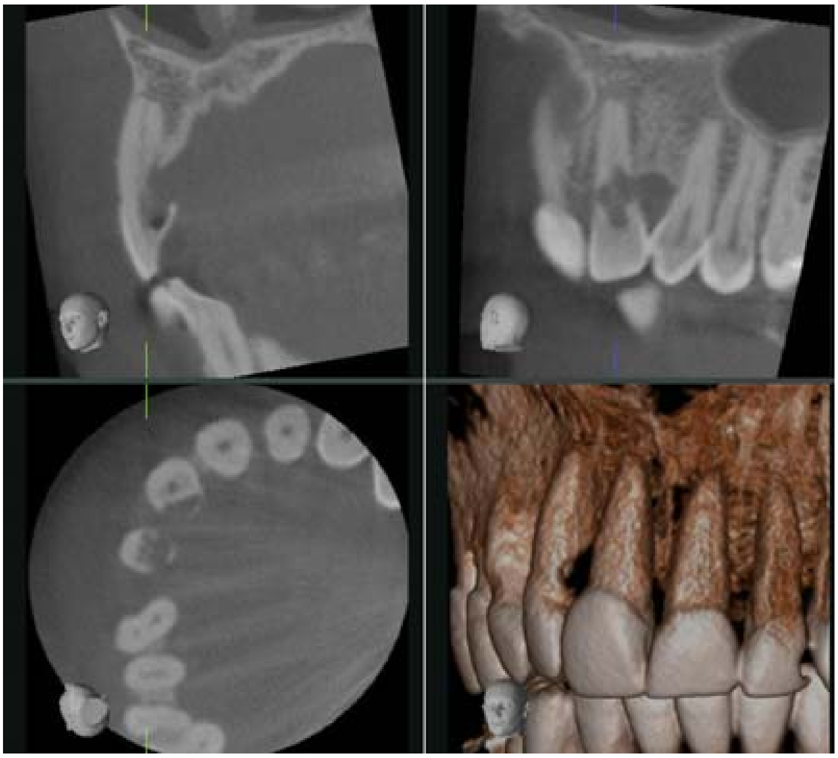

Figure 7 External invasive cervical resorption (EICR) tooth 12. Extension to the middle third of the root, circumferential extension > 270 °, possible pulp involvement: CBCT based classification tooth 12 = 3Dp; additionally tooth 11 affected = 2Bd.

5. General endodontic indications

General endodontic indications when two-dimensional imaging diagnostics provide no or insufficient information for treatment planning and prognosis, or the existing clinical findings and symptoms do not sufficiently substantiate a corresponding tentative diagnosis:

- periapical examination,
- detection of root fractures,
- suspicion or presence of perforations, especially post perforations (Fig. 2),
- in individual cases, if endodontological therapy is made more difficult by certain accompanying circumstances, such as complex anatomy of the root canal system (Fig. 1),
- planning of endodontic-surgical treatments, especially when aggravating factors, such as the endangerment of anatomical neighboring structures, are present (Fig. 5),
- determining the position of intracanal fractured root canal instruments (Fig. 2),
- assessment of internal and external root resorptions (Fig. 7),
- assessment of bone conditions (esp. buccal cortical and furcation areas) (Fig. 8),
- dental or dentoalveolar trauma,
- obliterated, calcified root canals,
- retreatment and/or assessment of root canal fillings.

5.1 Endosurgery

In principle, the increased use of the surgical microscope in endodontic surgery has overcome many of the shortcomings of earlier techniques. This is also true in the context of the development of microsurgical instruments, axis-aligned retrograde preparation with ultrasonic tips, and new are more biologically compatible root-end filling materials. Endodontic microsurgery is a minimally invasive technique associated with less postoperative pain, edema and faster wound healing, with a significantly higher success rate than traditional apical surgery [19].

Three-dimensional diagnostics is also mentioned as a component, key concept and important procedural step of endodontic microsurgery. The advantages of three-dimensional diagnostics clearly result from the superimposition-free display of all details and their neighboring structures. Even though endosurgical procedures in the “pre-CBCT era” were always planned and performed using conventional diagnostics, CBCT has special significance as a valuable diagnostic aid in decision-making, especially in complex cases [1, 34]. Consodering the adjacent anatomical structures that could be injured in the course of an endosurgical procedure, knowledge of the exact structures would appear to be useful. The mental foramen, maxillary sinus, Underwood septa in the maxillary sinus (Fig. 9), inferior alveolar nerve, retromolar canal, nasal spina, incisive canal, nasopalatine duct, and nasal floor can be reliably diagnosed and evaluated in their actual positional relationship to the apices [8, 29, 37, 56] (Fig. 10). The complexity of the cases increases with the destruction of the cortical structures with or without communication to the marginal periodontium or the so-called “through-and-through” defects (oral and vestibular cortices affected) (Fig. 8 and 9). Here, membranes are usually required for regeneration (GBR/GTR) [61]. This results in a necessity for 3D diagnostics with regard to the treatment planning for or against tooth preservation and especially for surgical intervention.

5.2 Non-endodontic surgical procedures

Furthermore, information regarding the treatment options can also be obtained in the context of primarily non-endodontic surgical procedures. With regard to the treatment of external cervical resorption (ECR), a new classification has already been implemented based on 3D diagnostics [33]. This new classification allows a more reliable treatment planning, effective and accurate communication between colleagues, and a more reliable statement regarding the prognosis of the affected teeth.

Similarly, analogs can be printed in advance for teeth that are not worth preserving, if needed, with a regard to possible (auto)transplantation of teeth, and thus the graft bed (recipient bed)

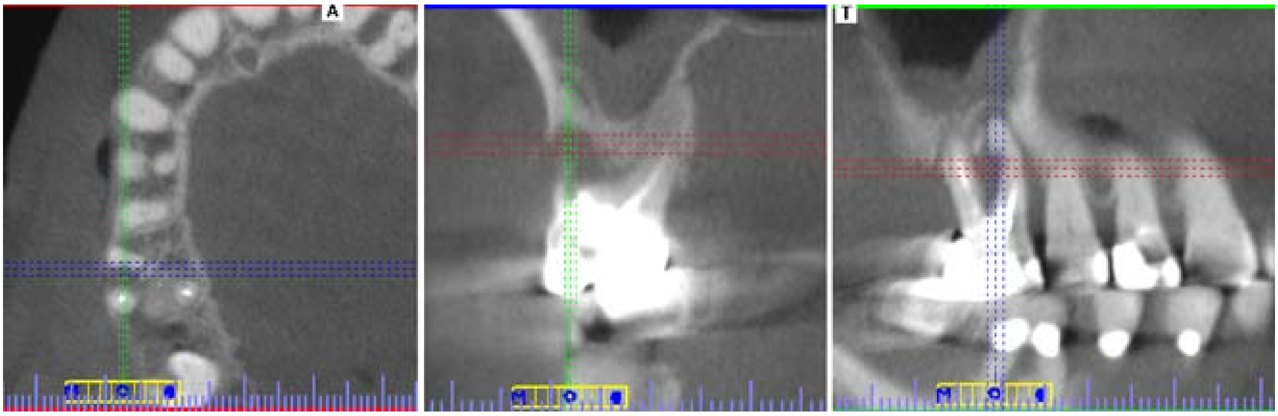

Figure 8 Superimposition-free axial, coronal and sagittal CBCT-views (tooth 16) with an apical periodontitis and loss of buccal lamella and inter-radicular bone

can be ideally adapted to the graft without damaging it [5, 23, 58].

5.3 Guided endodontic surgery

Computer-aided dynamic navigation and "guided surgery" can also be regarded as a new field. There are now several case reports that have successfully performed surgical procedures using navigated, guided surgery – based on CBCT data. The size of the bone window, the angulation and the depth of the trephine drill can be planned and defined preoperatively and appropriate templates can be made. After preparation of the mucoperiosteal flap, the apicoectomy is then performed dynamically guided by means of a stereoscopic motion-tracking camera or directly and simultaneously using a template-guided trephine drill [3, 20, 52, 53]. In cadaver studies, the use of CBCT-based surgical templates was shown to be a more accurate method for accessing the root apex compared to a "hands-free" CBCT-guided method [2, 18].

5.4 Guided endodontics

A distinction must also be made between navigated endodontics, which has already become established as a treatment option. Instead of surgical intervention, a guided orthograde procedure based on CBCT data can also be considered in special cases. Precise planning and the fabrication of a suitable drilling template, based solely on DICOM and/or an intraoral scan (STL data) linked to the CBCT data, can determine the depth and direction of the access cavity. Thus, a reliable location of the obliterated canal system in "deep" root areas is possible and surgical intervention can thus be avoided [26, 28]. The increased costs and time expenditure for the creation of the splint as well as the possibly increased radiation exposure must be taken into consideration.

6. "Treatment outcome" in endosurgery

Traditionally, success rates in endodontics are determined by means of dental X-rays with the PAI (periapical index), whereas in the context of endodontic surgical procedures the classification according to Rud and Molven is used [30, 31, 45]. Here, the periapex of the roots is analyzed and evaluated in the image with regard to any pathologies (especially osteolysis and widening of the periodontal ligament). The evaluation of treatment courses using dental X-rays is well established in the literature despite the inherent limitations (superimpositions, distortions, addition and subtraction effects, and hardening artefacts). This guarantees comparability with older studies as well as good radiation hygiene.

Studies have described a number of predictors for the success of endosurgical therapies, in particular being indirectly negatively influenced by a decrease in crestal bone height. Root defects, the presence of preoperative clinical signs and previously performed retrograde root canal fillings, size of the lesion, axis-appropriate retrograde preparation are also discussed as factors [22] (Fig. 1–5). In summary, positive treatment outcomes have been demonstrated in up to 94 % of cases using microsurgical techniques [11, 41, 55]. In this context, microsurgical procedures seem to be more promising than traditional techniques [50]. Thus, microsurgery can be considered "state of the art" at least in specialist practice [11, 19, 24, 50, 51].

If CBCT is used to monitor outcome (follow-up), significantly more indices (e.g.: thickness of cortical bone, resection area and angle, axial position of retrograde root filling) can be investigated and thus healing can be evaluated more accurately [60] (Fig. 1 and 3). Reliable CBCT-based periapical indices have been proposed

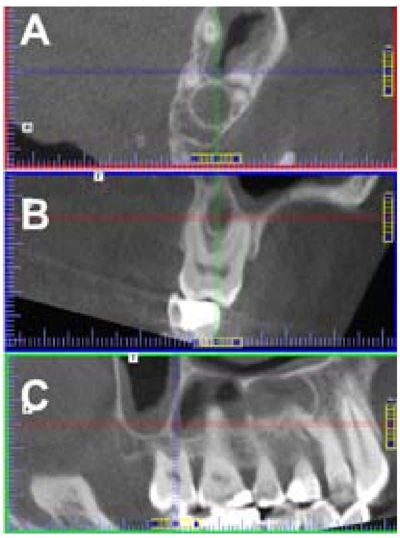

Figure 9 A,B,C = axial, coronal and sagittal CBCT images regio 17. A septum in the maxillary sinus (Underwood septum) extends between the buccal roots and the palatal root.

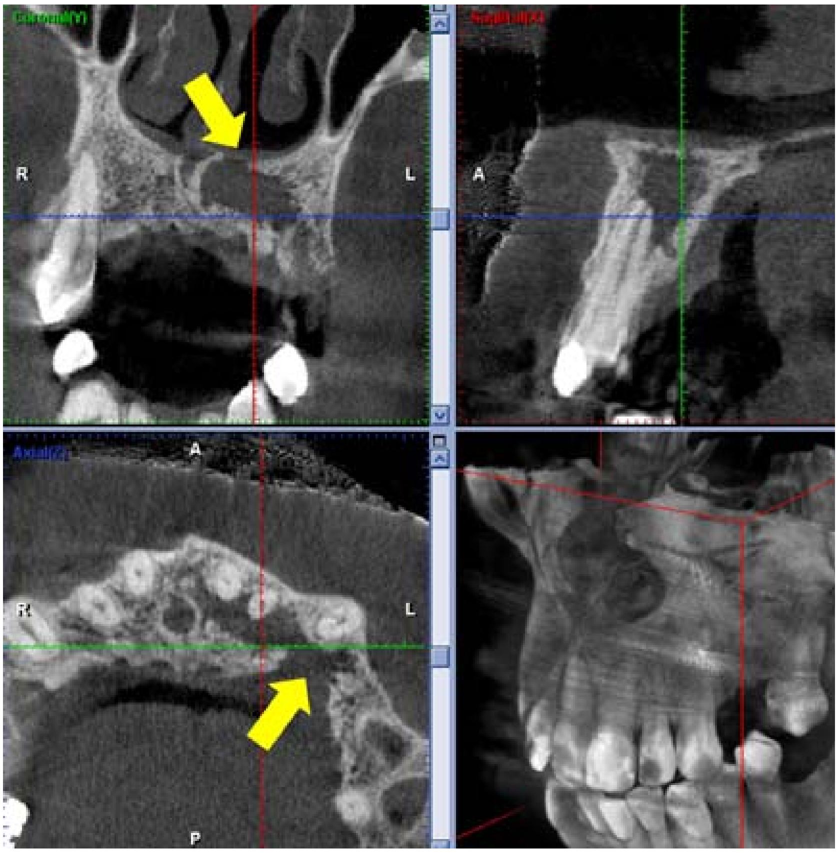

Figure 10 Coronal, axial and sagittal slice (CBCT) regio 23. Extensive osteolytic process starting from tooth 23 with loss of the bony barrier to the nasal floor as well as the palatal corticalis (palatum durum).

[15, 16] and now there are some studies evaluating traditional two-dimensional (2D) and three-dimensional (3D) healing in endosurgical procedures [10, 47, 54, 59]. All studies suggest that CBCT has up to 1/3 higher sensitivity in detecting pathological structures than dental X-ray. Nevertheless, this does not justify CBCT analysis for periapical diagnosis as a standard method [27], even though the exact measurement and comparison of the volume (cm^3) of any pre- or postoperative osteolysis can be considered as a clear advantage of 3D evaluation (Fig. 2). With regard to the influence of regenerative techniques (GBR/GTR) on healing, this can provide valuable information [24] and clarity as to whether complete healing/regeneration has occurred and whether the one-year follow-up is sufficient to assess healing (uncertain healing). CBCT seems to be suited reliably differentiating cortical bone loss caused by the osseous access cavity from other pathologies or osteolytic processes. Irrespective of this, histological examination is indispensable for an exact assessment and differentiation of apical pathologies and the detection of malignancies [6].

7. Radiation protection

In general, the risk-benefit ratio in terms of radiation exposure during diagnosis and follow-up visits is in favor of conventional two-dimensional radiography, which is associated with an effective dose of 0.6–5 µSv when a dental X-ray is made, whereas CBCT can manage 19–55 µSv with adapted setting parameters and a small FOV according to SEDENTEXCT [35].

However, CBCT devices differ in technology (sensor, detector) as well as frame rate, rotation time, and rotation angle when the patient is exposed, so that effective doses can vary extremely (factor 20 to 170) for comparable parameters [4, 35]. In general, a higher-resolution and higher-contrast image is produced via a higher number of baseline projections. However, this is countered by a resulting higher radiation dose. In most CBCT devices, programs are therefore implemented that either reduce the number of base projections or the radiation dose. The higher the resolution, the higher the radiation dose required for this purpose with the same field-of-view (FOV), because more raw images are taken in high-resolution mode, which is always associated with a longer exposure time. However, when using a reduced number of raw images in order to reduce radiation dose, the risk of blurring due to motion artefacts may be increased (Fig. 6).

Nevertheless, the height of the field-of-view (FOV) is the most important factor for the radiation dose. Depending on the detector size, the current, modern CBCT devices allow the acquisition of different volume sizes representing cylinders with adjustable diameters and corresponding heights (e.g., large volumes [12–15 cm], medium volumes [8–11 cm] and small volumes [approx. 5 cm diameter]). The function of "pre-shots" (Fig. 2 B1,2) from 2 planes can reliably ensure the exact alignment of the volume with the ROI (region of interest). For endodontic purposes, small FOVs sufficient for the diagnostic task should always be selected. This leads to a lower radiation dose and a reporting limited to the ROI, as it is mandatory to evaluate all structures visible in the CBCT. When evaluating small FOVs and strictly limited ROIs, it is usually not necessary to analyze cranial structures, which may be beyond the scope of even experienced dentists. However, more endodontic graduate and post-graduate education about CBCT use and diagnostics seem to be needed [39].

8. Conclusion

The routine acquisition of three-dimensional images (i.e. CBCT) with corresponding limited FOV is currently not "state of the art" in endodontic diagnostics and follow-up care. For radiation protection and legal requirements, the practitioner "must" provide a justifying indication for each X-ray exposure. The exposure of the patient to ionizing radiation must be considered according to the

(Fig. 2, 4, 6–11: Sebastian Bürklein)

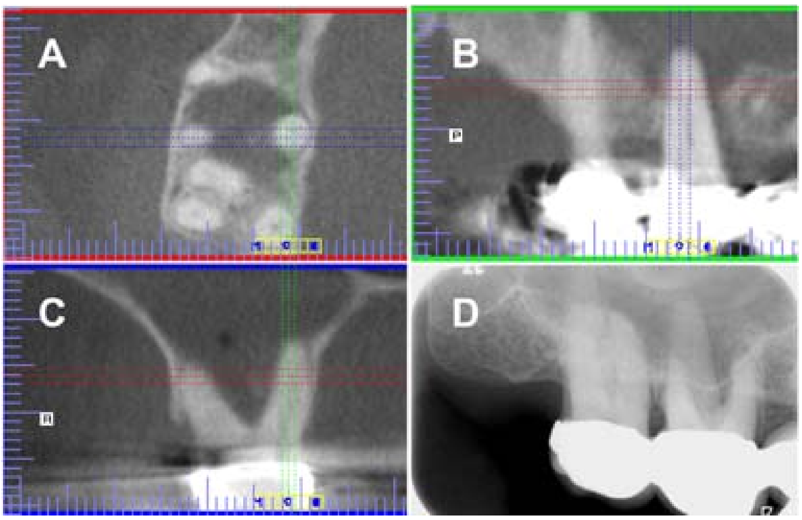

Figure 11 A,B,C = axial, sagittal and coronal slice (CBCT) regio 16. The CBCT slices show the loss of basal bone structures in the furcation area of the affected tooth. Mouth-antrum communication due to advanced periodontitis (no primary endodontic cause). **D** = associated X-ray regio 16, which cannot adequately display the destruction.

ALARA principle ("As Low As Reasonably Achievable"). Thus, the practitioner must always decide whether the patient's well-being is more compromised by not taking the radiograph than by the ionizing radiation and its consequences, even though there is current evidence that exposure to low-dose radiation with a cumulative dose of up to 100 mSv does not appear to increase the risk of cancer [48]. This may justify to replace the ALARA principle by ALADA ("As Low As Diagnostically Acceptable").

Nevertheless, 3D diagnostics has become indispensable in endodontics and has become a real "game-changer" for experienced colleagues and specialists. The increasing complexity of cases, especially in specialist offices, leads to "negative selection" of supposedly hopeless cases. Here, due to the possibly multiple previous treatment and rescue attempts with possibly iatrogenic root canal transportations and/or perforations [21], a realistic assessment of the preservability of the affected teeth is no longer possible without a spatial, superimposition-free visualization of all involved structures. This may lead to an increased need of CBCT analysis by the specialized colleagues. They have special expertise not only concerning treatment but also in the diagnosis of these complex cases (Fig. 11). The following applies to many cases: the common is common, the rare is rare, but with special expertise, at some point the rare becomes common and this may require extended/further diagnostics. A thorough examination and diagnostic represent a prerequisite of a serious treatment planning with an assessment of the prognosis of the teeth to be treated and an adequate (evidence-based) patient clarification. This is especially relevant for surgical endodontics, as these cases often exhibit the maximum extent of unsuccessful pretreatment. With the multiple anatomically neighboring structures, the medical principle of "nihil nocere" must be adhered to by means of appropriate diagnostics and imaging, which is why CBCT is of particular importance here. However, the indication for follow-up must be more stringent, especially since the clinical findings (calor, rubor, dolor, tumor, functio laesa), in addition to the imaging (conventional periapical X-ray), provide important evidence for healing.

The question of whether a CBCT should be taken as the sole diagnostic imaging or in addition to the intraoral X-ray or panoramic radiograph therefore depends on many factors and is always an individual decision based on the specific indication.

Conflicts of interest

Birger Thonemann states that he operates a DVT in his own practice. The other authors declare that there is no conflict of interest as defined by the guidelines of the International Committee of Medical Journal Editors.

References

1. AAE and AOMR Joint position statement. Use of cone beam computed tomography in endodontics 2015 update. J Endod 2015; 41: 1393–1396

2. Ackerman S, Aguilera FC, Buie JM et al.: Accuracy of 3-dimensional-printed endodontic surgical guide: a human cadaver study. J Endod 2019; 45: 615–618

3. Ahn SY, Kim NH, Kim S, Karabucak B, Kim E: Computer-aided design/computer-aided manufacturing-guided endodontic surgery: guided osteotomy and apex localization in a mandibular molar with a thick buccal bone plate. J Endod 2018; 44: 665–670

4. Al-Okshi A, Lindh C, Salé H, Gunnarsson M, Rohlin M: Effective dose of cone beam CT (CBCT) of the facial skeleton: a systematic review. Br J Radiol 2015; 88: 20140658

5. Anssari Moin D, Verweij JP, Waars H, van Merkesteyn R, Wismeijer D: Accuracy of computer-assisted template-guided autotransplantation of teeth with custom three-dimensional designed/printed surgical tooling: a cadaveric study. J Oral Maxillofac Surg 2017; 75: 925.e1–925.e7

6. Bornstein MM, Bingisser AC, Reichart PA, Sendi P, Bosshardt DD, von Arx T: Comparison between radiographic (2-dimensional and 3-dimensional) and histologic findings of periapical lesions treated with apical surgery. J Endod 2015; 41: 804–811

7. Bruellmann D, Schulze R: Spatial resolution in cbct machines for dental/maxillofacial applications|what do we know today? Dento Maxillofac Radiol 2015; 44: 20140204

8. Bürklein S, Grund C, Schäfer E: Relationship between root apices and the mandibular canal: a cone-beam computed tomographic analysis in a German population. J Endod 2015; 41: 1696–1700

9. Chong BS, Dhesi M, Makdissi J: Computer-aided dynamic navigation: a novel method for guided endodontics. Quintessence Int 2019;50:196–202

10. Christiansen R, Kirkewang LL, Gotfredsen E, Wenzel A: Periapical radiography and cone beam computed tomography for assessment of the periapi-

cal bone defect 1 week and 12 months after root-end resection. Dento Maxillofac Radiol 2009; 38: 531–536

11. Curtis DM, VanderWeele RA, Ray JJ, Wealleans JA: Clinician-centered outcomes assessment of retreatment and endodontic microsurgery using cone-beam computed tomographic volumetric analysis. J Endod 2018; 44: 1251–1256

12. de Man B, Basu S: Distance-driven projection and backprojection in three dimensions. Phys Med Biol 2004; 49: 2463–2475

13. de Man B: Metal streak artefacts in X-ray computed tomography: a simulation study. IEEE Trans Nuc Sci 1999; 46: 691–696

14. Ee J, Fayad MI, Johnson BR: Comparison of endodontic diagnosis and treatment planning decisions using cone-beam volumetric tomography versus periapical radiography. J Endod 2014; 40: 910–916

15. Esposito S, Cardaropoli M, Cotti E: A suggested technique for the application of the cone beam computed tomography periapical index. Dento Maxillofac Radiol 2011; 40: 506–512

16. Estrela C, Bueno MR, Azevedo BC, Azevedo JR, Pécora JD: A new periapical index based on cone beam computed tomography. J Endod 2008; 34: 1325–1331

17. European Commission. Radiation protection no 172: cone beam ct for dental and maxillofacial radiology. Evidence based guidelines. a report prepared by the sedentexct project, 2012

18. Fan Y, Glickman GN, Umorin M, Nair MK, Jalali P: A novel prefabricated grid for guided endodontic microsurgery. J Endod 2019; 45: 606–610

19. Floratos S, Kim S: Modern endodontic microsurgery concepts: a clinical update. Dent Clin North Am 2017; 61: 81–91

20. Giacomino CM, Ray JJ, Wealleans JA: Targeted endodontic microsurgery: a novel approach to anatomically challenging scenarios using 3-dimensional-printed guides and trephine burs – a report of 3 cases. J Endod 2018; 44: 671–677

21. Gorni FG, Gagliani MM: The outcome of endodontic retreatment: a 2-yr follow-up. J Endod 2004; 30: 1–4

22. Guerreo CG, Quijano Guaugue S, Molano N, Pineda GA, Nino-Barrera JL, Marin-Zuluaga DJ: Predictors of clinical outcomes in endodontic microsurgery: a systematic review and meta-analysis. G Ital Endond 2017: 31: 2–13

23. He W, Tian K, Xie X, Wang E, Cui N: Computer-aided autotransplantation of teeth with 3D printed surgical guides and arch bar: a preliminary experience. PeerJ 2018; 6: e5939. doi:10.7717/peerj.5939

24. Kang M, In Jung H, Song M, Kim SY, Kim HC, Kim E: Outcome of nonsurgical retreatment and endodontic microsurgery: a meta-analysis. Clin Oral Investig 2015; 19: 569–582

25. Kim D, Ku H, Nam T, Yoon TC, Lee CY, Kim E: Influence of size and volume of periapical lesions on the outcome of endodontic microsurgery: 3-dimensional analysis using cone-beam computed tomography. J Endod 2016; 42: 1196–1201

26. Krastl G, Zehnder MS, Connert T, Weiger R, Kühl S: Guided endodontics: a novel treatment approach for teeth with pulp canal calcification and apical pathology. Dent Traumatol 2016; 32: 240–246

27. Kruse C, Spin-Neto R, Wenzel A, Kirkevang LL: Cone beam computed tomography and periapical lesions: a systematic review analysing studies on diagnostic efficacy by a hierarchical model. Int Endod J 2015; 48: 815–828

28. Lara-Mendes STO, Barbosa CFM, Machado VC, Santa-Rosa CC: A new approach for minimally invasive access to severely calcified anterior teeth using the guided endodontics technique. J Endod 2018; 44: 1578–1582

29. López-Jarana P, Díaz-Castro CM, Falcão A, Falcão C, Ríos-Santos JV, Herrero-Climent M: Thickness of the buccal bone wall and root angulation in the maxilla and mandible: an approach to cone beam computed tomography. BMC Oral Health 2018; 18: 194. doi:10.1186/s12903–018–0652-x

30. Molven O, Halse A, Grung B: Incomplete healing (scar tissue) after periapical surgery – radiographic findings 8 to 12 years after treatment. J Endod 1996; 22: 264–268

31. Molven O, Halse A, Grung B: Observer strategy and the radiographic classification of healing after endodontic surgery. Int J Oral Maxillofac Surg 1987; 16: 432–439

32. Mota de Almeida FJ, Knutsson K, Flygare L: The effect of cone beam CT (CBCT) on therapeutic decision-making in endodontics. Dento Maxillofac Radiol 2014; 43: 20130137. doi:10.1259/dmfr.20130137.

33. Patel S, Foschi F, Mannocci F, Patel K: External cervikal resorption: a three-dimensional classification. Int Endod J 2018; 51: 206–214

34. Patel S, Brown J, Semper M, Abella F, Manocci F. European Society of Endodontology position statement: use of cone beam computed tomography in endodontics. Int Endod J 2019; 52: 1675–1678

35. Pauwels R, Beinsberger J, Collaert B et al.: SEDENTEXCT Project Consortium. Effective dose range for dental cone beam computed tomography scanners. Eur J Radiol 2012; 81: 267–271

36. Petersson A, Axelsson S, Davidson T et al.: Radiological diagnosis of periapical bone tissue lesions in endodontics: a systematic review. Int Endod J 2012; 45: 783–801

37. Porto OCL, Silva BSF, Silva JA et al.: CBCT assessment of bone thickness in maxillary and mandibular teeth: an anatomic study. J Appl Oral Sci 2020; 28: e20190148

38. Prell D, Kyriakou Y, Beister M, Kalender WA: A novel forward projection-based metal artifact reduction method for flat-detector computed tomography. Phys Med Biol 2009; 54: 6575–6591

39. Rabiee H, McDonald NJ, Jacobs R, Aminlari A, Inglehart MR: Endodontics program directors', residents', and endodontists' considerations about CBCT-related graduate education. J Dent Educ 2018; 82: 989–999

40. Radon J: Über die Bestimmung von Funktionen durch ihre Integralwerte längs gewisser Mannigfaltigkeiten. Ber Verh Sächs Akad Wiss Leipzig, Math Phys Kl 1917; 69: 262–277

41. Riis A, Taschieri S, Del Fabbro M, Kvist T: Tooth survival after surgical or nonsurgical endodontic retreatment: long-term follow-up of a randomized clinical trial. J Endod 2018; 44: 1480–1486

42. Rodríguez G, Abella F, Durán-Sindreu F, Patel S, Roig M: Influence of cone-beam computed tomography in clinical decision making among specialists. J Endod 2017; 43: 194–199

43. Rodríguez G, Patel S, Durán-Sindreu F, Roig M, Abella F: Influence of cone-beam computed tomography on endodontic retreatment strategies among general dental practitioners and endodontists. J Endod 2017; 43: 1433–1437

44. Rosen E, Taschieri S, Del Fabbro M, Beitlitum I, Tsesis I: The diagnostic efficacy of cone-beam computed tomography in endodontics: a systematic review and analysis by a hierarchical model of efficacy. J Endod 2015; 41: 1008–1014

45. Rud J, Andreasen JO, Jensen JE: Radiographic criteria for the assessment of healing after endodontic surgery. Int J Oral Surg 1972; 1: 195–214

46. Scarfe WC, Levin MD, Gane D, Farman AG: Use of cone beam computed tomography in endodontics. Int J Dent 2009; 2009: 634567. doi:10.1155/2009/634567

47. Schloss T, Sonntag D, Kohli MR, Setzer FC: A comparison of 2– and 3-dimensional healing assessment after endodontic surgery using cone-beam computed tomographic volumes or periapical

radiographs. J Endod 2017; 43: 1072–1079

48. Schultz CH, Fairley R, Murphy LS, Doss M: The risk of cancer from CT scans and other sources of low-dose radiation: a critical appraisal of methodologic quality. Prehosp Disaster Med 2020; 35: 3–16

49. Schulze R, Heil U, Groß D et al.: Artefacts in CBCT: a review. Dento Maxillofac Radiol 2011; 40: 265–273

50. Setzer FC, Kohli MR, Shah SB, Karabucak B, Kim S: Outcome of endodontic surgery: a meta-analysis of the literature – part 2: comparison of endodontic microsurgical techniques with and without the use of higher magnification. J Endod 2012; 38: 1–10

51. Setzer FC, Shah SB, Kohli MR, Karabucak B, Kim S: Outcome of endodontic surgery: a meta-analysis of the literature – part 1: comparison of traditional root-end surgery and endodontic microsurgery. J Endod 2010; 36: 1757–1765

52. Strbac GD, Schnappauf A, Giannis K, Moritz A, Ulm C: Guided modern endodontic surgery: a novel approach for guided osteotomy and root resection. J Endod 2017; 43: 496–501

53. Sutter E, Lotz M, Rechenberg DK, Stadlinger B, Rücker M, Valdec S: Guided apicoectomy using a CAD/CAM drilling template. Int J Comput Dent 2019; 22: 363–369

54. Tanomaru-Filho M, Jorge ÉG, Guerreiro-Tanomaru JM, Reis JM, Spin-Neto R, Gonçalves M: Two- and tridimensional analysis of periapical repair after endodontic surgery. Clin Oral Investig 2015; 19: 17–25

55. Tsesis I, Rosen E, Taschieri S et al.: Outcomes of surgical endodontic treatment performed by a modern technique: an updated meta-analysis of the literature. J Endod 2013; 39: 332–339

56. Uğur Aydın Z, Göller Bulut D: Relationship between the anatomic structures and mandibular posterior teeth for endodontic surgery in a Turkish population: a cone-beam computed tomographic analysis. Clin Oral Investig 2019; 23: 3637–3644

57. Venskutonis T, Plotino G, Juodzbalys G, Mickevičienė L: The importance of cone-beam computed tomography in the management of endodontic problems: a review of the literature. J Endod 2014; 40: 1895–1901

58. Verweij JP, Jongkees FA, Anssari Moin D, Wismeijer D, van Merkesteyn JPR: Autotransplantation of teeth using computer-aided rapid prototyping of a three-dimensional replica of the donor tooth: a systematic literature review. Int J Oral Maxillofac Surg 2017; 46: 1466–1474

59. von Arx T, Janner SF, Hänni S, Bornstein MM: Agreement between 2D and 3D radiographic outcome assessment one year after periapical surgery. Int Endod J 2016; 49: 915–925

60. von Arx T, Janner SF, Hänni S, Bornstein MM: Evaluation of new cone-beam computed tomographic criteria for radiographic healing evaluation after apical surgery: assessment of repeatability and reproducibility. J Endod 2016; 42: 236–242

61. von Arx T, Cochran DL: Rationale for the application of the GTR principle using a barrier membrane in endodontic surgery: a proposal of classification and literature review. Int J Periodontics Restorative Dent 2001; 21: 127–139

(Photo: Sebastian Bürklein)

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Root canal irrigation: How much activation is necessary?

Introduction: Current systems for activating irrigation solutions mainly use sound, ultrasound or laser. The simple form of manual dynamic activation must be differentiated.

Methods: In comparison to the conventional irrigation technique, the described methods generally result in a greater cleaning effect under experimental conditions (removal of pulp tissue and debris, penetration depth into the root dentin, antibacterial effect, removal of calcium hydroxide). Gradual differences seem to be the result of the chosen experimental setup and the material used.

Result and Conclusion: Given that comparative clinical studies are largely lacking and the advantages of a defined irrigation protocol involving the activation of the irrigation solution have not been clinically proven so far, only a recommendation for their application can be derived from existing experimental studies. Also, with respect to the activation method, different approaches can be justified.

Keywords: activated root canal irrigation; laser; root canal preparation; root canal treatment; ultrasound

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Figure 1 A new type of rotary root canal instrument (XP-endo Finisher, FKG Dentaire, La Chaux-de-Fonds, Switzerland)

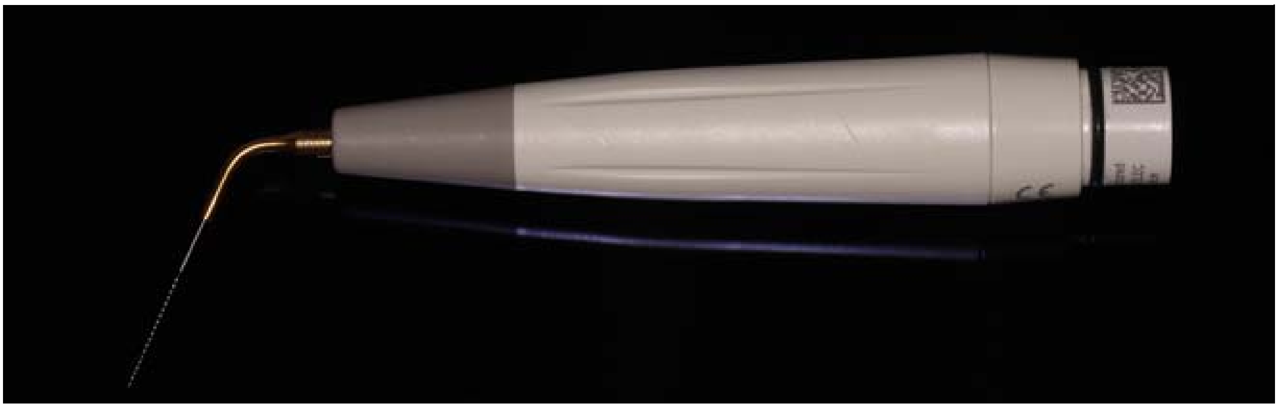

Figure 2 Ultrasound driven handpiece with Irri S file (VDW München, Germany)

Introduction

Besides the mechanical preparation of the main root canals, a sufficient chemical disinfection of the root canal system by means of root canal irrigation is required. In this manner, the term chemo-mechanical preparation is derived. The reason for this lies in the limitations of mechanical preparation and the complexity of the root canal system. Hand instruments as well as rotary root canal instruments do not prepare the canal walls of the main root canals entirely and do not reach the side canals of the root canal system. Despite careful preparation, at least 35 % of the inner surfaces of root canals usually remain untouched [11, 21]. This is why efficient root canal irrigation is required to clean isthmi, side canals and open dentinal tubules in addition to the main root canals, and depending on microbial colonization, for disinfection.

In the best case, the contribution of a particular irrigation technique to the clinical success of endodontic treatment can be evaluated [4]. The prerequisite for a comparative clinical study would be that all other relevant and currently known influencing variables are largely identical or equally distributed within the comparison groups. In view of the large number of variables that can influence the prognosis of a tooth after root canal treatment, unequivocal evidence for a single parameter in prospective, randomized clinical studies seems extremely difficult. The number of cases and recall rates required for this are so high that, depending on the question being addressed, the implementation would be associated with very great effort.

What potential could lie in the activation of irrigation solutions is answered mostly by older clinical studies, among others, that managed without the aid of modern irrigation techniques. As early as 1961, Grahnen and Hansen [10] reported a high success rate of 81 % four to five years after root canal treatment. The work of Sjögren et al. which was published 30 years later [23] and a review by Ng et al. from 2011 [19] likewise confirm that the healing rates – using conventional irrigation methods – are in a similarly high range. From this point of view, the potential for activation of irrigation solutions can be classified as limited. If, on the other hand, the lower root canal treatment success rates that are achieved in ordinary practice conditions [5, 31] are used as a reference point, the table turns, and the question arises of whether methods for activating irrigation solutions under these conditions could make a significant contribution, provided that they are efficient and easy to implement. On the basis of these considerations, this paper outlines the most important methods for the activation of irrigation solutions, and it summarizes the findings, which have primarily been published in the last 5 years in the context of in vitro and in vivo studies.

Goals of activated root canal irrigation

The activation of an irrigation solution is intended to increase the well-known and positive effects of conventional irrigation techniques when combined with conventional irrigation solutions such as sodium hypochlorite – especially in those areas

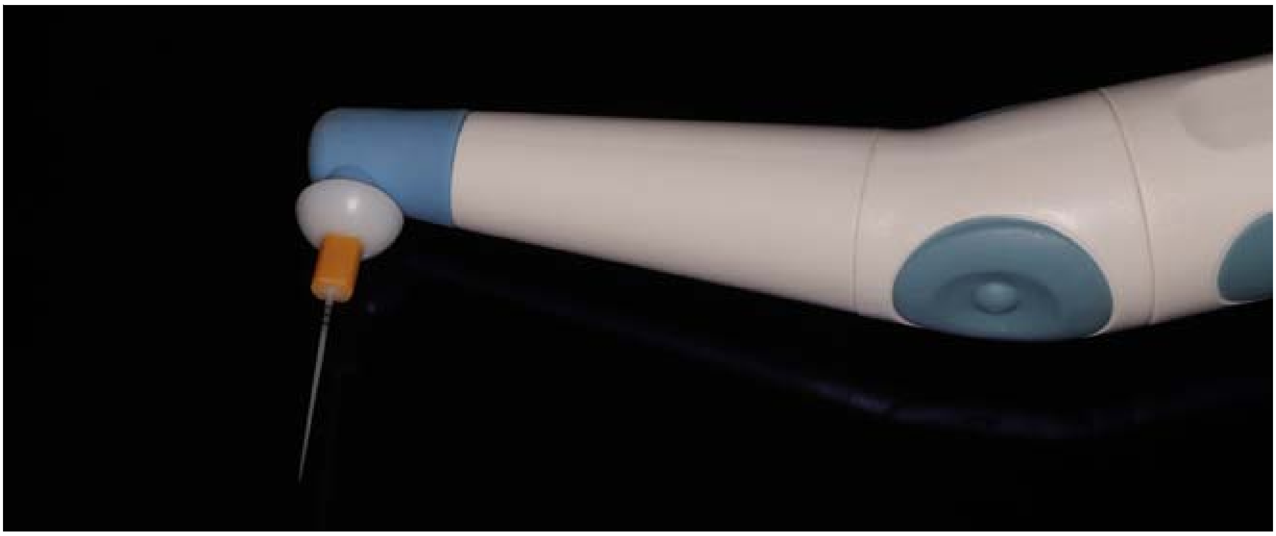

Figure 3 Special sound-activated tips for the EndoActivator (Dentsply Sirona York, PA, USA)

Figure 4 Special sound-activated tips from Eddy (VDW, München, Germany)

of the root canal system that are not accessible to root canal instruments. Essentially these are:

a. Removal of pulp tissue, tissue residues as well as microorganisms, fungi and viruses
b. Dissolving and removal of dentin debris (including the smear layer)
c. Destruction and removal of biofilm
d. Antibacterial effect and neutralization of bacterial toxins
e. Removal of intracanal deposits (e.g. calcium hydroxide) as well as of sealer and remnants of gutta-percha.

At the same time, no side effects should occur due to the activation of irrigation solutions; this includes the extrusion of fluid and/or debris and occurrence of postoperative complaints.

If a narrow root canal has to initially be accessed, the effect of irrigation remains limited in this phase. Only in the final phase of mechanical preparation, and once the apical preparation size is sufficient, does the irrigation solution reach deeper apical areas and isthmi; in favorable cases, it penetrates into lateral canals and dentinal tubules. When a small irrigation cannula with a diameter of 0.30 mm (gauge 30) is used, apical preparation with instruments of at least size 25.06 (e.g. rotary file) or size ISO 30 (e.g. hand file) is required to ensure that the irrigation solution reaches the deep apical areas. Just in these conditions, once the preparation of the root canals is complete, is the final irrigation with or without activation particularly important.

Irrigation solution activation methods

Nowadays, the commonly used activation systems are based on the in-

Figure 5 Erbium-YAG Laser (Orcos, Medical, Küssnacht, Switzerland)

troduction of energy into the irrigation solution by means of sound, ultrasound or laser, which have the appropriate wavelengths, as well as, through the generation of mechanical vertical movements in the liquid (manual dynamic activation). In comparison to the classical irrigation technique, these various methods generally lead to an increase in the mechanical cleaning effect in vitro [29], although differences exist depending on the study design.

Mechanically-activated irrigation technique

In a simple way, the irrigation solution can be manually activated with a gutta-percha cone using rapid up and down movements in the root canal. This form of activation is, however, labor-intensive for the practitioner. In terms of penetration depth into the surrounding dentin, this procedure remains inferior to laser, sound and ultrasound-supported methods [8]. The reduction of debris in the mesial root canals and isthmus regions of lower molars does not show any advantage over conventional manual irrigation in vitro [20]. On the contrary, there is an increased risk of postoperative pain in cases of irreversible pulpitis when manual dynamic activation is used [25].

A new type of rotary root canal instrument (XP-endo Finisher, FKG Dentaire, La Chaux-de-Fonds, Switzerland) (Fig. 1) is particularly suitable for the activation of the irrigation solution, preferably at the end of preparation. The instrument is bent like a spoon and, using the corresponding rotation, it not only sets the irrigation solution in motion, but also reaches canal areas which conventional conical files cannot reach. According to two recent experimental studies, more debris could be removed when using the XP-endo Finisher together with passive ultrasonic activation than with conventional irrigation [7, 32]. This instrument is also suitable for the removal of calcium hydroxide from the root canal [15].

Ultrasonic-activated irrigation methods

Ultrasound-based irrigation techniques have been used in endodontics for over 10 years. The ultrasonic range starts at a frequency of about 20,000 Hz. With the aid of an ultrasonic handpiece, the energy can be transferred to a clamped file or a smooth-walled tapered instrument tip. With the latter, a so-called passive ultrasonic irrigation – without mechanical treatment of the canal wall – can be performed. This involves the insertion of the attachment tip into the root canal which is filled with irrigation solution, if possible, up to about 1–2 mm before the working length. The tip is then activated for 20 sec without any additional vertical movement. The greatest effect is achieved when the file can oscillate in the root canal as freely as possible. Limitations arise from the curvature and dimensions of the root canal. Passive ultrasonic activation of the irrigation solution is usually recommended as part of the final irrigation after the root canal has been shaped.

Under favorable conditions, the described effects, namely cavitation and "acoustic streaming", occur. Through the oscillation of the file in a plane with at least 20,000 Hz, so-called nodes and antinodes are created, which set the irrigation liquid in motion. Such high localized fluid movements are produced that these can contribute significantly to the removal of debris and pulp tissue. Another consequence, especially at the end of the freely oscillating instrument tip, is cavitation. This process produces small bubbles that increase in size in a very short time, which then immediately implode again. The resulting pressure waves accelerate the irrigation medium towards the root canal walls. Noteworthy is that the maximum input occurs in the plane of oscillation (parallel to the orientation of the contra-angle handpiece). This is a relevant consideration when cleaning the isthmus between the mesiobuccal and distobuccal root canals of lower molars for example. In this case, the tip should be rotated slowly during the activation phase. There can be clinical limitations to this, however, because the contra-angle handpiece cannot be rotated as desired in the patient's mouth.

In principle, "non-cutting" tips are preferable (Fig. 2). Given that an

Standard irrigation medium	NaOCl (normally 1–3 %)	
during RC preparation:	using a 5 ml syringe and a conventional cannula (Luer-Lock-system)	at least 1 ml => after each hand instrument => for rotary instruments after 3 "pecks" or after retraction of the instrument due to "jamming" (increased resistance)
after final RC preparation:		
removal of the smear layer:	with EDTA (15–17 %) or citric acid (20 %)	
activation of NaOCl:	using an ultrasonic-activated tip or using Eddy: 3 x 20 sec (with renewal of the irrigation solution) or continuously 60 sec per canal	

Table 1 Possible irrigation protocol (RC = root canal)
(Fig. 1–5 and Tab. 1: R. Weiger)

intermittent contact between the tip and the canal wall is usually unavoidable in everyday clinical practice, these tips do not remove root dentin on contact with the wall and do not create legdes. Improper use can also lead to the fracture of the ultrasonic tip in the root canal. Only in very wide and straight root canals, e.g. in frontal teeth with wide open foramen, can the tip be placed "centrally" in the root canal – without contact with the canal wall; the tip can then swing freely with maximum energy input given that the practitioner's hand remains steady. However, even in root canals with a smaller apical preparation of 20/04, ultrasonic-activated irrigation has a beneficial effect on the removal of residual pulp, as shown in the study by Lee et al. [13].

The above mentioned explanations make it clear that the handling of the ultrasonic tip has an influence on the cleaning result. However, detailed information on this topic is rarely found in investigations that are performed mostly in vitro.

In a recent systematic review on the effect of ultrasonic-activated irrigation, a total of 45 in vitro studies and 3 clinical studies were analyzed [2]. The experimental work focused on the parameters of pulp tissue and debris removal as well as antimicrobial effect. With regard to the removal of pulp tissue and debris, ultrasonic-activated irrigation proved to be superior to conventional irrigation in the majority of the studies that were ultimately analyzed. Whether ultrasonic activation has an additional antibacterial effect on the microorganisms in the root canal system cannot be proven. The authors of this systematic review limit the evaluation of the summary results to a low evidence level [2]. The same conclusion was reached in another review published in 2018 which included 5 investigations in a meta-analysis [16]. In contrast, Nagendrababu et al. [17] conclude from their review that the reduction of the microbial load is more pronounced after the use of ultrasound compared to other methods. Recent in vitro studies from 2019 and 2020 confirm that positive effects are attributable to ultrasonic activation with regard to debris removal [7, 18, 22], penetration depth of the irrigation solution [8, 12] and pulp tissue removal [27]. Compared to manual irrigation, a higher chemical conversion rate of sodium hypochlorite by ultrasonic activation can be observed [9].

The GentleWave system (Sonendo Inc, Laguna Hills, CA, USA) was shown to be superior to ultrasound in terms of debris removal in the isthmus area [3]. GentleWave is not commercially available in Europe.

Only one clinical study which examined the healing of apical periodontitis in association with activated irrigation met the inclusion criteria from 2 reviews [2, 24]. This randomized study showed no significant differences between manual and ultrasonic-activated irrigation [14]. In the study, apical lesions of single-rooted teeth with mostly straight root canals were evaluated 10 to 19 months after root canal treatment based on DVT imaging. Although there was no statistically significant difference based on a significance level of alpha = 0.05, closer examination revealed evidence in favor of ultrasonic-activated irrigation with a healing rate of 95.1 % (39 of 41 teeth) vs. 88.4 % (38 of 43 teeth) with the conventional irrigation technique.

Sound-activated irrigation methods

The special sound-activated tips oscillate in the root canal with a frequency in the upper audible sound range (16–20,000 Hz). EndoActivator (Dentsply Sirona) (Fig. 3) and Eddy (VDW, Munich) (Fig. 4) are typical representatives of this group.

An Eddy is a sound-activated polyamide tip that is screwed in an Airscaler attachment. In addition to being highly flexible, the narrow, flexible plastic tip can be pushed forward as far as possible into the root canal and can be used for cleaning in almost all phases of root canal preparation. When it comes in contact with a wall, no undesirable dentin removal occurs. It is questionable whether the effects, cavitation and "acoustic streaming", are actually achieved in the root canal with the maximum frequency of 6,000 Hz generated by the Eddy tip. The frequency range covered is clearly below the required frequency of at least 14,000 Hz (see ultrasound). Theoretically, the maximum amplitude of about 350 mm that is achieved by the plastic tip requires an apically prepared root canal up to ISO 100, so that the tip can oscillate freely and the energy input into the irrigation solution is at its maximum. Nevertheless, current experimental studies on root canals that have been prepared up to an apical size of 40.06 show that the effect on adjacent dentin wall areas after sound activation with the Eddy tip corresponds to root canals that have been irrigated with ultrasound or laser [8].

Eddy proved to be as effective as the passive ultrasonic irrigation technique for removing the debris and smear layer [26]. Both methods have a comparable effect in terms of reducing the number of bacteria in the root canal [18]. Eddy also supports the removal of calcium hydroxide; it performed better than the Endoactivator (Dentsply Sirona, York, PA; USA) which is also based on the principle of sound activation [15]. The manufacturer of the Endoactivator, which provides flexible attachable polymer tips in sizes 15.02, 25.04 and 35.04, recommends additional pumping movements. In vitro, irrigation solutions penetrate into the surrounding apical dentin after application of the Endoactivator as far as laser or ultrasound-supported procedures [8]. In contrast, Varela et al. 2019 [27] report that, after rotary preparation with 25/08, the pulp tissue remains in the apical region to a greater extent when the Endoactivator is used as compared to passive ultrasound application.

Laser-activated irrigation methods

Laser light can be introduced into the liquid-filled root canal via narrow fiber optic light tips. The effect depends largely on the wavelength generated by the respective laser system, the energy density and the absorption of the hard and soft tissues that are being exposed.

The light emitted by an infrared laser is completely absorbed by water-based solutions. At the aperture of the laser tip, cavitation occurs in the irrigation medium. Pulsed lasers produce additional small bubbles through the cavitation process, which trigger "acoustic streaming" in the irrigation solution. The PIPS system (Photon Initiated Photoacoustic Streaming) represents a modern method for laser-induced activation which uses an Erbium-YAG laser with low pulse energy (10–20 mJ) and short pulse length (50 µs) (Fig. 5). A further development which makes use of an adaptive pulse mode is the SWEEPS system (Shock Wave Enhanced Emission Photoacoustic Streaming).

The tip is placed in the pulp chamber at the root canal entrance. The "primary" arising air bubbles collapse; this produces shock waves that strike against the canal wall at high speed as well as additional "secondary" bubbles. The shear forces that are generated act on tissue residues, biofilm and the smear layer and they should contribute to cleaning of the root canal system. With regard to the removal of debris in the isthmus area, PIPS proves to be equivalent to ultrasonic-activated irrigation and conventional laser-activated irrigation [28]. In the latter case, the tip is advanced into the root canal as deep as the dimensions of the optic fiber and the prepared root canal permit. PIPS completely removed calcium hydroxide from artificially created depressions in the root canal, whereas after the use of ultrasound and EndoActivator, there was evidence of residues [1]. In terms of the penetration depth of the irrigation solution and debris removal, no advantages of SWEEPS over PIPS could be demonstrated. However, in this respect, both methods were superior to conventional irrigation with a cannula [8, 20].

Photo-activated disinfection (PAD) requires the addition of a dye such as methylene blue. The dye adheres to cell walls and is apparently effective against Gram-positive and Gram-negative bacteria after activation in the red light range (diode laser). A reliable comparison with the other methods is not possible because valid studies are not currently available.

Closing considerations

The explanations found in literature regarding the possible "side effects" are limited. With regard to the frequency of postoperative pain, based on 6 clinical studies, Decurcio et al. [6] concluded that on days 1 and 2 after root canal treatment, symptoms occur less frequently when using "machine-supported" root canal irrigation as compared to conventional irrigation.

Since the advantages of a defined irrigation protocol with respect to the activation of the irrigation solution could not be proven in comparative clinical studies so far, at least from valid experimental investigations, different approaches regarding the activation methods can be justified. The author shares the view of Virdee et al. 2018 [29], which on the one hand, describes the 16 publications included in the meta-analysis as heterogeneous, while on the other hand, based on the results of the investigations, derives a recommendation for the use of activated irrigation techniques. An irrigation protocol which is widely applied in practice for activation is outlined in Table 1 for guidance. In principle, the recommendations of the device manufacturer should be respected when performing irrigation. In clinical use, the effect of an activated root canal irrigation depends on other factors such as the type and concentration of the irrigation medium, penetration depth, contact time and volume of the irrigation solution used [28].

Conflicts of Interest

The author declares that there is no conflict of interest within the meaning of the guidelines of the International Committee of Medical Journal Editors.

References

1. Arslan H, Akcay M, Capar ID, Saygili G, Gok T, Ertas H: An in vitro comparison of irrigation using photon-initiated photoacoustic streaming, ultrasonic, sonic and needle techniques in removing calcium hydroxide. Int Endod J 2015; 48: 246–251

2. Căpută PE, Retsas A, Kuijk L Chávez de Paz LE, Boutsioukis C: Ultrasonic irrigant activation during root canal treatment: a systematic review. J Endod 2019; 45: 31–44

3. Chan R, Versiani MA, Friedman S et al.: In vitro efficacy of 3 supplementary

irrigation protocols in the removal of hard tissue debris from the mesial root canal system of mandibular molars. J Endod 2019; 45: 923–929

4. Chubb DWR: A review of the prognostic value of irrigation on root canal treatment success. Aust Endod J 2019; 45: 5–11

5. Connert T, Truckenmüller M, ElAyouti A et al.: Changes in periapical status, quality of root fillings and estimated endodontic treatment need in a similar urban German population 20 years later. Clin Oral Investig 2019; 23: 1373–1382

6. Decurcio DA, Rossi-Fedele G, Estrela C, Pulikkotil SJ, Nagendrababu V: Machine-assisted agitation reduces postoperative pain during root canal treatment: a systematic review and meta-analysis from randomized clinical trials. J Endod 2019; 45: 387–393

7. De-Deus G, Belladonna FG, de Siqueira Zuolo A et al.: In vitro Micro-CT comparison of XP-endo Finisher and passive ultrasonic irrigation as final irrigation protocols on the removal of accumulated hard-tissue debris from oval shaped-canals. Clin Oral Invest 2019; 23: 3087–3093

8. Galler KM, Grubmüller V, Schlichting R et al.: In vitro penetration depth of irrigants into root dentine after sonic, ultrasonic and photoacoustic activation. Int Endod J 2019; 52: 1210–1217

9. Gołąbek H, Borys KM, Kohli MR, Brus-Sawczuk K, Strużycka I: In vitro chemical aspect of sodium hypochlorite activation in obtaining favorable outcomes of endodontic treatment: An in-vitro study. Adv Clin Exp Med 2019; 28: 1311–1319

10. Grahnén H, Hansen L: The prognosis of pulp and root canal therapy. Odontologisk Revy 1961; 12: 146–165

11. Hülsmann M, Peters OA, Dummer PHM: Mechanical preparation of root canals: shaping goals, techniques and means. Endodontic Topics 2005; 10: 30–76

12. Iandolo A, Abdellatif D, Amato M et al.: Dentinal tubule penetration and root canal cleanliness following ultrasonic activation of intracanal-heated sodium hypochlorite. Aust Endod J 2020; 46: 204–209

13. Lee OYS, Khan K, Li KY et al.: Influence of apical preparation size and irrigation technique on root canal debridement: a histological analysis of round and oval root canals. Int Endod J 2019; 52: 1366–1376

14. Liang YH, Jiang LM, Jiang L et al.: Radiographic healing after a root canal treatment performed in single-rooted teeth with and without ultrasonic activation of the irrigant: a randomized controlled trial. J Endod 2013; 39: 1218–1225

15. Marques-da-Silva B, Alberton CS, Tomazinho FSF et al.: In vitro effectiveness of five instruments when removing calcium hydroxide paste from simulated internal root resorption cavities in extracted maxillary central incisors. Int Endod J 2020; 53: 366–375

16. Moreira RN, Pinto EB, Galo R, Falci SGM, Mesquita AT: Passive ultrasonic irrigation in root canal: systematic review and meta-analysis. Acta Odontol Scand 2019; 77: 55–60

17. Venkateshbabu N, Jayakumar J, Anand S, Senthilnayagam K, Prasanna N: Effectiveness of ultrasonically activated irrigation on root canal disinfection: a systematic review of in vitro studies. Clin Oral Investig 2018; 22: 655–670

18. Neuhaus KW, Liebi M, Stauffacher S, Eick S, Lussi A: Antibacterial efficacy of a new sonic irrigation device for root canal disinfection. J Endod 2016; 42: 1799–1803

19. Ng YL, Mann V, Gulabivala K: A prospective study of the factors affecting outcomes of nonsurgical root canal treatment: part 1: periapical health. Int Endod J 2011; 44: 583–609

20. Passalidou S, Calberson F, De Bruyne M, De Moor R, Meire MA: In vitro debris removal from the mesial root canal system of mandibular molars with Laser-activated irrigation. J Endod 2018; 44: 1697–1701

21. Peters OA, Schönenberger K, Laib A: Effects of four Ni-Ti preparation techniques on root canal geometry assessed by micro computed tomography. Int Endod J 2001; 34: 221–230

22. Rödig T, Sedghi M, Konietschke F, Lange K, Ziebolz D, Hülsmann M: Efficacy of syringe irrigation, RinsEndo and passive ultrasonic irrigation in removing debris from irregularities in root canals with different apical sizes. Int Endod J 2010; 43: 581–589

23. Sjögren U, Hagglund B, Sundqvist G, Wing K: Factors affecting the long-term results of endodontic treatment. J Endod 1990; 16: 498–504

24. Silva EJN , Rover G, Belladonna FG, Herrera DR, De-Deus G, da Silva Fidalgo TK: Effectiveness of passive ultrasonic irrigation on periapical healing and root canal disinfection: a systematic review. Br Dent J 2019; 227: 228–234

25. Topçuoğlu HS, Topçuoğlu G, Arslan H: The effect of different irrigation agitation techniques on postoperative pain in mandibular molar teeth with symptomatic irreversible pulpitis: a randomized clinical trial. J Endod 2018; 44: 1451–1456

26. Urban K, Donnermeyer D, Schäfer E, Bürklein S: In vitro canal cleanliness using different irrigation activation systems: a SEM evaluation. Clin Oral Invest 2017; 21: 2681–2687

27. Varela P, Souza E, de Deus G, Duran-Sindreu F, Mercadé M: In vitro effectiveness of complementary irrigation routines in debriding pulp tissue from root canals instrumented with a single reciprocating file. Int Endod J 2019; 52: 475–483

28. Verstraeten J, Jacquet W, De Moor RJG, Meire MA: Hard tissue debris removal from the mesial root canal system of mandibular molars with ultrasonically and laser-activated irrigation: a micro-computed tomography study. Lasers Med Sci 2017; 32: 1965–1970

29. Virdee SS, Seymour DW, Farnell D, Bhamra G, Bhakta S: Efficacy of irrigant activation techniques in removing intracanal smear layer and debris from mature permanent teeth: a systematic review and meta-analysis. Int Endod J 2018; 51: 605–621

30. Virdee SS, Farnell DJJ, Silva MA, Camilleri J, Cooper PR, Tomson PL: The influence of irrigant activation, concentration and contact time on sodium hypochlorite penetration into root dentine: an ex vivo experiment. Int Endod J 2020; 53: 986–997

31. Weiger R, Hitzler S, Hermle G, Löst C: Periapical status, quality of root canal treatment and estimated endodontic treatment needs in an urban German population. Endod Dent Traumatol 1997; 13: 69–74

32. Zhao Y, Fan W, Xu T, Tay FR, Gutmann JL, Fan B: Evaluation of several instrumentation techniques and irrigation methods on the percentage of untouched canal wall and accumulated dentine debris in C-shaped canals. Int Endod J 2019; 52: 1354–1365

(Photo: Roland Weiger)

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Calcium silicate-based sealers: The end of thermoplastic obturation?

Abstract: All obturation techniques require a certain amount of root canal sealers in order to fill small irregularities along the canal wall. Epoxy resin-based sealers have been the gold standard to date. A more recent development is represented by calcium silicate-based sealers (CSS), which derive from calcium silicate-based cements (MTA). CSS are proven to be biocompatible and bioactive. A hydroxyapatite-like precipitate forms on the surface of CSS when they come in contact with tissue fluid so that these sealers are not recognized as foreign bodies, even in cases of sealer extrusion. After their setting, CSS release OH^- and Ca^{2+} ions over a longer period of time through which they potentially exhibit certain antibacterial effects and support the healing of periapical inflammation. For this reason, consideration has been given to the idea of filling root canals mainly with CSS and minimizing the proportion of gutta-percha. To date, however, no long-term clinical studies have been performed to confirm the advantages of this new concept.

Although gutta-percha has been successfully used for root canal obturation for a very long time, there are different perspectives with regard to which root canal filling technique is better: cold or warm (thermoplastic) obturation. After the exposure of sufficiently filled root canals with saliva, microorganisms always infiltrate into the root canal system regardless of the obturation method. Until now, no known obturation method leads to a bacteria-proof sealing of the root canal. Thus, in terms of clinical success rates, no superiority of the frequently recommended thermoplastic root canal filling technique compared with cold lateral compaction could be demonstrated.

As a rule, CSS are not approved for thermoplastic obturation, as these sealers are water-based; there is the concern that high temperatures of up to 200 °C will remove too much water from the sealer, which can have a negative impact on its properties. It is questionable whether such high temperatures are clinically achieved during thermoplastic obturation.

A disadvantage of CSS is their higher solubility compared to epoxy resin sealers. In the long term, this can lead to the dissolution of the root canal filling. In the studies that have been performed to date, however, no difference in the clinical success rates between epoxy resin sealers and CSS has been determined. Overall, CSS represent an interesting alternative to conventional root canal sealers. In principle, the success of a root canal treatment depends not only on the obturation technique, but above all, on the complete removal of the infected tissue, the permanent disinfection of the root canal system and the bacteria-proof post-endodontic restoration.

Keywords: calcium silicate; thermoplastic obturation; root canal filling techniques; root canal sealer

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1. Introduction

Epoxy resin-based sealers such as AH Plus (Dentsply Sirona, Konstanz, Germany) have become the standard material for root canal obturation in case of both cold and warm obturation methods. Currently, they are considered to be the "gold standard" among root canal sealers [26]. However, these sealers have a major disadvantage: they are not bioactive [21]. Moreover, epoxy resin-based sealers show a certain toxicity during setting, but after curing, prove to be virtually insoluble and non-cytotoxic [29, 30]. Thus, extrusion of epoxy sealers does not normally cause harmful reactions of the periapical tissue, except in cases where the sealer is displaced into the mandibular nerve canal, where this root canal filling paste – like all other sealers – has a neurotoxic effect [24].

The latest development in the field of sealers is calcium silicate-based root canal filling pastes. The goal is to make use of the known positive properties, particularly biocompatibility and bioactivity, of calcium silicate-based cements such as Mineral Trioxide Aggregate (MTA; e.g. ProRoot MTA, Dentsply Sirona, Ballaigues, Switzerland; MTA-Angelus, Angelus, Londrina, Brazil) or Biodentine (Septodont, Saint-Maur-des-Fossés, France) for conventional orthograde root canal fillings. The main components are di- and/or tricalcium silicates, which is why these root canal filling pastes are also referred to as "calcium silicate-based sealers" (CSS) [14] (Fig. 1 and 2). Often, the term "bioceramic" is used incorrectly in context with these calcium silicate-based sealers [50]. More specifically, these sealers can be considered "hydraulic" because they set in contact with both air and water [5]. CSS even require water to set completely. In contrast to conventional sealers, calcium silicate-based sealers do not require that the root canal lumen is as dry as possible in order to ensure optimal setting conditions. The setting properties of CSS are not affected by the presence of residual moisture in the root canal [16].

Figure 1 Calcium silicate-based sealers (CSS) can be divided into 2 dosage forms: premixed, one-component ready-to-use CSS in syringes and two-component CSS made of powder and water or 2 pastes, which need to be mixed before use. An example of a one-component MTA-based sealer containing calcium silicate (EndoSeal MTA; Maruchi, Wonju, Korea) for direct application into the root canal.

Calcium hydroxide is formed during the setting of CSS, which is known to trigger biological healing processes [10, 49]. CSS are therefore bioactive. In contact with simulated body fluid, the formation of a hydroxyapatite-like surface has also been reported for CSS [36, 45]. Since this layer does not cause a foreign body reaction, CSS can be considered biocompatible, even when they are extruded at the apex or when they come in contact with periapical tissues.

In comparison to other root canal sealers, CSS are thus biocompatible and bioactive [29, 30] (Fig. 3 and 4). In terms of biocompatibility and bioactivity, CSS are clearly superior to other sealers, which can be advantageous for the treatment outcome [16]. For this reason, consideration has been given to deviate from the previous treatment concept of "as much gutta-percha and as little sealer as possible", and instead, to fill root canals mainly (but not exclusively) with CSS. Gutta-percha should only be introduced into the root canal using the single cone technique – regardless of the fit – in order to make the most of the biological effects of CSS. However, long-term clinical studies are not yet available to confirm the advantages of this new concept.

The aim of this review article is to elucidate the new CSS within the framework of the various root canal filling techniques that employ gutta-percha such as the single cone, lateral compaction and thermoplastic obturation as well as to present the current state of research.

2. Gutta-percha

Gutta-percha has been successfully used for root canal obturation for well over 120 years. The material is virtually insoluble, inert, biocompatible, has a weak antibacterial effect due to its zinc oxide content, can be cold and warm processed, condensable and dimensionally stable. Although gutta-percha is not perfect for obturation, it is still the material of choice for most root canal fillings [11]. However, it is still controversially discussed as to which root canal filling technique is preferable, particularly with regard to cold versus warm (thermoplastic) obturation with gutta-percha [27]. There is general agreement that all obturation techniques require a certain amount of root canal sealer in order to fill small irregularities along the root canal wall, or more specifically, the lateral or accessory canals and the exposed dentinal tubules, so as to ensure a better adaptation of the gutta-percha to the canal walls. Also, a tight seal between gutta-percha and canal walls is pursued [27]. In performing this, the amount of sealer should be as low as possible. Many commercially available root canal sealers can be used as long as they are (virtually) insoluble, biocompatible (or at least well tolerated by the tissue) in addition to being non-resorbable and non-shrinking during setting [11].

Figure 2 Example of a two-component calcium silicate-based sealer consisting of powder and water (BioRoot RCS; Septodont, Saint-Maur-des-Fossés, France). For powder and water-based sealers, the consistency can be adjusted to match the clinical situation.

3. Cold obturation technique

3.1 Single cone technique

A distinction is made between the single-cone and lateral compaction techniques when performing cold root canal fillings. The goal of the single-cone technique is to insert a precisely fitting gutta-percha cone in combination with a sealer into the root canal in such a way that the entire canal is densely filled. The areas of the root canal where the gutta-percha cone is not marginally adapted should be filled by the sealer [11, 39]. The principal disadvantage of the single-cone technique is that the proportion of sealer in the root canal filling is comparatively high for all root canals which do not exactly match the conical shape of the gutta-percha cone after root canal preparation. Due to the possible shrinkage of some root canal sealers during the setting reaction, a maximum possible proportion of gutta-percha is considered an important factor for successful root canal treatment [32, 48]. Higher proportions of sealer can lead to leakage and bacterial infiltration [6], and thus, impair the success of root canal treatment [4, 15]. This is especially a problem in root canals with an oval root canal shape where a circular preparation cannot be attained [11, 39]. Root canals which have been prepared using manual preparation techniques are also not suitable for the single-cone technique because the shape of the prepared root canal and the gutta-percha cone differ too greatly. Thus, a requirement when using the single-cone technique is the uniform and conical root canal preparation with rotary nickel-titanium instruments; the cone should correspond to the shape of the last instrument used for root canal preparation as closely as possible. This reduces the amount of sealer required. Furthermore, another disadvantage of the single-cone technique is that no compaction of the filling material takes place and irregularities in the canal wall and side canals may not be adequately filled [39]. This means that it is possible for irregular root canal sections or root canal areas, which cannot be reached by mechanical instrumentation, to remain unfilled. Also, air inclusions can arise in the sealer.

3.2 Lateral Compaction

In order to densely and completely fill oval or manually prepared root canals with as much gutta-percha and as little sealer as possible, the goal of lateral compaction is to apply smaller accessory gutta-percha cones into the root canal in addition to the master cone. For this purpose, the cold gutta-percha cone which is already in the root canal is laterally pressed with a finger spreader and compacted into the root canal cross-section to create space for more gutta-percha cones. However, one complication of lateral compaction can be vertical root fractures which are caused by the force applied with the finger spreader. Whether lateral compaction is actually associated with an increased risk of longitudinal fractures when the force is appropriately applied, has not yet been conclusively elucidated. The application of too much force should nevertheless be avoided [27]. Conversely, it is questionable if sufficient sealer is pressed into all areas of the root canal when too little force is applied.

4. Warm (thermoplastic) obturation techniques

Due to the disadvantages of cold root canal filling techniques, warm thermoplastic obturation techniques were recommended to increase the amount of gutta-percha in the filling. Ideally, using this technique, the entire root canal system, including the accessory canals and apical ramifications, can be filled with gutta-percha instead of just sealer. Since the root canal filling is performed under pressure, the heated and thus liquefied gutta-percha is pressed into the side canals in a more or less controlled manner [22, 40]. It is easier, faster and safer to fill wide lumen or irregularly-shaped root canal systems using thermoplastic root canal filling techniques. Even for complex root canal anatomies (e.g. deep branching of root canals) or root canals with a very irregular cross-section (e.g. c-shaped canals; internal granuloma), thermoplastic obturation seems to have a clear advantage [27].

When using the "Continuous Wave Technique" according to Buchanan, a temperature of 200 °C is generally recommended when heating the gutta-percha cone. The applied sealer should therefore be compatible with the thermoplastic obturation and remain stable at the temperature interval used, as this can otherwise lead to chemical deterioration or more serious changes in the material's properties. Conceivable consequences are the clumping together of the sealer or premature or absent setting [27]. In literature, there is controversy regarding which sealer groups are compatible with thermoplastic obturation techniques. For example, it was recommended that sealers containing epoxy resin should only be subjected to a maximum temperature of 100 °C. Otherwise, chemical changes can occur. In contrast, CSS continue to be chemically stable up to 125 °C even if they are not approved by the manufacturers for warm filling techniques. In comparison, sealers containing zinc oxide eugenol are not thermostable at all [3]. In another study, it was also determined that epoxy resin-based sealers are not compatible with thermoplastic obturation techniques – this is in contrast to calcium hydroxide-based sealers [9]. On the other hand, other authors could not find any significant physical or chemical changes in epoxy resin or zinc oxide-eugenol-based sealers through heat treatment [18].

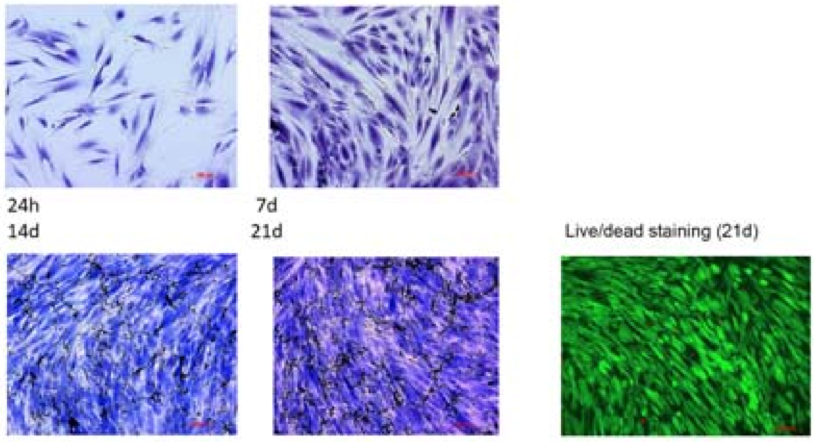

Figure 3 Human osteoblasts after direct contact with an eluate of BioRoot RCS and after up to 21 days in vitro. In the BioRoot RCS group, all osteoblasts survived contact with a 1:2 dilution of the extract and significant cell proliferation was observed. This speaks for the biocompatibility and bioactivity of CSS (Richardson staining and live (green)/dead (red) staining; magnification x 100) [30].

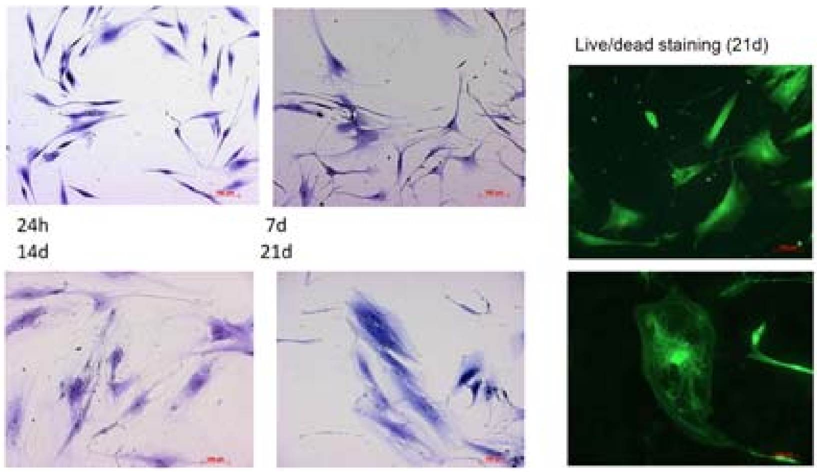

Figure 4 In the AH Plus group (Dentsply Sirona, Konstanz, Germany), almost all human osteoblasts died in the first days after addition of the sealer extract in a 1:10 dilution. In the Richardson stain and the life/death stain, only a few cells were visible after 14 and 21 days, respectively. In contact with AH Plus, the morphology of the osteoblasts was altered; they are enlarged due to a longer incubation time (days 14 and 21; magnification x 100) [30].

5. Cold vs. warm obturation techniques

Whether thermoplastic filling techniques do indeed lead to improved success rates in comparison to the single-cone or lateral compaction techniques is controversially discussed in literature. One study reported a 10 % higher thermoplastic obturation success rate in cases of apical periodontitis in comparison to (cold) lateral compaction [20], although not many studies substantiate this finding, and instead, they show that there is no difference [11]. According to a meta-analysis, cold lateral compaction and thermoplastic root canal filling techniques can be considered equivalent in terms of success rates [35]. Ten clinical studies, 9 of which were randomized, were included in this meta-analysis, where 1748 previously untreated teeth were either obturated using cold lateral compaction or thermoplastically

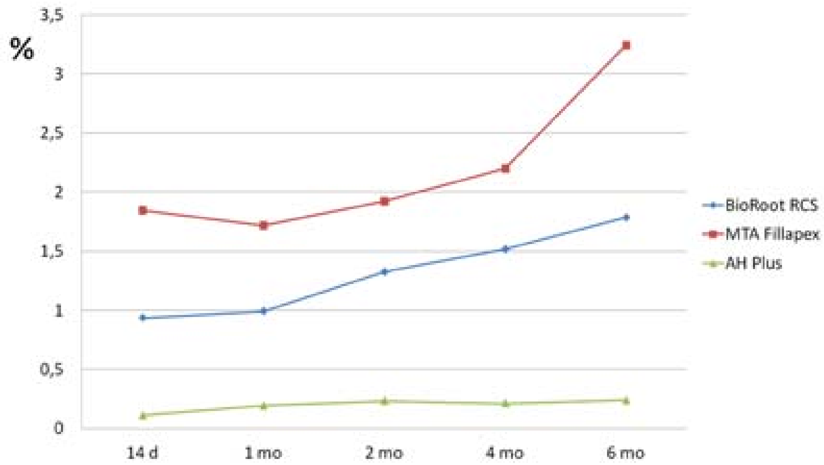

Figure 5 Solubility of BioRoot RCS, MTA Fillapex (Angelus, Londrina, Brazil) and AH Plus in phosphate-buffered saline (PBS) to simulate body fluid The solubility of CSS BioRoot RCS and MTA Fillapex was significantly increased compared to AH Plus. However, the solubility of BioRoot RCS did meet the ISO 6876:2012 requirements of less than 3 % over a 6-month period [45].

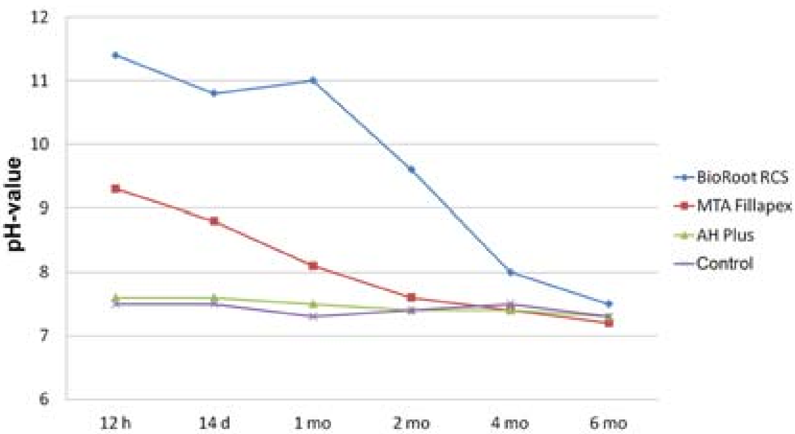

Figure 6 pH values of BioRoot RCS, MTA Fillapex and AH Plus in phosphate buffered saline (PBS) to simulate body fluid. BioRoot RCS maintains a basic pH in phosphate buffered saline for up to 4 months in vitro. This can be explained by the release of OH^- ions from the sealer (control = PBS without sealer) [45].

using warm gutta-percha. An evaluation was performed over a period of 1–5 years. While both methods – cold lateral compaction and thermoplastic obturation – showed statistically similar levels of postoperative complaints, long-term results and filling quality, thermoplastic obturation frequently resulted in significantly more extrusion of the root canal filling material [35].

6. Bacteria-proof root canal fillings

In principle, microleakage compromises the result and success of every root canal treatment [6]. Thus, a root canal filling that is as bacteria-proof as possible is desirable. Yet, no root canal filling technique, neither warm nor cold, has so far been able to achieve a reliable bacteria-proof obturation of the root canal system [31, 41]. After appropriately filled root canals are exposed to saliva, microorganisms penetrate into the root canal system. Within a period of 3–60 days, an exposed root canal filling made of gutta-percha and sealer, which is exposed to the oral environment, exhibits microbial leakage along the root canal filling regardless of the obturation method [31, 41].

Not only bacteria, but also endotoxins are able to penetrate into root canal fillings and produce an inflammation of the periapical tissue. Endotoxins are part of the outer cell membrane of Gram-negative bacteria and are released when these bacteria decompose. Endotoxins may penetrate the root canal filling material faster than bacteria and may trigger an apical inflammatory response [1]. Based on numerous evidence-based studies available to date, it can thus be concluded that the seal of the post-endodontic coronal restoration is just as important for the success of a root canal therapy as the actual root canal filling itself. There is no significant difference between the two factors with regard to the healing chance after root canal treatment [23]. Coronal leakage is considered one of the main causes endodontic treatment failure [1]. Leakage of the coronal restoration is therefore the most likely explanation for the recurrence of apical periodontitis [37] and not the type of root canal filling technique applied and how high the proportion of sealer is.

7. Solubility of calcium silicate based sealers

When weighing the advantages and disadvantages of the various root canal filling techniques that have been presented above, and the idea of deviating from the postulate of "as much gutta-percha and as little sealer as possible" in the case of CSS, an aspect requiring closer examination emerges: although sealers containing epoxy resin are considered nearly insoluble, the solubility of CSS is significantly higher than that of AH Plus for example [36, 45]. This can negatively affect the treatment concept "as much sealer and as little gutta-percha as possible".

According to the ISO 6876:2012 standard, the decrease in sealer weight should be less than 3 % during the initial 24 hours after storage in double-distilled water [28]. Higher solubility has been reported in some studies performed on CSS BioRoot RCS and iRoot SP. Conversely, other publications on iRoot SP, BioRoot RCS, Endoseal MTA and Endo C.P.M. sealer confirm a solubility of less than 3 %. Overall, the data found in literature that relates to this topic has been inconsistent so far [16].

Figure 7 Radiograph after root canal filling with gutta-percha and BioRoot RCS on tooth 16 (cold, lateral compaction).

Figure 8 Radiograph showing apical healing at the mesial root 6 months after root canal treatment on tooth 16.

(Fig. 1–8: T. Dammaschke)

The solubility is in large part dependent on the storage medium. In double-distilled water (as specified in ISO 6876:2012 [28]), the solubility of CSS is significantly higher than in simulated body fluid (phosphate-buffered saline, or PBS) [36, 45]. A long-term study showed that the solubility of a CSS (BioRoot RCS) also met the requirements of ISO 6876:2012 over a period of 6 months when stored in PBS [45] (Fig. 5).

Owing to its solubility, the volume of the CSS decreases within 7 days after being stored in distilled water and PBS. However, no significant difference in void formation was observed between CSS and AH Plus during the storage period [44]. All sealers have voids after root canal filling regardless of the type of sealer used [34]. Although TotalFill BC-Sealer (FKG Dentaire, La Chaux-de-Fonds, Switzerland) has a higher solubility than AH Plus, this CSS showed volumetric stability when evaluated by micro-computer tomography (micro-CT) [43].

In principle, however, the solubility of CSS seems to be associated with a positive biological result due to the release of ions from the sealer [50]. The solubility of the sealers is therefore a double-edged sword. This is because, on the one hand, sealers should be as insoluble as possible in order to tightly seal the root canal for years. On the other hand, it is known that in order to attain bioactive and biocompatible effects, ions from the sealers must dissolve in the surrounding tissue. It is recognized that even in conditions that simulate body fluids in vitro, CSS have high levels of Ca^{2+} and OH^- ion release. But, also silicon ions are released [7, 10, 49]. All of these ions are known to contribute to the healing of apical lesions.

The release of OH^- ions also leads to a basic pH value in vitro for a period of up to 4 months [45] (Fig. 6). This may explain the proven antimicrobial effects of CSS [33, 47, 51]. For example, Endosequence BC-Sealer and BioRoot RCS are effective against E. faecalis, both directly after application and in the set state [8, 33]. CSS are also active against many other microorganisms in the root canal [16]. The antibacterial effect is enhanced through their contact with dentin [8, 47].

With respect to the apical sealing capacity of CSS, the data found in literature has been contradictory so far. Compared to conventional sealers, the new CSS have been certified to have a comparable or even better apical sealing capacity. Conversely, other studies found significantly increased apical microleakage [16]. During the setting process, CSS interact with the surface of root canal wall dentin and this process can continue for months. To what extent this reduces the solubility of a CSS over time and lead to an improvement in the sealing of the root canal can be speculated [42]. Yet, a matter of concern is that, due to a possible dissolution process of the CSS, especially in the apical third, a recolonization with microorganisms can occur and this can subsequently contribute to a reinfection of the root canal system.

The voids that are formed in the apical region when sealer dissolution occurs can lead to a recolonization by microorganisms. In principle, this can happen in 3 ways: 1. penetration of microorganisms from coronal regions, 2. persistence of microorganisms in the apical region (biofilm in the root canal), 3. reinfection with, for example, biofilm outside of the canal or infected soft tissue.

8. Calcium silicate-based sealer und thermoplastic obturation

In order to avoid the issue of CSS solubility and keep the proportion of sealer as low as possible, one could be inclined to employ thermoplastic obturation methods. However, most CSS have not yet been approved by manufacturers for warm root canal filling techniques because CSS require moisture for setting and thermoplastic obturation could remove too much moisture from them. This could compromise the material's properties [9, 27].

After heating BioRoot RCS to over 100 °C, water loss and an irreversible change in the chemical structure of the material have been reported. Moreover, reversible changes in the chemical structure of iRoot SP after heating above 125 °C have been described [3]. In another study, the chemical or physical properties of iRoot SP were not affected by heat treatment [12]. However, the type and duration of heat application differed between the studies. But, precisely the type and duration of heat application could influence the results of such in vitro studies [3, 18, 46]. The simulation of heat treatment should reflect the clinical situation as closely as possible in order to obtain results with clinical relevance. Thus, intracanalicular temperatures and clinically relevant heating times should be considered when investigating the effect of thermal treatment on sealers during thermoplastic obturation [17].

In this respect, it is questionable whether these high temperatures in the range of 100–200 °C can be achieved during thermoplastic obturation of the root canal. In a recently published in vitro study, the highest measured temperature using the "Continuous Wave Technique" was 56 °C and this likely has little influence on the sealer [17]. In summary, information regarding the effect of clinically relevant temperatures on CSS is limited.

Only one product, Sealer Endosequence BC Sealer HiFlow (Brasseler USA, Savannah, USA), that is also sold as Total Fill BC Sealer HiFlow (FKG Dentaire) is recommended for thermoplastic obturation of the root canal. According to the manufacturer, this sealer should only be used in combination with low melting gutta-percha. In the only study to date which heated BC Sealer HiFlow accordingly, its chemical composition was not changed through thermal treatment. Also, the flow rate, film thickness and setting time were not clinically affected [12].

9. Clinical studies on calcium silicate-based sealers

Since their introduction onto the market in 2007, CSS have been tested numerous times in vitro and they show positive results. This confers them a promising perspective for future clinical applications. Yet, there have been relatively few clinical studies on CSS [19]. In a randomized, controlled trial using 114 teeth, no significant difference in postoperative pain was found between the conventional AH Plus Sealer and the CSS Total Fill BC Sealer. Root canal fillings without sealer extrusion rarely lead to postoperative pain. The choice of sealer has no influence on the likelihood of complaints [25]. A further study obtained comparable results. The results also showed that there was no significant difference between the AH Plus and iRoot SP groups with regard to the incidence of postoperative pain. However, painkiller medication was consumed significantly more frequently after root canal treatment when AH Plus Sealer was used as compared to when iRoot SP Sealer was used [2].

Root canal fillings using the single-cone technique in combination with Endosequence BC Sealer can achieve high success rates. After a 30-month average follow-up period, 90.9 % of root canal treatments were evaluated as being successful; 83.1 % of the cases were classified as healed and 7.8 % as healing. In 47.4 % of cases, sealer extrusion occurred, although this did not have a significant effect on the success of treatment [13]. In a direct comparison between the single-cone technique using CSS (BioRoot RCS) and warm vertical compaction using an epoxy-based sealer (AH Plus), no significant difference in success rates was observed after one year. Based on CBCT imaging, success rates of 80 % using AH Plus (warm vertical compaction) and 84 % for BioRoot RCS (single-cone technique) were determined. Periapical radiographs showed success rates of 89 % (AH Plus) and 90 % (BioRoot RCS). This difference was not statistically significant. In view of these results, the authors see a clinically validated justification that advocates for the use of the single-cone technique with CSS, even though the study was non-randomized [50].

10. Conclusion

Although there are insufficient studies regarding their long-term clinical success, CSS have become a relevant alternative to epoxy-based sealers. The validity of clinical studies available to date should certainly be viewed with caution due to their short follow-up periods. However, there is a clear tendency for root canal treatment with CSS to be successful [19] – even with the single-cone technique and without thermoplastic obturation (Fig. 7 and 8).

In a micro-CT analysis, the obturation quality of two filling methods was compared: the single-cone technique with the CSS EndoSequence BC and thermoplastic obturation with AH Plus sealer. No significant difference in filling volume and voids was observed. Using both filling methods, a comparable root canal filling quality could be achieved. Neither one of the two methods in combination with its respective sealer was able to fill the root canal system completely [38].

Due to their biocompatibility and bioactivity, CSS in combination with cold obturation methods represent an alternative to thermoplastic obturation methods. However, the question of whether cold or warm obturation is the better technique when CSS are used remains unanswered.

CSS will probably not lead to the end of thermoplastic obturation methods. However, according to current data, it must be mentioned that thermoplastic obturation methods are not entirely necessary for successful endodontic treatment.

In principle, it is worth considering that the success of root canal treatment and the healing of inflammatory processes is not only associated to the obturation technique, but also directly to the sufficient removal of infected tissue, microorganisms and their toxins along with the correct disinfection of the root canal system, as well as a bacteria-proof restoration of the endodontically treated tooth.

Conflicts of interest

Till Dammaschke states that he received honoraria from Septodont for lectures.

References

1. Alves J, Walton R, Drake D: Coronal leakage: endotoxin penetration from mixed bacterial communities through obturated, post-prepared root canals. J Endod 1998; 24: 587–591

2. Atav Ates A, Dumani A, Yoldas O, Unal I: Post-obturation pain following the use of carrier-based system with AH Plus or iRoot SP sealers: a randomized controlled clinical trial. Clin Oral Investig 2019; 23: 3053–3061

3. Atmeh AR, Hadis M, Camilleri J: Real-time chemical analysis of root filling materials with heating: guidelines for safe temperature levels. Int Endod J 2020; 53: 698–708

4. Bachicha WS, DiFiore PM, Miller DA, Lautenschlager EP, Pashley DH: Microleakage of endodontically treated teeth restored with posts. J Endod 1998; 24: 703–708

5. Berzins DW: Chemical properties of MTA. In: Torabinejad M (ed): Mineral trioxide aggregate. Properties and clinical applications. Wiley Blackwell Publishing, Hoboken, New Jersey 2014, 17–36

6. Bogen G, Kuttler S: Mineral trioxide aggregate obturation: a review and case series. J Endod 2009; 35: 777–790

7. Borges RP, Sousa-Neto MD, Versiani MA et al.: Changes in the surface of four calcium silicate-containing endodontic materials and an epoxy resin-based sealer after a solubility test. Int Endod J 2012; 45: 419–428

8. Bukhari S, Karabucak B: The antimicrobial effect of bioceramic sealer on an 8-week matured Enterococcus faecalis biofilm attached to root canal dentinal surface. J Endod 2019; 45: 1047–1052

9. Camilleri J: Sealers and warm gutta-percha obturation techniques. J Endod 2015; 41: 72–78

10. Camps J, Jeanneau C, El Ayachi I, Laurent P, About I: Bioactivity of a calcium silicate-based endodontic cement (BioRoot RCS): interaction with human periodontal ligament cells in vitro. J Endod 2015; 41: 1469–1473

11. Castellucci A: Obturation of the radicular spaces. In: Rotstein I, Ingle JI (ed): Ingle's endodontics. 7th Edition. PMPH USA, Raleigh 2019, 669–727

12. Chen B, Haapasalo M, Mobuchon C, Li X, Ma J, Shen Y: Cytotoxicity and the effect of temperature on physical properties and chemical composition of a new calcium silicate-based root canal sealer. J Endod 2020; 46: 531–538

13. Chybowski EA, Glickman GN, Patel Y, Fleury A, Solomon E, He J: Clinical outcome of non-surgical root canal treatment using a single-cone technique with endosequence bioceramic sealer: A retrospective analysis. J Endod 2018; 44: 941–945

14. Dammaschke T: Sealer auf Kalziumsilikatbasis. Der Freie Zahnarzt 2020; 64: 64–71

15. Davalou S, Gutmann JL, Nunn MH: Assessment of apical and coronal root canal seals using contemporary endodontic obturation and restorative materials and techniques. Int Endod J 1999; 32: 388–396

16. Donnermeyer D, Bürklein S, Dammaschke T, Schäfer E: Endodontic sealers based on calcium silicates: a systematic review. Odontology 2019; 107: 421–436

17. Donnermeyer D, Schäfer E, Bürklein S: Real-time intracanal temperature measurement during different obturation techniques. J Endod 2018; 44: 1832–1836

18. Donnermeyer D, Urban K, Bürklein S, Schäfer E: Physico-chemical investigation of endodontic sealers exposed to simulated intracanal heat application: epoxy resins and zinc oxide-eugenols. Int Endod J 2020; 53: 690–697

19. Donnermeyer D: Literatur-Rundschau: Kalziumsilikat-basierte Wurzelkanalsealer – die klinische Datenlage. Endodontie 2020; 29: 209–216

20. Farzaneh M, Abitbol S, Lawrence HP, Friedman S: Treatment outcomes in endodontics – the Toronto study. Part II: initial treatment. J Endod 2004; 30: 302–309

21. Giacomino CM, Wealleans JA, Kuhn N, Diogenes A: Comparative biocompatibility and osteogenic potential of two bioceramic sealers. J Endod 2019; 45: 51–56

22. Gilhooly RMP, Hayes SJ, Bryant ST, Dummer PMH: Comparison of cold lateral condensation and a warm multiphase gutta-percha technique for obturating curved root canals. Int Endod J 2000; 33: 415–420

23. Gillen BM, Looney SW, Gu LS et al.: Impact of the quality of the cornonal restoration versus the quality of the root canal fillings on success of root canal treatment: a systematic review and meta-analysis. J Endod 2011; 37: 895–902

24. González-Martín M, Torres-Lagares D, Gutiérrez-Pérez JL, Segura-Egea JJ: Inferior alveolar nerve paresthesia after overfilling of endodontic sealer into the mandibular canal. J Endod 2010; 36: 1419–1421

25. Graunaite I, Skucaite N, Lodiene G, Agentiene I, Machiulskiene V: Effect of resin-based and bioceramic root canal sealers on postoperative pain: A split-mouth randomized controlled trial. J Endod 2018; 44: 689–693

26. Hergt A, Wiegand A, Hülsmann M, Rödig T: AH Plus root canal sealer – an updated literature review. Endo (Lond Engl) 2015; 9: 245–265

27. Herrmann H-W, Hülsmann M, Schäfer E: Probleme bei der Wurzelkanalfüllung. In: Hülsmann M, Schäfer E (Hrsg): Probleme in der Endodontie. Prävention, Identifikation und Management. 2. Aufl., Quintessenz Verlag, Berlin 2019, 291–322

28. International Organization for Standardization: International Standard ISO 6876:2012: Dental root canal sealing materials. International Organization for Standardization, Geneva 2012

29. Jung S, Libricht V, Sielker S, Hanisch MR, Schäfer E, Dammaschke T: Evaluation of the biocompatibility of root canal sealers on human periodontal ligament cells ex vivo. Odontology 2019; 107: 54–63

30. Jung S, Sielker S, Hanisch MR, Libricht V, Schäfer E, Dammaschke T: Cytotoxic effects of four different root canal sealers on human osteoblasts. PLoS One 2018; 13: e0194467. doi: 10.1371/journal.pone.0194467

31. Khayat A, Lee SJ, Torabinejad M: Human saliva penetration of coronally unsealed obturated root canals. J Endod 1993; 19: 458–461

32. Kontakiotis EG, Wu M-K, Wesselink PR: Effect of sealer thickness on long-term sealing ability: a 2-year follow-up study. Int Endod J 2003; 30: 307–312

33. Long J, Kreft JU, Camilleri J: Antimicrobial and ultrastructural properties of root canal filling materials exposed to bacterial challenge. J Dent 2020; 93: 103283. doi: 10.1016/j.jdent.2020.103283

34. Milanovic I, Milovanovic P, Antonijevic D, Dzeletovic B, Djuric M, Miletic V: Immediate and long-term porosity of calcium silicate-based sealers. J Endod 2020; 46: 515–523

35. Peng L, Ye L, Tan H, Zhou X: Outcome of root canal obturation by warm gutta-percha versus cold lateral condensation: a meta-analysis. J Endod 2007; 33: 106–109

36. Prüllage RK, Urban K, Schäfer E, Dammaschke T: Material properties of a tricalcium silicate-containing, a mineral trioxide aggregate-containing, and an epoxy resin-based root canal sealer. J Endod 2016; 42: 1784–1788

37. Ricucci D, Siqueira JF Jr.: Recurrent apical periodontitis and late endodontic treatment failure related to coronal leakage: a case report. J Endod 2011; 37: 1171–1175

38. Roizenblit RN, Soares FO, Lopes RT, Dos Santos BC, Gusman H: Root canal filling quality of mandibular molars with EndoSequence BC and AH Plus sealers: a micro-CT study. Aust Endod J 2020; 46: 82–87

39. Schäfer E, Nelius B, Bürklein S: A comparative evaluation of gutta-percha filled areas in curved root canals obturated with different techniques. Clin Oral Investig 2012; 16: 225–230

40. Schilder H: Filling root canals in three dimensions. Dent Clin North Am 1967; 11: 723–744

41. Siqueira JF Jr, Rôças IN, Favieri A, Abad EC, Castro AJ, Gahyva SM: Bacterial leakage in coronally unsealed root canals obturated with 3 different techniques. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2000; 90: 647–650

42. Steffen R, Coray R, Stratigaki E: Mineraltrioxidaggregat und bioaktive Zement in der Kinderzahnmedizin. Quintessenz Zahnmed 2019; 70: 302–314

43. Tanomaru-Filho M, Torres FFE, Chavez-Andrade GM et al.: Physicochemical properties and volumetric change of silicone/bioactive glass and calcium silicate-based endodontic sealers. J Endod 2017; 43: 2097–2102

44. Torres FFE, Zordan-Bronzel CL, Guerreiro-Tanomaru JM, Chávez-Andrade GM, Pinto JC, Tanomaru-Filho M: Effect of immersion in distilled water or phosphate-buffered saline on the solubility, volumetric change and presence of voids within new calcium silicate-based root canal sealers. Int Endod J 2020; 53: 385–391

45. Urban K, Neuhaus J, Donnermeyer D, Schäfer E, Dammaschke T: Solubility and pH value of 3 different root canal sealers: a long-term investigation. J Endod 2018; 44: 1736–1740

46. Viapiana R, Moinzadeh AT, Camilleri L, Wesselink PR, Tanomaru Filho M, Camilleri J: Porosity and sealing ability of root fillings with gutta-percha and BioRoot RCS or AH Plus sealers. Evaluation by three ex vivo methods. Int Endod J 2016; 49: 774–782

47. Wang Z, Shen Y, Haapasalo M: Dentin extends the antibacterial effect of endodontic sealers against Enterococcus faecalis biofilms. J Endod 2014; 40: 505–508

48. Wu M-K, Wesselink PR: A primary observation on the preparation and obturation of oval canals. Int Endod J 2001; 34: 137–141

49. Xuereb M, Vella P, Damidot D, Sammut CV, Camilleri J: In situ assessment of the setting of tricalcium silicate-based sealers using a dentin pressure model. J Endod 2015; 41: 111–124

50. Zavattini A, Knight A, Foschi F, Mannocci F: Outcome of root canal treatment using a new calcium silicate root canal sealer: a non-randomized clincial trial. J Clin Med 2020; 9: 782 doi: 10.3390/jcm9030782

51. Zhang H, Shen Y, Ruse ND, Haapasalo M: Antibacterial activity of endodontic sealers by modified direct contact test against Enterococcus faecalis. J Endod 2009; 35: 1051–1055

(Photo: T. Dammaschke)

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Is pulpotomy a valid treatment option for irreversible pulpitis?

Scientific Communication of the German Society of Endodontology and Dental Traumatology

Summary: Based on the current state of knowledge, vital pulp treatment on teeth with deep carious lesions is indicated only in vital teeth which are asymptomatic, or at the most, show symptoms of reversible pulpitis. In cases of irreversible pulpitis, vital pulp extirpation and root canal treatment constitutes a reliable and established method that should still be considered the gold standard. However, recently published clinical studies show that, despite the diagnosis of "irreversible pulpitis", surprisingly high success rates can be achieved after partial or full pulpotomy. These findings do not only challenge the current treatment concepts for teeth affected by pulpitis, but also the current system for diagnosing different stages of the disease. Although the diagnosis of "irreversible pulpitis" is consistent with histologically detectable areas of bacterially infected or already necrotic tissue, these areas are localized beneath the carious lesion in the coronal pulp and do not affect the entire pulp tissue.

Pulpotomy involves the complete removal of inflamed, and therefore heavily bleeding, pulp tissue up to the level where the remaining pulp tissue is healthy in order to create the necessary conditions for healing. To date, a total of 12 clinical studies with a focus on vital pulp treatment in teeth with deep carious lesions and irreversible pulpitis have been published. Success rates after observation periods of 1 to 5 years range between 85 % and 95 % in most studies, regardless of patient age and type of pulpotomy (partial or full). However, it must be taken into account that long-term studies are lacking, and the significance of the individual studies is limited by various qualitative deficits. In spite of these shortcomings, based on the current data, pulpotomy can be regarded as a valid treatment option for irreversible pulpitis and it certainly represents an alternative to vital pulp extirpation. Whereas the correct indication is critical, the success of a pulpotomy procedure mainly relies on the adequate performance of the necessary treatment steps. This includes, in addition to the aseptic treatment concept in combination with the consistent use of rubber dam and sterile instruments, the use of magnifying aids to enable a sufficiently precise amputation procedure, the endodontic expertise to assess the exposed pulp tissue, the application of appropriate disinfection measures and capping of the tissue with a bioactive material followed by an immediate coronal seal.

Keywords: partial pulpotomy; pulpitis; vital pulp treatment; full pulpotomy

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Introduction

The high success rate of correctly performed root canal treatment has been proven in many studies. This is particularly true for teeth that require treatment, but do not exhibit signs of a preoperative apical periodontitis [45]. Even though the success rates 5 years after vital pulp extirpation and root canal treatment are around 90 % [22], the complete loss of pulpal tissue function is an imperative consequence [18]. This leads to several disadvantages, including an increased risk of fracture due to hard tissue removal during preparation as well as morphological and structural changes of dentin that occur during treatment, and possibly, to an increased maximum loading owing to the partial loss of proprioceptive protective mechanisms [23, 36]. Other potential drawbacks after root canal treatment include coronal discolorations [29], higher susceptibility to caries as a consequence of accelerated biofilm formation due to alterations of the microflora [41], the lack of defensive capacity of the pulp-dentin complex as well as the absence of a functional pain response system. Endodontic treatment often proves to be more complex than anticipated initially, which can significantly impair the treatment outcome. In case of failure, subsequent therapies to preserve the tooth (e.g. root canal retreatment or apicoectomy) are associated with significantly increased efforts.

The above-mentioned problems can be avoided if the vitality of the pulp is maintained. Procedures that aim for the preservation of pulp vitality are conservative measures which can be performed with considerably less time expenditure than root canal treatment [6]. If correctly indicated and implemented, vital pulp treatment is associated with high success rates [18] and is cost-effective in the long term [52, 63].

Moreover, in recent years, the dental literature shows a clear trend in favor of preserving tooth vitality which is scientifically pursued in different dental specialties [10, 18, 21, 51].

For an overview of vital pulp treatment subsequent to pulp exposure, the position paper "Current recommendations for vital pulp treatment" by the German Society of Endodontology and Dental Traumatology (DGET) should be referred to [18].

The present article focuses exclusively on vital pulp treatment and in particular on partial removal of pulp tissue in teeth that require root canal treatment according to current standards, which are based on the belief that preservation of pulp vitality was not possible. Thus, partial pulpotomy (partial amputation of the coronal pulp) and full pulpotomy (complete amputation of the coronal, but preservation of the radicular pulp) are discussed here.

Vital pulp treatment after traumatic exposure (by direct pulp capping and partial pulpotomy following complicated crown fractures) are not considered in this publication, as preservation of pulp vitality in such cases is implicit and can be achieved predictably and successfully [24, 30]. Likewise, cases with deep carious lesions but without signs of irreversible pulpitis are excluded as these neither represent a primary indication for root canal treatment.

1. Biological background regarding pulpotomy in cases of carious exposure

In the majority of cases, inflammatory reactions in the pulpal tissue develop due to microbial irritation originating from carious lesions, but may also occur after mechanical, thermal or chemical irritation or due to traumatic damage. Depending on the intensity of the stimulus, the inflamed tissue may either heal or increase in intensity to take on acute or chronic forms. The inflammation spreads from the site of injury into the pulp tissue. During this process, both healthy and affected tissue with varying degrees of inflammation, can be present concomitantly. Furthermore, changes occur constantly as the inflammatory process progresses. Various classification systems have been developed over time in order to adequately describe the pulpal status; either based on clinical or histological observations. Histologically, a large variety of pulp tissue states can be described, whereas the currently available clinical diagnostic tools allow only a rough classification. Since the histopathological condition of the pulp cannot be evaluated clinically, the therapeutic decision must be based on the clinical diagnosis. The AAE (American Association of Endodontists) has adhered to the current consensus to classify pulpits clinically as reversible and irreversible [1, 2]. Whereas in teeth with reversible pulpitis, pain is most often induced upon stimulation only, irreversible pulpitis is typically associated with lingering pain induced by thermal stimuli, spontaneous (unprovoked) pain and possibly by the patient's inability to precisely localize which tooth is the culprit and source of the pain.

According to the current state of knowledge, vital pulp therapy in teeth with deep caries is indicated only if the pulp is vital pulp and the tooth is asymptomatic, or at the very most, shows symptoms of reversible pulpitis [21]. This applies to selective caries excavation, too [10]. Up to now, vital pulp treatment is considered to be contraindicated if there is already evidence of irreversible pulpitis, due to the belief that the tissue cannot heal predictably after the removal of the triggering stimulus. Surprisingly, several recent clinical studies have shown high success rates after partial and full pulpotomy in cases of irreversible pulpitis [3–6, 31, 33, 39, 47, 56–58, 60]. This challenges the suitability of the current classification system of pulpal diseases to adequately describe the condition of the pulp and accordingly, its clinical relevance [62]. Some studies suggest that the histological condition of the pulp correlates with the clinical diagnosis in many cases [15, 48], especially in healthy teeth and teeth with reversible pulpitis [48], which display a moderate chronic inflammatory reaction. Furthermore, in the majority of cases in which an "irreversible pulpitis" was diagnosed clinically, areas of necrotic and infected pulp were actually detected histologically. In the presence of bacteria in the pulp chamber, microabscesses and tissue necrosis can be found, which are engulfed by polymorphonuclear neutrophilic granulocytes, and inflammatory infiltrates are present at the periphery [48]. However, this histologic condition does not affect the entire pulp tissue, but remains restricted to the areas beneath the carious lesion, while the radicular pulp ap-

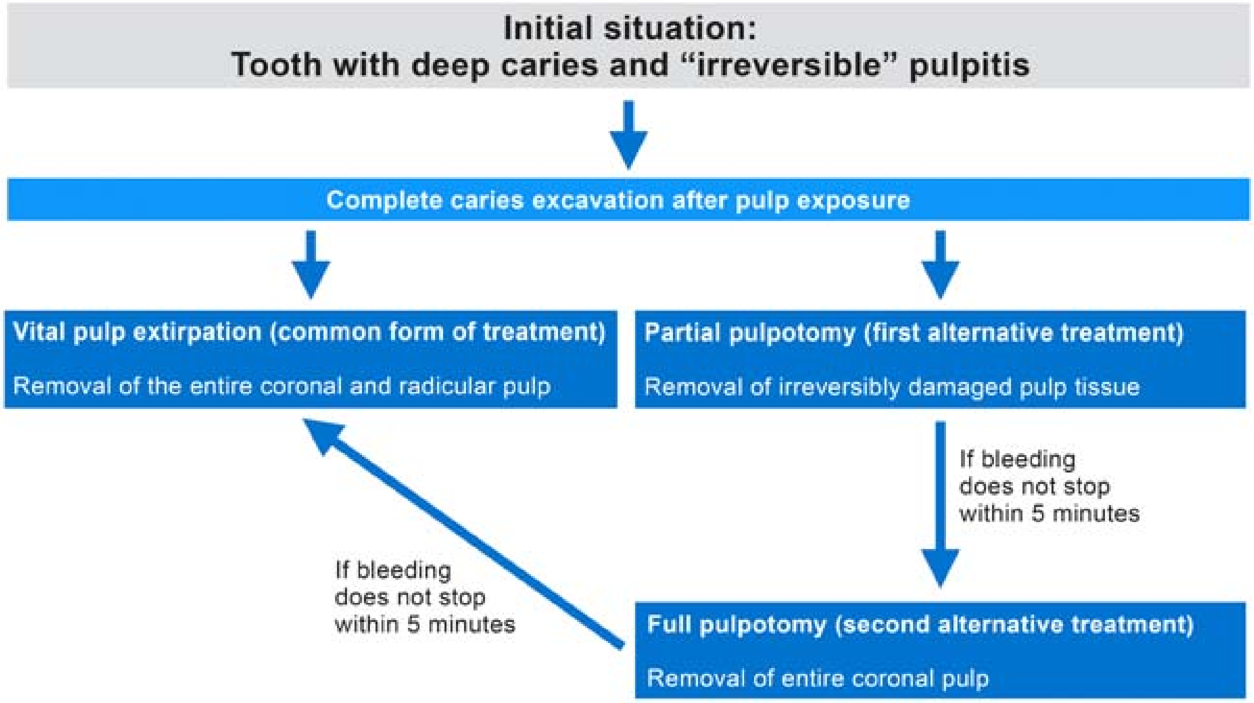

Figure 1 Treatment options for irreversible pulpitis

pears unchanged apart from a partial loss of the odontoblast layer [48, 50]. Thus, the term irreversible pulpitis is misleading as the clinical diagnosis cannot be equated with the tissue's ability to heal after therapeutic intervention. Vital tissue may still be present in the root canal even in cases with radiographic signs of an initiating periapical lesion, which is regarded as a local immune reaction in the periapical tissue triggered by inflammatory mediators [55]. Therefore, it may not represent an absolute contraindication for vital pulp treatment [56].

Yet, irreversible pulpitis can be completely asymptomatic. According to histological findings, teeth which displayed an immune reaction as described above were clinically symptom-free in 14–60 % of cases [42, 53]. Another study showed that in 15.6 % of cases, the clinical and histological diagnoses did not correspond [48]. Moreover, a significant correlation between spontaneous pain prior to treatment, which suggests irreversible pulpitis, and the success of vital pulp treatment is not necessarily existent [40]. When diagnosing "irreversible pulpitis", it must be considered that pain sensation is always subjective, does not correlate with the extent of the inflammation, and cannot be detected histologically. The treatment of pulpitis should thus be based on the extent of the bacterial infection; unfortunately, in a clinical scenario, this cannot be determined precisely due to the insufficient correlation of clinical symptoms and histological findings.

There is, however, a good correlation between the depth of bacterial penetration into dentin and the histologically detectable pulpal response to the carious lesion [38]. Thus, the clinical classification of the symptoms in terms of reversible or irreversible pulpitis has nothing to say about the regenerative capacity of the tissue [11]. In contrast, the assessment of tissue bleeding after pulp exposure is a more reliable diagnostic procedure compared to the sensitivity test and pain symptoms. In cases of mild inflammation, less profuse bleeding occurs, especially in the case of reversible pulpitis. However, if bacteria have penetrated deeper into the pulp tissue, the more pronounced inflammatory reaction causes more severe bleeding from the tissue, particularly in the case of irreversible pulpitis. Pulpal bleeding thus reflects the degree of inflammation and the chance of healing; heavy or prolonged bleeding indicates significant damage of the affected pulp tissue and reduced chances of healing [14, 28, 34, 40]. As a consequence, inflamed and heavily bleeding pulp tissue needs to be removed completely up to the level where healthy tissue remains in order to create the necessary conditions for successful pulp preservation. Similarly to an acute infection in the fingernail area, for example, in which a targeted excision of the infected tissue is performed rather than the amputation of the entire finger [35], the exclusive excision of the irreversibly damaged areas of the pulp would also be sufficient to allow healing in cases of pulpitis.

Pulpotomy has been considered an established emergency treatment measure for irreversible pulpitis for decades. Recently, two randomized controlled trials have shown that pain relief after pulpotomy is as reliable as after vital pulp extirpation [19, 20]. In this manner, the noticeably more time-consuming root canal treatment including chemo-mechanical preparation can be performed at a subsequent point. In these cases, the idea of using pulpotomy, not only as a temporary measure, but rather as a definitive endodontic treatment is not new and dates back to the last century [12].

However, this topic has been researched more extensively only in recent years, on the one hand due to advances in the field of pulp biology, on the other hand the availability of new bioactive materials [54].

Furthermore, in countries where root canal treatment is not accessible to the general public for cost-related reasons, pulpotomy has been considered to be a less costly alternative to avoid an otherwise necessary extraction [3, 63]. In fact, the treatment duration of a pulpotomy procedure amounts to about one-third of that of a root canal treatment [6].

2. Pulpotomy as a clinical procedure after carious exposure

The starting point for performing a pulpotomy is a tooth with a deep lesion with pulp exposure in carious dentin and/or symptoms of irreversible pulpitis (Fig. 1). After isolation with rubber dam and disinfection of the tooth crown, complete caries excavation has to be performed, beginning from the periphery towards the center, ideally using optical magnification devices. This is followed by an initial examination of the pulp tissue at the exposure site. Infected dentin chips, which were transported into the pulp tissue during excavation, can often be observed. Hyperemic and necrotic pulp areas may be found contiguously; a pale-yellow color indicates absent blood circulation and necrosis, occasionally, micro-abscesses are present [49]. The aim of a pulpotomy procedure is to remove damaged tissue and to lay open healthy pulp by means of amputation. For this purpose, a water-cooled, high-speed diamond bur is used.

From a technical standpoint, the full (= cervical) pulpotomy is the easiest to perform because the endpoint of amputation is clearly defined by reaching the root canal orifices. Given that significantly more tissue is removed in a full compared to a partial pulpotomy, the probability of leaving behind only healthy tissue that is capable of healing is increased, meaning that the prospect of success is high. However, this procedure also comes with disadvantages. For instance, in the context of clinical follow-up examinations, the sensitivity test is inconclusive and the success of treatment can only be assessed radiologically – with the corresponding limitations. Moreover, in contrast to partial pulpotomy, the risk of root canal obliteration after full pulpotomy is increased [18].

Within this framework, the extent of amputation should be based on the depth at which healthy pulp tissue can be identified and bleeding can be controlled. While inflammatory changes within the pulp tissue remain limited to the coronal 2 mm after trauma-related pulp exposure and subsequent contact with the oral milieu for up to 7 days [17, 26], the depth of tissue destruction that results from a carious process is significantly more variable. In this case, a reliable assessment of the tissue condition is only possible by use of using sufficient magnification and illumination.

Sodium hypochlorite (NaOCl) is recommended for rinsing and disinfection of the amputation site whereby the concentration of the endodontic irrigant (1–5.25 %) does not appear to be a prognostically decisive factor [43]. Careful compression using a cotton pellet soaked in NaOCl may facilitate further hemostasis. The use of a hemostatic agent is not recommended as it would "mask" the true inflammatory state of the pulp [64]. Also, the use of a laser is not recommended due to insufficient evidence. In a recent randomized controlled trial, the supplementary use of an Er,Cr:YSGG laser for pulpotomy after carious exposure of asymptomatic immature teeth was not beneficial [59].

After amputation and rinsing, bleeding should stop within 5 minutes. However, this time frame is only a reference value because, in some studies, significantly longer bleeding times (15 minutes and longer) have led to successful treatment [47]. Persistent bleeding indicates that the reduction of pulpal tissue was not sufficient to reach the level of healthy tissue [64]; in this case, a deeper pulpotomy or even a full pulpotomy can be considered. Although reports of successful deeper pulpotomies can be found in the literature, in which the amputation site was up to several millimeters below the root canal orifices, in the authors' view, there is no discernible decisive advantage compared to vital pulp extirpation and subsequent root canal treatment, at least in mature teeth.

The exposed pulp surface should be capped with an aqueous suspension of calcium hydroxide or preferably a hydraulic calcium silicate cement, the cap can be coated with a thin layer of a fast-setting material [16]. There is clear evidence for the superiority of hydraulic calcium silicate cements compared to calcium hydroxide when used for vital pulp treatment after carious pulp exposure [13, 27, 32, 37, 58]. Within the group of hydraulic calcium silicate cements, distinct clinical differences do not seem to exist [37], however, the discoloration potential of the respective product has to be considered. The application of light-curing flowable materials with additives of MTA in direct contact with the pulp is not recommended due to their limited biocompatibility [7, 46]. After the pulp capping procedure, an adhesive seal and coronal restoration should be placed immediately, since this step is critical for the success of the treatment.

3. State of evidence: chance of success in cases of irreversible pulpitis and potential influencing factors

Compared to teeth with traumatic damage, it can be assumed that the pulp of teeth with carious exposure is significantly pre-damaged, as the pulp has already been in contact with bacterial toxins or even with the bacteria themselves for a considerable amount of time. The lesion size, bacterial spectrum, and the speed at which the lesion progresses affect the pulpal status [18]. Thus, it can be expected that the high success rates of over 90 % after partial pulpotomy in teeth with complicated crown fractures [24] are considerably higher than after carious pulp exposure. In spite of this, more than 10 current clinical studies have focused on vital pulp treatment measures in carious teeth with a diagnosis of "irreversible pulpitis". High success rates ranging between 85 % and 95 % after observation periods of 1 to 5 years have been recorded in most studies, regardless of whether a

Study	Study type	Patient age	Number of treated teeth	Initial diagnosis of the pulp	Observation period	Treatment measure	Capping material	Success	Age influence
(Asgary & Eghbal 2013)	RCT	9–65 years ø 27 years	413	Irreversible pulpitis	1 year	Full pulpotomy	CEM MTA	92 % (CEM) 95 % (MTA)	N/S
(Asgary & Eghbal 2014)	RCT	9–65 years	407	Irreversible pulpitis	2 years	Full pulpotomy vital pulp extirpation	CEM	86 % (full pulpotomy) 80 % (vital pulp extirpation)	N/S
(Asgary et al. 2015)	RCT	9–65 years	407	Irreversible pulpitis	5 years	Full pulpotomy vital pulp extirpation	CEM	71 % (full pulpotomy 66 % (vital pulp extirpation)	none
Kunert et. Al 2015	Retrosp.	8–79 years	273	Not explicitly specified but referred for root canal treatment	5 years (1–29 years)	Full pulpotomy	KH	89 % (1 year) 63 % (10 years)	none
Kumar et al 2016	RCT	14–32 years	54	Irreversible pulpitis	1 year	Full pulpotomy	MTA KH PRF+MTA	44 % (MTA) 38 % (CH) 36 % (PRF+MTA)	N/S
(Taha, Ahmad et al. 2017)	Prosp.	11–51 years	52	Irreversible pulpitis (> 80 %)	3 years	Full pulpotomy	MTA	92,7 %	none
(Qudeimat et al. 2017)	Prosp.	7–13 years ø 10.7 years	23	Irreversible pulpitis	5 years (19–74 months)	Full pulpotomy	MTA	100 %	N/S
(Linsuwanont et al. 2017)	Retrosp.	7–68 years ø 29 years	55	Irreversible pulpitis	3 years (8–62 months)	Full pulpotomy	MTA	84 %	none
Asgary, Eghbal 2017	RCT	9–65 years	412	Irreversible pulpitis	5 years	Full pulpotomy	MTA CEM	85 % (MTA) 78 % (CEM)	none
Taha, Khazali et al. 2017)	RCT	20–52 years ø 30 years	50	Irreversible pulpitis	2 years	Partial pulpotomy	MTA KH	85 % (MTA) 43 % (CH)	N/S
Taha et al 2018	Prosp.	19–69 years	52	Irreversible pulpitis	1 year	Full pulpotomy	Biod.	98 %	N/S
Uesrichai et al 2019	RCT	6–18 years ø 10 years	69	Irreversible pulpitis	32,2 ± 17,9 months	Partial pulpotomy	MTA Biod.	92 % (MTA) 87 % (Biod.)	N/S

(**Abbreviations:** RCT = randomized control trial; Retrosp. = retrospective clinical study; Prosp. = prospective clinical study; N/S = not specified; CH = calcium hydoxide; PRF = platelet–rich fibrin; **abbreviations of hydraulic calcium silicate cements:** MTA = mineral trioxid aggregate); CEM = calcium enriched mixture; Biod. = Biodentine)

Table 1 Overview of clinical studies investigating vital pulp treatment on permanent teeth with "irreversible pulpitis".
(Fig. 1 and Tab. 1: G. Krastl)

partial or full pulpotomy was performed (Tab. 1).

Half of the studies as mentioned are randomized controlled trials, and therefore regarded at the highest level of evidence among all primary study types. Still, it must be taken into consideration that even this type of study design can only generate robust results if the planning, conduct and evaluation are methodologically correct and appropriately tailored to the research question. In general, the validity of single studies may be limited by various qualitative deficiencies such as the lack of blinding of the investigators as well as by inaccurately and inconsistently defined success criteria [8]. In most studies, pulpotomy procedures are categorized as successful if there is no clinical or radiological evidence of pulp necrosis. However, the actual condition of the remaining pulp tissue is difficult to assess. The lack of response to sensitivity testing, at least in the case of complete pulpotomy, has to be attributed to the treatment itself and cannot be considered a criterion for failure. Since the most frequent cause of failure after pulpotomy is assumed to be asymptomatic apical periodontitis [31], it must be assumed that pulp necrosis remains undetected and is considered a failure only when radiological signs of apical periodontitis are present. For this reason, long-term studies that span more than 5 years are critical because the success of pulpotomy procedures in cases of irreversible pulpitis has only been proven clinically, but not histologically.

In a randomized, controlled, multicenter study, where pulpotomy was compared to root canal treatment in teeth with irreversible pulpitis, no significant difference between the two treatment options (vital pulp extirpation vs. pulpotomy) were found [5]. However, the success rate for endodontic treatment after vital pulp extirpation after 5 years in this study was 66 %, which is significantly lower than the reported success rates of over 90 % in other studies [22]. Furthermore, a comparison between success rates of pulpotomy and root canal treatment may not be feasible, as, in case of failure, the conditions for long-term preservation of the tooth are different. If vital pulp treatment fails, root canal treatment can still be performed with high success rates, whereas retreatment shows significantly reduced success rates.

Among the factors that potentially influence the prognosis of vital pulp treatment, patient age is frequently discussed. Favorable conditions for pulp preservation are found in young patients with a high potential for regeneration, provided that the pulp tissue has not been damaged previously [61]. In particular, teeth with immature roots benefit the most from vital pulp treatment which enables continued formation of dentin and cementum and thus further root development. With increasing age, a reduced regenerative capacity is expected due to changes such as a reduced cell number and increased content of fibrous tissue [25, 44]. Nevertheless, patient age does not seem to have a decisive influence on the success rate: In the existing clinical studies on vital pulp treatment of permanent teeth with irreversible pulpitis, patients up to the age of 79 years were included (Table 1).

The question whether teeth after (partial) preservation of pulp vitality after pulpotomy procedures indeed have a better prognosis compared to teeth treated with vital pulp extirpation and subsequent root canal treatment remains unanswered. This would be the case if – given that tooth vitality is preserved in the long-term – the susceptibility to fracture does not increase after this type of treatment. In this respect, the critical long-term data are not available. However, it can be conjectured that the biomechanical stability of a tooth after partial pulpotomy with the preservation of most of the coronal pulp is more similar to a sound and vital tooth compared to a tooth with remnants of vital pulp only in the root canals up to the level of the canal orifices after a full pulpotomy.

4. Conclusion

From a patient's perspective, teeth with deep carious lesions and symptoms of irreversible pulpitis need to be treated in a way that is most likely to keep the affected tooth free of symptoms in the long term and the periradicular tissue healthy. Root canal treatment subsequent to vital pulp extirpation is a reliable and established method in these cases, which is undoubtedly still to be considered the gold standard. In comparison, the evidence for vital pulp treatment in teeth with irreversible pulpitis is rather sparse at present, especially because long-term data is missing.

In spite of this, based on the current data, pulpotomy can be considered a valid treatment option for irreversible pulpitis and it surely represents an alternative to vital pulp extirpation [37]. In the context of treatment concepts for inflammatory pulp diseases, the shortcomings of the current classification of pulpitis should also be emphasized. A more precise and treatment-oriented classification that reflects the possibilities for tissue preservation would be desirable.

In addition to the correct indication, the success of a (partial or full) pulpotomy to a large extent depends on whether the necessary measures are performed adequately. This implies an aseptic treatment concept with the consistent use of rubber dam and sterile instruments, the use of appropriate magnification aids in order to be able to precisely perform the pulp amputation, thorough endodontic knowledge to assess the condition of the exposed pulp, disinfection and capping of the tissue with a suitable bioactive material and an immediate adhesive seal and permanent coronal restoration. Recent data show that deviations from these requirements significantly reduce the success of vital pulp treatment measures after pulp exposure [9].

Given that every dentist should be familiar with pulpotomies as emergency treatment for irreversible pulpitis, a next step would be to establish pulpotomy as a definitive measure (under the condition of an enhanced treatment protocol) besides root canal treatment. Especially in young patients with immature teeth, long-term pulp preservation would be most beneficial.

However, the effort required to correctly perform a (partial or full) pulpotomy as a definitive measure is unfortunately not sufficiently reflected in the payment system of health insurance companies in Germany.

The present position paper is based on the current state of scientific knowledge. As this field is actively researched, the necessity of updates in the near future is anticipated.

Conflicts of interest

Till Dammaschke states that he has received honoraria from Septodont for lectures. The authors G. Krastl, K. Galler, and E. Schäfer declare that there is no conflict of interest as defined by the guidelines of the International Committee of Medical Journal Editors.

References

1. American Association of Endodontists: AAE Consensus conference recommended diagnostic terminology. J Endod 2007; 35: 1634

2. American Association of Endodontists: Glossary of endodontic terms. 10th Edition. 2020. (https: //www.aae.org/specialty/clinical-resources/glossary-endodontic-terms/)

3. Asgary S, Eghbal MJ: Treatment outcomes of pulpotomy in permanent molars with irreversible pulpitis using biomaterials: a multi-center randomized controlled trial. Acta Odontol Scand 2013; 71: 130–136

4. Asgary S, Eghbal MJ, Bagheban AA: Long-term outcomes of pulpotomy in permanent teeth with irreversible pulpitis: a multi-center randomized controlled trial. Am J Dent 2017; 30: 151–155

5. Asgary S, Eghbal MJ, Fazlyab M, Baghban AA, Ghoddusi J: Five-year results of vital pulp therapy in permanent molars with irreversible pulpitis: a non-inferiority multicenter randomized clinical trial. Clin Oral Investig 2015; 19: 335–341

6. Asgary S, Eghbal MJ, Ghoddusi J: Two-year results of vital pulp therapy in permanent molars with irreversible pulpitis: an ongoing multicenter randomized clinical trial. Clin Oral Investig 2014; 18: 635–641

7. Bakhtiar H, Nekoofar MH, Aminishakib P et al.: Human pulp responses to partial pulpotomy treatment with TheraCal as compared with Biodentine and ProRoot MTA: a clinical trial. J Endod 2017; 43: 1786–1791

8. Bjørndal L: Is pulpotomy preferable to root treatment where there is pulp exposure? Evid Based Dent 2019; 20: 117–118

9. Bjørndal L, Fransson H, Bruun G et al.: Randomized clinical trials on deep carious lesions: 5-year follow-up. J Dent Res 2017; 96: 747–753

10. Buchalla W, Frankenberger R, Galler KM et al.: Aktuelle Empfehlungen zur Kariesexkavation. Wissenschaftliche Mitteilung der Deutschen Gesellschaft für Zahnerhaltung (DGZ). Deutsche Zahnärztliche Zeitschrift 2017; 72: 484–494

11. Bürklein S, Sabandal M, Dammaschke T: Pulpa: Beurteilung von Vitalität und Sensibilität. Zahnmedizin up2date 2019; 13: 355–369

12. Chatterton DB: Pulp curettage. J Am Dent Assoc 1952; 45: 462–465

13. Cho SY, Seo DG, Lee SJ, Lee J, Lee SJ, Jung IY: Prognostic factors for clinical outcomes according to time after direct pulp capping. J Endod 2013; 39: 327–331

14. Christensen GJ: Pulp capping 1998. J Am Dent Assoc 1998; 129: 1297–1299

15. Cisneros-Cabello R, Segura-Egea JJ: Relationship of patient complaints and signs to histopathologic diagnosis of pulpal condition. Aust Endod J 2005; 31: 24–27

16. Cohenca N, Paranjpe A, Berg J: Vital pulp therapy. Dent Clin North Am 2013; 57: 59–73

17. Cvek M, Cleaton-Jones PE, Austin JC, Andreasen JO: Pulp reactions to exposure after experimental crown fractures or grinding in adult monkeys. J Endod 1982; 8: 391–397

18. Dammaschke T, Galler KM, Krastl G: Current recommendations for vital pulp treatment. Dtsch Zahnärztl Z Int 2019; 1: 43–52

19. Eghbal MJ, Haeri A, Shahravan A, et al.: Postendodontic pain after pulpotomy or root canal treatment in mature teeth with carious pulp exposure: a multicenter randomized controlled trial. Pain Res Manag 2020; 2020: 5853412

20. Eren B, Onay EO, Ungor M: Assessment of alternative emergency treatments for symptomatic irreversible pulpitis: a randomized clinical trial. Int Endod J 2018; 51 (Suppl 3): e227–e237

21. Duncan HF, Galler KM, Tompson PL et al.: European Society of Endodontology position statement: management of deep caries and the exposed pulp. Int Endod J 2019; 52: 923–934

22. Friedman S, Abitbol S, Lawrence HP: Treatment outcome in endodontics: the Toronto study. Phase 1: initial treatment. J Endod 2003; 29: 787–793

23. Fuss Z, Lustig J, Katz A, Tamse A: An evaluation of endodontically treated vertical root fractured teeth: impact of operative procedures. J Endod 2001; 27: 46–48

24. Galler KM, Dammaschke T, Krastl G: Vitalerhaltung der Pulpa nach Trauma. Die Quintessenz 2019; 70: 1042–1048

25. Goodis HE, Kahn A, Simon S: Aging and the pulp. In: Hargreaves K, Goodis HE, Tay F (Hrsg): Seltzer and Bender's dental pulp. Quintessenz, Berlin 2012

26. Heide S, Mjør IA: Pulp reactions to experimental exposures in young permanent monkey teeth. Int Endod J 1983; 16: 11–19

27. Hilton TJ, Ferracane JL, Mancl L: Northwest practice-based research collaborative in evidence-based D. Comparison of CaOH with MTA for direct pulp capping: a PBRN randomized clinical trial. J Dent Res 2013; 92: 16S–22S

28. Kang CM, Sun Y, Song JS et al.: A randomized controlled trial of various MTA materials for partial pulpotomy in permanent teeth. J Dent 2017; 60: 8–13

29. Krastl G, Allgayer N, Lenherr P, Filippi A, Taneja P, Weiger R: Tooth discoloration induced by endodontic materials: a literature review. Dent Traumatol 2013; 29: 2–7

30. Krastl G, Weiger R: Vital pulp therapy after trauma. ENDO (Lond Engl) 2014; 8: 293–300

31. Kumar V, Juneja R, Duhan J, Sangwan P, Tewari S: Comparative evaluation of platelet-rich fibrin, mineral trioxide aggregate, and calcium hydroxide as pulpotomy agents in permanent molars with irreversible pulpitis: a randomized controlled trial. Contemp Clin Dent 2016; 7: 512–518

32. Kundzina R, Stangvaltaite L, Eriksen HM, Kerosuo E: Capping carious exposures in adults: a randomized controlled trial investigating mineral trioxide aggregate versus calcium hydroxide. Int Endod J 2017; 50: 924–932

33. Kunert GG, Kunert IR, da Costa Filho LC, de Figueiredo JAP: Permanent teeth pulpotomy survival analysis: retrospective follow-up. J Dent 2015; 43: 1125–1131

34. Langeland K: Management of the inflamed pulp associated with deep carious lesion. J Endod 1981; 7: 169–181

35. Langer M, Wieskötter B, Oeckenpöhler S, Breiter S: Akute Infektionen im Bereich des Fingernagels – die akuten Paronychien. Handchirurgie Scan 2014; 03: 69–85

36. Lertchirakarn V, Palamara JE, Messer HH: Patterns of vertical root fracture: factors affecting stress distribution in the root canal. J Endod 2003; 29: 523–528

37. Li Y, Sui B, Dahl C et al.: Pulpotomy for carious pulp exposures in permanent teeth: A systematic review and meta-analysis. J Dent 2019; 84: 1–8

38. Lin LM, Ricucci D, Saoud TM, Sigurdsson A, Kahler B: Vital pulp therapy of mature permanent teeth with irreversible pulpitis from the perspective of pulp biology. Aust Endod J 2020; 46: 154–166

39. Linsuwanont P, Wimonsutthikul K, Pothimoke U, Santiwong B: Treatment outcomes of mineral trioxide aggregate pulpotomy in vital permanent teeth with carious pulp exposure: the retrospective study. J Endod 2017; 43: 225–230

40. Matsuo T, Nakanishi T, Shimizu H, Ebisu S: A clinical study of direct pulp cap-

ping applied to carious-exposed pulps. J Endod 1996; 22: 551–556

41. Merdad K, Sonbul H, Bukhary S, Reit C, Birkhed D: Caries susceptibility of endodontically versus nonendodontically treated teeth. J Endod 2011; 37: 139–142

42. Michaelson PL, Holland GR: Is pulpitis painful? Int Endod J 2002; 35: 829–832

43. Munir A, Zehnder M, Rechenberg DK: Wound lavage in studies on vital pulp therapy of permanent teeth with carious exposures: a qualitative systematic review. J Clin Med 2020; 9: 984. doi: 10.3390/jcm 9040984

44. Murray PE, Stanley HR, Matthews JB, Sloan AJ, Smith AJ: Age-related odontometric changes of human teeth. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2002; 93: 474–482

45. Ng YL, Mann V, Rahbaran S, Lewsey J, Gulabivala K: Outcome of primary root canal treatment: systematic review of the literature – part 2. Influence of clinical factors. Int Endod J 2008; 41: 6–31

46. Nilsen BW, Jensen E, Ortengren U, Michelsen VB: Analysis of organic components in resin-modified pulp capping materials: critical considerations. Eur J Oral Sci 2017; 125: 183–194

47. Qudeimat MA, Alyahya A, Hasan AA: Mineral trioxide aggregate pulpotomy for permanent molars with clinical signs indicative of irreversible pulpitis: a preliminary study. Int Endod J 2017; 50: 126–134

48. Ricucci D, Loghin S, Siqueira JF, Jr: Correlation between clinical and histologic pulp diagnoses. J Endod 2014; 40: 1932–1939

49. Ricucci D, Siqueira JF, Jr., Li Y, Tay FR: Vital pulp therapy: histopathology and histobacteriology-based guidelines to treat teeth with deep caries and pulp exposure. J Dent 2019; 86: 41–52

50. Ricucci D, Siqueira JF, Jr., Loghin S, Lin LM: Pulp and apical tissue response to deep caries in immature teeth: a histologic and histobacteriologic study. J Dent 2017; 56: 19–32

51. Schwendicke F, Frencken JE, Bjørndal L et al.: Managing carious lesions: consensus recommendations on carious tissue removal. Adv Dent Res 2016; 28: 58–67

52. Schwendicke F, Stolpe M: Direct pulp capping after a carious exposure versus root canal treatment: a cost-effectiveness analysis. J Endod 2014; 40: 1764–1770

53. Seltzer S, Bender IB, Ziontz M: The dynamics of pulp inflammation: correlations between diagnostic data and actual histologic findings in the pulp. Oral Surg Oral Med Oral Pathol 1963; 16: 846–871

54. Simon S, Perard M, Zanini M, et al: Should pulp chamber pulpotomy be seen as a permanent treatment? Some preliminary thoughts. Int Endod J 2013; 46: 79–87

55. Stashenko P, Teles R, D'Souza R: Periapical inflammatory responses and their modulation. Crit Rev Oral Biol Med 1998; 9: 498–521

56. Taha NA, Abdelkhader SZ: Outcome of full pulpotomy using Biodentine in adult patients with symptoms indicative of irreversible pulpitis. Int Endod J 2018; 51: 819–828

57. Taha NA, Ahmad MB, Ghanim A: Assessment of mineral trioxide aggregate pulpotomy in mature permanent teeth with carious exposures. Int Endod J 2017; 50: 117–125

58. Taha NA, Khazali MA: Partial pulpotomy in mature permanent teeth with clinical signs indicative of irreversible pulpitis: a randomized clinical trial. J Endod 2017; 43: 1417–1421

59. Tozar KN, Erkmen Almaz M: Evaluation of the efficacy of erbium, chromium-doped yttrium, scandium, gallium, and garnet laser in partial pulpotomy in permanent immature molars: a randomized controlled trial. J Endod 2020; 46: 575–583

60. Uesrichai N, Nirunsittirat A, Chuveera P, Srisuwan T, Sastraruji T, Chompu-Inwai P: Partial pulpotomy with two bioactive cements in permanent teeth of 6– to 18-year-old patients with signs and symptoms indicative of irreversible pulpitis: a noninferiority randomized controlled trial. Int Endod J 2019; 52: 749–759

61. Wang G, Wang C, Qin M: Pulp prognosis following conservative pulp treatment in teeth with complicated crown fractures-A retrospective study. Dent Traumatol 2017; 33: 255–260

62. Wolters WJ, Duncan HF, Tomson PL et al.: Minimally invasive endodontics: a new diagnostic system for assessing pulpitis and subsequent treatment needs. Int Endod J 2017; 50: 825–829

63. Yazdani S, Jadidfard MP, Tahani B, Kazemian A, Dianat O, Alim Marvasti L: Health technology assessment of CEM pulpotomy in permanent molars with irreversible pulpitis. Iran Endod J 2014; 9: 23–29

64. Zanini M, Hennequin M, Cousson PY: Which procedures and materials could be applied for full pulpotomy in permanent mature teeth? A systematic review. Acta Odontol Scand 2019; 77: 541–551

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