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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.

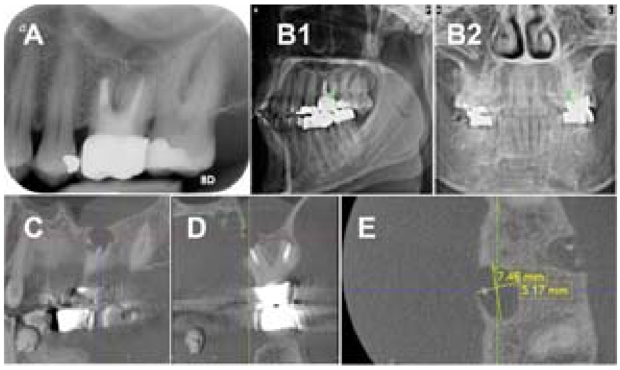


Figure 2 A = periapical X-ray (tooth 26) after multiple orthograde retreatment and surgical preservation attempts performed alio loco. **B1,2** = pre-shot-image in 2 planes to set the ROI (region of interest). **C,D** = CBCT (sagittal and coronal view) through the palatal root with involvement of the 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

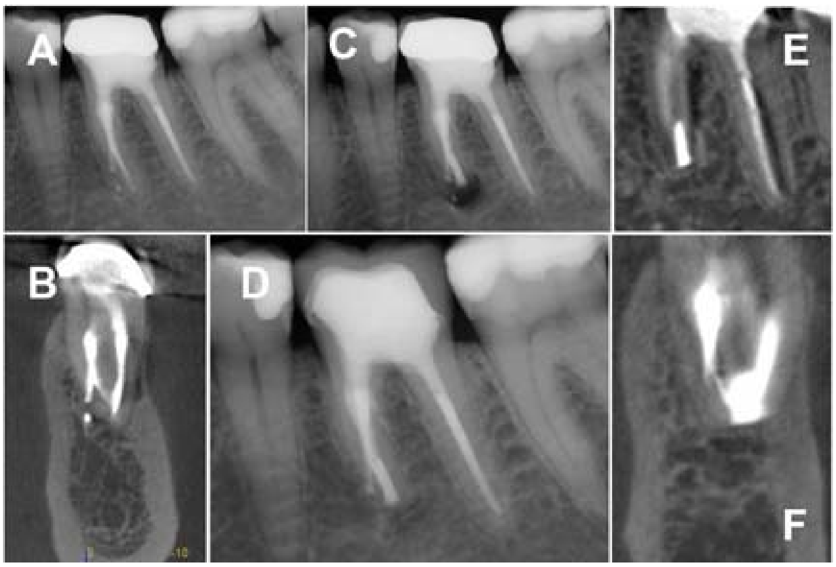


Figure 3 A = persistent complaints occurred in regio 36 after multiple retreatments and a perforation repair. **B** = coronal view (CBCT) with extruded root canal filling material in the area of perforation repair. **C** = situation after microsurgical apicoectomy. **D** = 1-year follow-up (periapical 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)

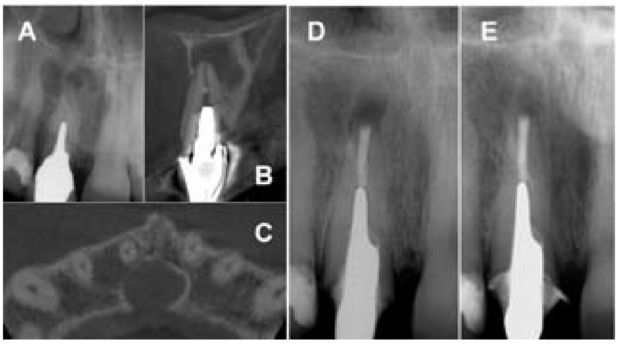


Figure 5 A = tooth 11 with an intact individual root post (orthograde only removable with a high risk), but without an appropriate root canal filling and an apical periodontitis. **B,C** = sagittal and axial section through the ROI. Note: a large incisive canal is visible directly adjacent to the apical 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).

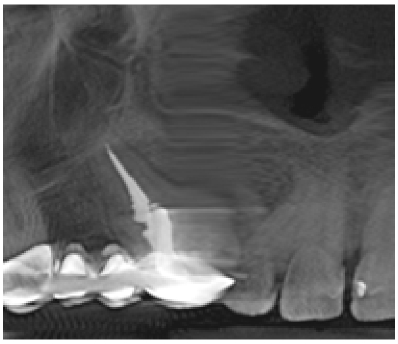


Figure 6 Detail out of the “implant view” in a CBCT. Considerable blurring due to patient movement

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.

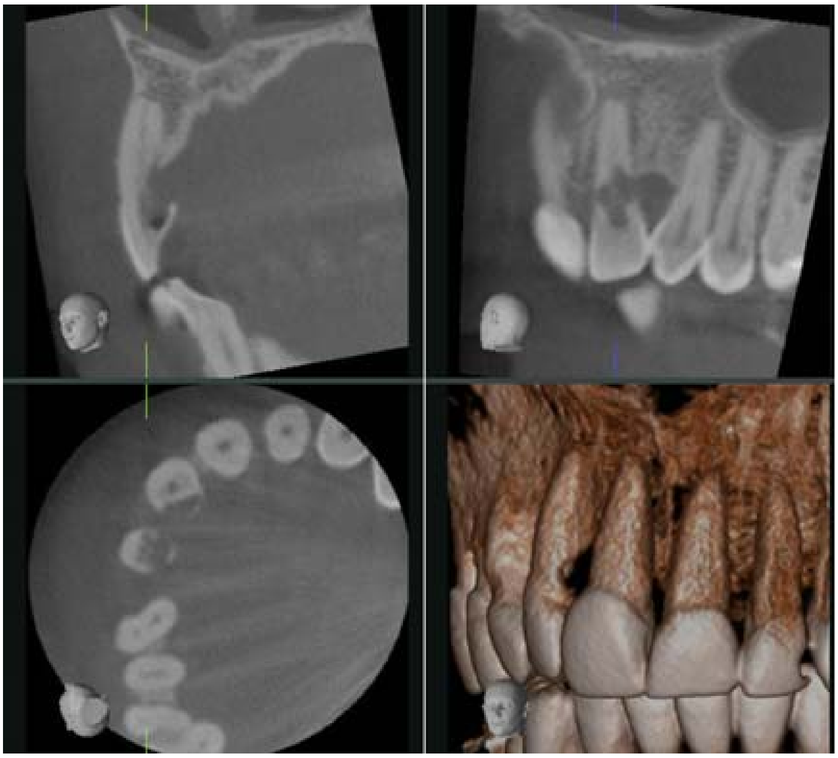


Figure 7 External invasive cervical resorption (EICR) tooth 12. Extension to the middle third of the root, circumferential extension > 270 °, possible pulp involvement: CBCT based classification tooth 12 = 3Dp; additionally tooth 11 affected = 2Bd.

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)

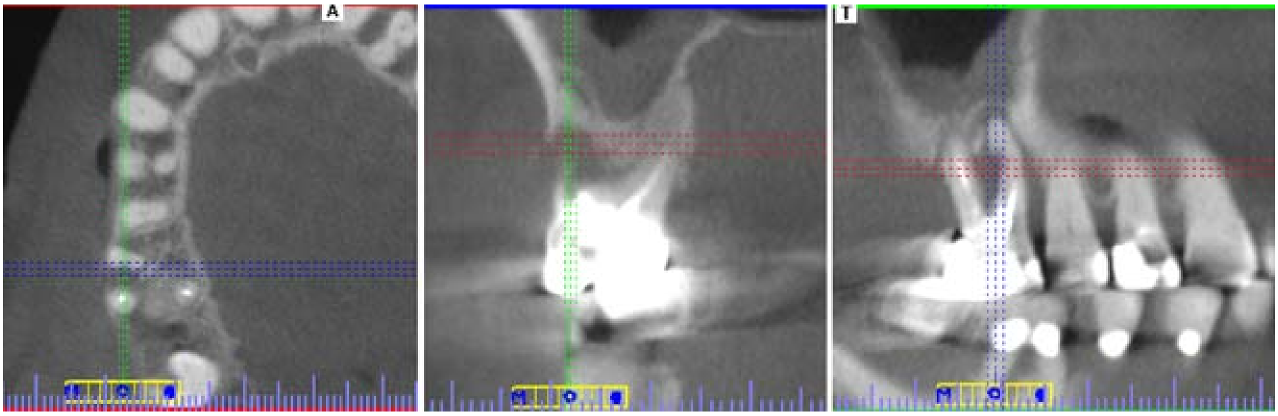


Figure 8 Superimposition-free axial, coronal and sagittal CBCT-views (tooth 16) with an apical periodontitis and loss of buccal lamella and inter-radicular bone

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

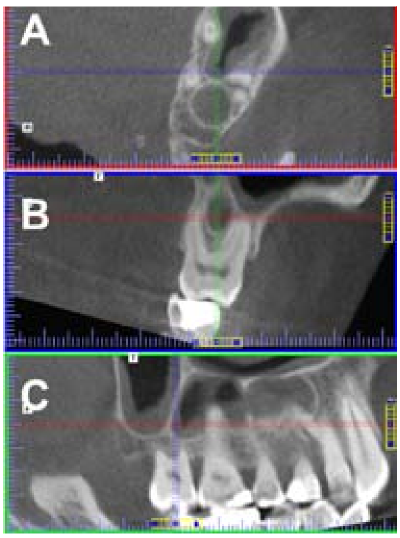


Figure 9 A,B,C = axial, coronal and sagittal CBCT images regio 17. A septum in the maxillary sinus (Underwood septum) extends between the buccal roots and the palatal root.

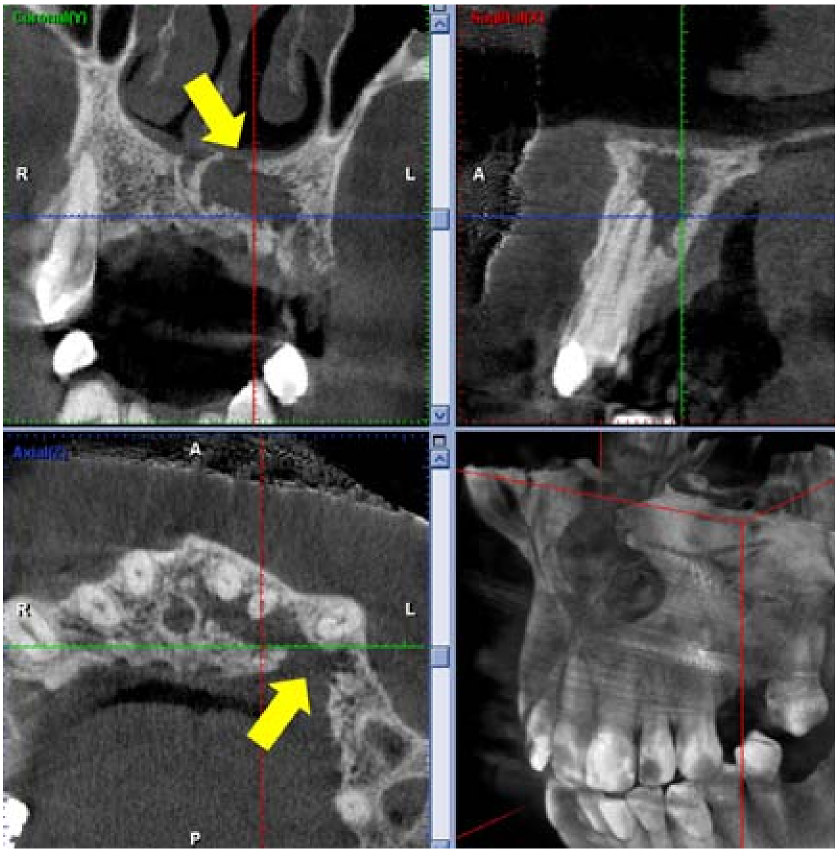


Figure 10 Coronal, axial and sagittal slice (CBCT) regio 23. Extensive osteolytic process starting from tooth 23 with loss of the bony barrier to the nasal floor as well as the palatal corticalis (palatum durum).

[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

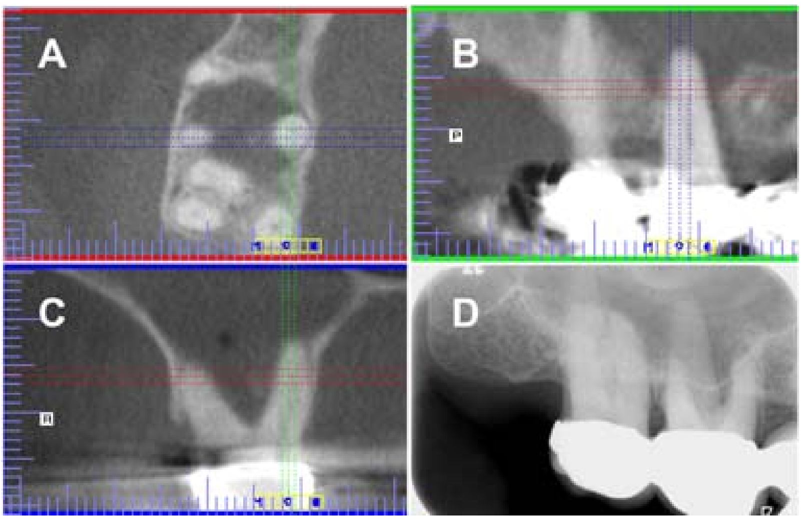
In general, the risk-benefit ratio in terms of radiation exposure during diagnosis and follow-up visits is in favor of conventional two-dimensional radiography, which is associated with an effective dose of 0.6–5 µSv when a dental X-ray is made, whereas CBCT can manage 19–55 µSv with adapted setting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

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