Radiation Dose Optimization in CBCT Endodontics

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Abstract- CBCT technique in the field of endodontics has become an important imaging modality providing 3D visualization to aid in diagnosis, treatment planning, and final outcome assessments. However, several authors confirm that CBCT, when used for very difficult cases, subjects the patient to increased radiation doses in comparison to conventional two-dimensional radiogrpahy. As most endodontic procedures involve comparatively younger patients and a very localized anatomical area, it becomes essential to avoid unnecessary exposure while ensuring adequate diagnostic image quality. Consideration needs to be given to measures put in place for the optimization of radiation dose based on ALARA (As Low As Reasonably Achievable) and ALADA (As Low As Diagnostically Acceptable) principles. Some of these methods include selecting appropriate cases at proper times; utilizing limited-field views; applying lower exposure parameters; using image reconstruction algorithms; and respecting clinical guidelines for radiation dose. This paper discusses the principles, techniques, and clinical considerations concerning exposure optimization in CBCT endodontics, where patient safety is weighed against diagnostic acceptance.

Indexed Terms- CBCT, Endodontics, Radiation Dose Optimization, ALARA, ALADA, Field of View, Image Quality, Patient Safety

I. INTRODUCTION

Cone-beam computed tomography (CBCT) has truly revolutionized the field of endodontics by affording clinicians the ability to obtain images of dental and periapical structures in a state of high resolution and three-dimensional view. In comparison to conventional periapical or panoramic radiography, CBCT allows visualization of complex root canal anatomy, periapical pathoses, root fractures, and treatment evaluation with a lot more precision. Increased diagnostic precision means increased radiation exposure, however The dose of radiation emitted by dental CBCT is less harmful to patients when compared to medical CT; now, on the other hand, it is more harmful than conventional intraoral radiographs. This presents a safety concern, especially given the fact that exposure to ionizing radiation is cumulative and that younger patients are more vulnerable. Therefore, the crux is to garner the maximum diagnostic yield with the least possible amount of radiation dose. Radiation dose optimization for CBCT endodontics demands the proper application of radiological protection principles, especially ALARA and ALADA, so that patients are not exposed to undue risks. A smaller field of view (FOV) selected appropriately for the diagnostic task, together with reduced exposure parameters, and the use of modern software for image enhancement, are expected to drastically reduce dose levels without a parallel compromise in diagnostic image quality. More importantly, adherence to evidence-based clinical guidelines ensures prescription of CBCT only if conventional imaging does not suffice. This paper focuses on radiation dose optimization strategies in endodontic CBCT imaging, weighing diagnostic necessity against patient safety, with recommendations for clinical practice.

II. COMMON CLINICAL APPLICATIONS OF CBCT IN ENDODONTICS

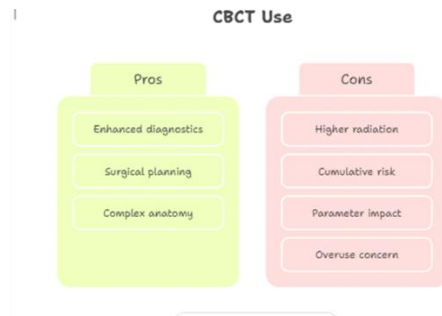
Before 2019, several articles substantiate the role of cone-beam computed tomography (CBCT) as a valuable adjunct in endodontics, especially when conventional two-dimensional radiography is insufficient. Identification of complex root canal anatomy stands among such major applications highlighted during that period. CBCT was shown to help in better visualization and treatment planning of extra canals, unusual morphologies, and anatomical variations that are mostly missed in periapical imaging, thus minimising the possibility of technical errors (Patel et al., 2019). CBCT was equally effective in the identification of periapical pathoses. Evidence supports that CBCT can identify periapical radiolucencies at an earlier instance and more correctly than conventional radiographs, especially where the anatomical structures align for superimposition to restrain diagnostic reliability (Kruse et al., 2019). Similarly, CBCT was demonstrated to be superior in the evaluation of root resorption, differentiating between internal and external resorptive defects, and in determining the exact extent of a lesion, a critical step in deciding the treatment option (Estrela et al., 2019). Another important clinical application in 2019 was in the assessment of vertical root fractures. CBCT was demonstrated to be more sensitive than periapical radiography, although it has its limitations of beam-hardening artifacts in teeth with metallic restorations or root fillings; thus, careful consideration during interpretation is warranted (Tsesis et al., 2019). From a diagnosis perspective latterly, CBCT saw even more prominence in pre-surgical planning. CBCT offered a thorough three-dimensional understanding of root apices, surrounding bone, and their relationship with anatomical landmarks such as the mandibular canal and maxillary sinus to ensure more predictable surgical outcomes and diminished operative risks (Bornstein et al., 2019). In 2019, this evidence further suggested that CBCT could affect decision-making in complicated endodontic cases. Several studies revealed that 3D imaging changed the treating clinician's treatment plan more often when compared to decisions based on conventional radiographs, especially for cases of medium to high complexity. The implication, therefore, is that CBCT contributes not only to enhanced diagnostic precision but critical clinical strategizing as well that leads to improved patient care (Gambarini et al., 2019).

III. ADVANTAGES OF CBCT OVER CONVENTIONAL RADIOGRAPHY

It may be said that by March 2019, CBCT had percolated into the endodontic world as the very fine instrument of imaging when compared to conventional two-dimensional radiography. One major advantage is the prevention of anatomical superimpositions. In simple words, in a periapical or panoramic radiograph, only a flat view of three-dimensional structures is offered. But in CBCT, with volumetric images, the clinicians are given the opportunity to see the teeth and surrounding tissues sans overlapping structures, thereby impinging strongly on the diagnostic accuracy (Patel et al., 2019). It can also capture very fine details of anatomy. CBCT accurately shows the morphology of root canals, accessory canals, or variations like C-shaped canals or dens invaginatus that are commonly missed by regular radiographs. Such detailed imaging leads to better treatment planning, hence reducing the chance of overlooking pathologies (Kruse et al., 2019). CBCT is more sensitive than conventional periapical radiographs in the detection of periapical lesions. Periapical radiographs may not show periapical radiolucencies at an early stage or when their size is small, because of superimposition of bone and absence of good contrast. Nonetheless, CBCT affords the detection of faint bone modifications and, thereby, proves to be favorable in periapical diagnosis and monitoring the healing after treatment (Estrela et al., 2019). In assessing root resorption and vertical root fractures, CBCT even offers additional advantages; it precisely establishes the type, site, and extent of resorption, which periapical radiographs cannot attain because they are affected by projection geometry. Similarly, CBCT also has a higher sensitivity for the diagnosis of vertical root fractures, though it needs to be interpreted with caution because of the possibility of artifacts brought about by restorations or root fillings (Tsesis et al., 2019). Besides being better for diagnosis, CBCT can assist greatly in treatment planning for complex cases. The three-dimensional representation of the root apex and critical anatomical structures facilitates surgical endodontics in mapping them in relation to the mandibular canal and maxillary sinus, thus improving surgical precision and minimizing risk to adjacent vital tissues (Bornstein et al., 2019). Furthermore, research studies published early in 2019 highlighted that in moderate to high complexity cases, CBCT frequently caused changes in clinical decision-making, reinforcing the fact that it influences treatment far beyond diagnosis (Gambarini et al., 2019). Thus, the advantages that CBCT enjoyed over conventional radiography were diagnostic accuracy, anatomical visualization, and influence over clinical decisions. With these strengths, CBCT has evolved as a very useful adjunct in endodontic practice, especially when conventional radiographs failed to suffice.

IV. RADIATION RISKS AND THE NEED FOR OPTIMIZATION

Being cone-beam computed tomography rarely delivers doses of ionizing radiation as low as those from medical computed tomography, meanwhile, patients can receive far higher doses while being imaged using conventional intraoral or panoramic radiographs. Prior to March 2019, authors had underlined the concerns that even relatively low doses of radiation in dental CBCT might add to the cumulative lifetime exposure and, therefore, slightly increase the long-term risk for stochastic effects such as carcinogenesis (Patel et al., 2019). This is highly relevant while addressing younger patients and cases where repeated imaging is necessary, as children and adolescents tend to rank higher among radiosensitive groups because of prolific mitotic activity in their tissues (Bornstein et al., 2019). A study from 2019 also highlighted that radiation doses had widely varied according to the selected exposure parameters, and alarming was the opinion that improper parameter setting only gave rise to unnecessary radiation exposure, in the absence of any further increase in the diagnostic yield (Kruse et al., 2019). This, of course, reiterates the fact that the justification and optimization of doses should always be considered so that CBCT is applied only when conventional radiography does not provide adequate diagnostic information. Prior to 2019, all the literature advised the application of concepts such as ALARA (As Low As Reasonably Achievable) and ALADA (As Low As Diagnostically Acceptable) to reduce these risks. Traditional ALARA sets its objective to reduce exposure even further than what has already been established in regulations. ALADA intends that low dose be complementary to diagnostic image quality. In 2019, clinical guidelines recommended that the use of CBCT should be restricted to those instances of complex anatomy, non-healing periapical lesions, or surgical planning in which additional three-dimensional information is absolutely necessary (Estrela et al., 2019). At the end of the day, optimization is needed because the clinician's double-edged sword serves both members: to maximize diagnostic benefit to the patient's detriment. In turn, in endodontics, as studies appeared repeatedly until March 2019, there can be no justification for irrational or routine use of CBCT; only from a wise selection of cases, adjustment of exposure parameters, and even implementation of evidence-based guidelines can patient safety be achieved (Gambarini et al., 2019).



V. IMPORTANCE OF IMAGING IN ENDODONTICS

Imaging holds a central place in modern endodontics, standing as a forté tool for diagnosis, treatment planning, and evaluation of therapeutic success. By March 2019, it had been in place for quite some time that radiographic examination is a sine qua non for the determination of periapical disease, assessment of root canal morphology, and identification of pathological conditions, which clinical examination fails to diagnose by itself (Patel et al., 2019). Historically, conventional periapical radiographs have provided the mainstay of endodontic diagnosis. Its two-dimensional nature casts significant limitations due to anatomical superimposition and geometric distortion (Kruse et al., 2019). The introduction of CBCT has resolved most of these problems, enabling three-dimensional imaging, which in turn allows better visualization of intricate root canal systems, incipient periapical lesions, and root resorption. By 2019, evidence had emerged to confirm that CBCT aids the clinician in better detecting extra canals and assessing periapical disease than traditional radiography, thereby improving its accuracy in guiding surgical procedures (Bornstein et al., 2019). These abilities have thus elevated imaging from a diagnostic adjunct to a determining factor of treatment outcomes, especially in the management of cases of moderate to high complexity. Monitoring treatment follow-up and healing represent other fields where imaging is important in endodontics. Early 2019 studies showed that CBCT was more reliable than periapical radiographs in assessing periapical healing or persistent disease, thereby minimizing the risks of unnoticed failures (Estrela et al., 2019). From a clinical perspective, advanced imaging also influences clinical decision-making. It was confirmed in 2019 that treatment plans had been frequently changed following CBCT evaluation, emphasizing the direct impact of imaging on clinical decisions and promoting evidence-based care (Gambarini et al., 2019). Taken together, the evidence before March 2019 makes clear that imaging is not an adjunct but the mainstay of endodontics; it supports diagnosis, guides treatment planning, and allows reliable follow-up to ascertain that the patient is going to receive the best care possible.

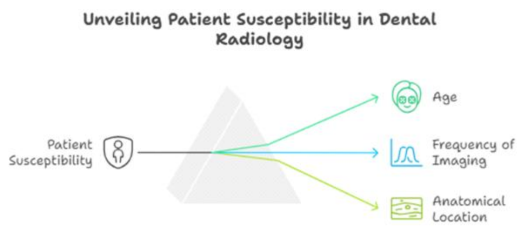
VI. RADIATION DOSE LEVELS IN CBCT VS. PERIAPICAL/PANORAMIC RADIOGRAPHS

Radiation epidemiology had by March'19 never failed to teach us the lesson that CBCT provides higher doses of radiation than conventional periapical and panoramic radiography, but far less than in medical CT. Patently, periapical and panoramic radiographs generally confer an effective dose in the order of a few microsieverts (μSv), somewhere in the range of 1–8 for periapical images and roughly 10–30 for panoramic exposures, all depending on technique and equipment (Patel et al., 2019). Conversely, dental CBCT examinations were reported to deliver doses ranging from 19 μSv for small field-of-view (FOV) protocols to beyond 600 μSv for large-FOV protocols, depending on appropriate choices of exposure parameters like voxel size, tube current, or scan time (Bornstein et al., 2019). On the clinical levels, the discrepancies of radiation dose and the prices attached thereto have hugely affected decision-making. One small-FOV CBCT scan could equal the dose of several panoramic radiographs. However, a large-FOV CBCT could receive orders of magnitude above these doses and thus raise concerns as to justification for routine use in endodontics (Kruse et al., 2019). For example, early 2019 adduced evidence demonstrating the full-arch-CBCT-scan-dose-equivalent possibility of dozens and even hundreds of periapical radiographs, making it necessary to use it with discretion (Estrela et al., 2019). On the other hand, CBCT does have some potential for dose saving, as demonstrated with scan settings adjustments to reduce exposure and maintain diagnostic quality. However, the evidence gathered until 2019 has been stressing that it is not worthy of replacing conventional radiography but deserves to have a complementary role to be used when two-dimensional (2D) radiographs are not sufficient (Gambarini et al., 2019). Hence CBCT, with its tremendous diagnostic reward, nevertheless has a higher radiation load vis-à-vis periapical and panoramic radiography, which locals the imperative of optimization strategies and compliance to ALARA and ALADA principles for weighing of diagnostic benefit against patient safety.

VII. PATIENT SUSCEPTIBILITY AGE, FREQUENCY OF IMAGING, ANATOMICAL LOCATION

By March 2019, interdisciplinary research in dental radiology focused on analyzing the factors influencing patient susceptibility, concluding that such susceptibility indeed plays a determining role in assessing the risks involved with cone-beam computed tomography (CBCT). Age is an important determinant, with younger patients being considered more radiosensitive due to higher rates of cellular mitosis and the fact that they have a longer post-radiation lifespan, thereby increasing the probability of radiation-induced stochastic effects such as malignancies (Patel et al., 2019). Hence, clinical guidelines in 2019 strongly recommended that CBCT should only be prescribed for pediatric and adolescent endodontic patients when conventional radiography is unable to provide sufficient information and when 3D imaging is expected to influence the treatment plan in a meaningful way (Bornstein et al., 2019). The frequency of imaging also attributes to susceptibility levels. While the dose from a solitary small field-of-view (FOV) CBCT scan may be justifiable, repeated exposures across the phases of diagnosis, treatment, and follow-up may have a hefty contribution to cumulative effective dose (Kruse et al., 2019). By 2019, the inappropriate or routine application of CBCT was considered unjustifiable exposure to unnecessary radiation risk to patients through repeated scans lacking a firm clinical indication (Estrela et al., 2019). Anatomical location is also considered an important factor in susceptibility. Critical structures such as the thyroid, salivary glands, and lens of the eye are highly sensitive to ionizing radiation. In 2019, maximum CBCT exposures, especially those associated with large FOV protocols, were said to have the potential to increase exposure to radiosensitive tissues such as the orbit and brain and while mandibular scans lay risks for the thyroid and cervical spine exposure (Gambarini et al., 2019).

Consequently, dose optimization strategies like using the smallest possible FOV and adjusting the exposure parameters according to the diagnostic need were stressed as necessary practices. In toto, the evidence available by early 2019 reinforced that susceptibility to radiation risk does not remain the same across patients but varies by age, frequency of imaging, and specific anatomical region exposed, hence underscoring the importance of well-considered case selection and adherence to radiological protection principles to ensure that diagnostic benefits surpass potential harms.



VIII. DISCUSSION

The emphasis on radiation dose optimization in CBCT for endodontics was supported in March 2019 by an increasing number of studies emphasizing dose reduction without compromising diagnostic quality. One major strategy involves adjusting exposure parameters, such as by changing operating potential (kV) and tube current–exposure time product (mAs), so as to reduce radiation dose to a great extent and yet preserving diagnostic efficacy. According to a 2019 systematic review, decreasing kV and mAs settings on CBCT units could indeed lower patient exposure significantly, and without negatively affecting image quality or diagnostic accuracy. The FOV should be carefully selected to suit the anatomy relevant to the task. Smaller FOV scans have the innate ability to provide dose reduction through the limitation of irradiated volume. This will be an important consideration when looking at complicated endodontic lesions, so as to avoid unnecessary irradiation of neighboring areas. Although studies continued to investigate low-dose protocols for endodontic situations in 2020, the trend favouring targeted, low-dose imaging had already gained momentum. Optimized scanning parameters (3 mA, 99 kVp, 450 projections, etc.) in phantoms and anthropomorphic models resulted in lower effective doses while providing satisfactory image quality, further bolstering the notion of fine-tuning CBCT acquisition parameters in the interest of patient safety. The 2019 guidance emphasizes that parameters should be set "as low as diagnostically acceptable," supporting clinical decision making through a risk-aware framework known as ALADA, which seeks to evolve the ALARA principle by balancing minimal dose against diagnostic adequacy. Together, these findings strongly suggest that with a common language of parameter optimization (kV/mAs), a selective FOV, and the ALADA principle, clinicians, in large part, will be able to drastically cut down radiation exposure for endodontic CBCT imaging while simultaneously retaining the clarity and diagnostic value necessary for treatment planning.

CONCLUSION

By 2019, radiation dose optimization had become essential in CBCT endodontics in relation to the balancing of diagnostic efficacy and patient safety. CBCT has indeed provided claims for better spatial visualization over conventional radiography but at the award of higher radiation doses, and therefore, its application must remain justifiable. Decreasing patient exposure with no loss of diagnostic capability can be achieved by reducing the exposure settings (kV, mAs, scan time), application of FOV limited to the region of interest, and adoption of low-dose protocols. The professional guidelines available then reiterated the ALARA and ALADA principles and suggested that CBCT would be prescribed only when ordinary imaging methods were insufficient and three-dimensional information would actually affect treatment planning or treatment outcomes. Therefore, considering radiation dose optimization for CBCT will allow for maximizing the benefit of diagnosis using advanced imaging machines while sparing patients from an unnecessary actual hazard, thereby presenting the safer and evidence-based endodontic practice.

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