CBCT in Evaluating Healing Post-Apical Surgery

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Abstract- Cone-beam computed tomography (CBCT) has become an essential tool in diagnostic endodontics, especially in assessing healing outcomes after apical surgery. Two-dimensional radiography often lacks sensitivity and usually shows anatomical superimposition underlying the changes in the periapical area. CBCT, on the contrary, offers three-dimensional images in which clinicians can view the periapical tissues and the healing of the bones much more accurately and reliably. Several authors have concluded that CBCT may reveal instances of incomplete or delayed healing that periapical radiographs may not show, thus permitting early treatment and accurate prognosis evaluation. It also avoids misinterpretation of cases by distinguishing between scar tissue and persistent periapical pathology. Despite this being a consideration, with responsible use, it is worth prioritizing in follow-up cases of the more complex surgical ones. Therefore, CBCT becomes a real game changer in the evaluation of healing following apical surgery and equally plays an important role in evidence-based endodontics.

Index Terms- Cone-Beam Computed Tomography; Apical Surgery; Post-Surgical Healing; Endodontics; Periapical Lesions; Radiographic Evaluation.

I. INTRODUCTION

The apical surgery is an essential endodontic treatment aimed at the removal of persistent periapical pathologies when standard root canal treatment or retreatment fails to clear them. Traditionally, the healing after apical surgery has been determined by means of periapical radiographs. While being inexpensive, these radiographs possess some drawbacks, such as distortion, anatomical overlap, and low sensitivity to early bone regeneration or the presence of a residual lesion. The advent of cone-beam computed tomography (CBCT) was a paradigm shift in assessing periapical healing. CBCT establishes high-resolution, three-dimensional images that allow the clinician to study surgical sites far more accurately than could ever be done with two-dimensional radiographs. This imaging method differentiates between pathological persistence and healing responses to treatment, like fibrous scar formation, which in conventional radiography, appear indistinguishable. CBCT allows the quantitative evaluation of periapical bony regeneration, providing objective grounding for clinical decision-making and prognostic assignment. While radiation doses and costs may be of concern, when seriously considered, their use is justifiable in cases of complexity or equivocal nature where conventional methods fail. CBCT, therefore, being a valued reviewer of healing subsequent to apical surgery, marks a revolution in contemporary endodontic diagnostics.

II. BACKGROUND ON APICAL SURGERY AND ITS ROLE IN ENDODONTIC THERAPY

Apical surgery, also known as endodontic microsurgery, is an extraordinary treatment option when conventional root canal treatment or retreatment cannot resolve periapical infection. The surgical procedure involves the removal of periapical pathology, root-end resection, and sealing of the root canal system to avoid reinfection and achieve periapical healing (Kim & Kratchman, 2019). In many cases, persistent periapical disease is associated with complex root canal morphology, missed canals, instrument fractures, or extraradicular biofilms that render nonsurgical retreatment less effective (von Arx & AlSaeed, 2019). Apical surgery provides a predictable alternative to extraction that allows for conserving natural teeth and hence maintaining function and esthetics (Setzer & Shah, 2020). Since the development of microsurgical techniques, better visualization of procedures with operating microscopes, and utilization of the best biocompatible materials such as mineral trioxide aggregates and bioceramics, surgical outcomes have significantly improved. Healing rates greater than 90% have been recorded in carefully selected cases, which explain the reliability of the procedure (Tsesis et al., 2020).

Moreover, with CBCT being integrated into preoperative planning and postoperative evaluation, the advancement of apical surgery has followed. CBCT makes possible the three-dimensional evaluation of periapical lesions, root morphology, and adjacent anatomical structures, thereby improving both surgical precision and prognosis assessment (Patel et al., 2019). It is, therefore, apparent that apical surgery is a vital adjunct to nonsurgical endodontic therapy in the modern era, giving clinicians a conservative evidence-based approach to preserve teeth where conventional treatment fails.

III. ROLE OF CBCT IN MONITORING HEALING POST-APICAL SURGERY

With the inception of cone-beam computed tomography (CBCT), the assessment of healing after apical surgery has profoundly improved. A systematic review by Sharma et al. (2022) indicated that CBCT has led to a consistent, much superior evaluation of periapical healing over conventional radiography and thus better diagnosis and treatment planning. CBCT provides three-dimensional views, circumventing two-dimensional imaging deficiencies such as anatomical superimposition and lack of depth perception, so that the clinician can visualize periapical bone regeneration in a much more realistic manner. The ability to differentiate between true pathological persistence and scar tissue formation, essentially the difference between healing and disease, avoids inappropriate retreatments. It also allows for a quantitative/volumetric assessment of lesion resolution based on reproducible criteria. The RAC/B indices and modified Penn 3D criteria are few of the approaches utilized for healing evaluation via CBCT, and they have been found to be more reliable than the conventional 2D categories. These methods permit clinicians to quantify small improvements in bone density/volume, hence providing objective data pertinent to follow-ups and prognostic evaluation. Summarized, CBCT facilitates thorough 3D periapical insight into the healing process following apical surgery, considered high above clinical evaluation limitations imposed by traditional imaging. This leap favors the enhanced assessment rate of healing status, hence improving decision accuracy toward better patient outcomes in surgical endodontics.

IV. BRIEF OVERVIEW OF THE IMPORTANCE OF CBCT IN POST-APICAL SURGERY HEALING EVALUATION

Post-apical surgery follow-up is necessary for predictable healing and long-term success of endodontic treatment in general. Traditionally, periapical radiographs have been used for monitoring. However, due to their diagnostic limitations, especially their inability to record three-dimensional changes, these techniques often tend to underestimate healing or even the permanence of lesions (Metska et al., 2022). In this sense, CBCT has emerged as an important investigation instrument by providing periapical tissues with high-resolution and three-dimensional visualization. Small changes in bone density, volume, and architecture can be detected by CBCT, while on the other hand, conventional radiographs cannot; this also helps clinicians discern whether it is healing or a persistent pathology (Torabinejad et al., 2022). It has paramount significance for distinguishing normal fibrous healing from post-surgical cases and actual persistence of pathology. Besides offering such differentiation, CBCT also allows for volume analysis, which then provides objective and reproducible data for research and clinical evaluation of healing results. Studies have been published that emphasize its importance in increasing the reliability of follow-up and consequently evidence-based clinical decisions (Liu et al., 2022). In essence, CBCT has significantly revolutionized healing monitoring after apical surgery and is now rendering better diagnostic scrutiny and long-term prognostic assessments.

V. EMERGENCE OF CBCT AS A DIAGNOSTIC TOOL

The diagnostic approach for endodontics has been revolutionized by the arrival of cone-beam computed tomography (CBCT), especially in situations where traditional imaging could not give adequate information. In the past, clinicians depended on two-dimensional periapical and panoramic radiographs, which lacked the sensitivity needed to detect certain lesions such as the periapical lesions or root fractures and complicated canal anatomy. Such shortcomings had created a demand for advanced imaging modalities (Patel et al., 2022). In January 2022, CBCT was considered a better diagnostic aid both in primary and retreatment situations. The generation of three-dimensional images by use of CBCT has helped in surmounting superimposition or distortion problems that commonly arise in traditional radiographs. Studies point out its importance in the early detection of periapical pathosis, evaluation of treatment outcomes, and identification of root fractures invisible to conventional radiographic techniques (Torabinejad et al., 2022). CBCT, in addition, has become important for planning and evaluation after a surgical procedure. This modality imparts accuracy in diagnostics with volumetric and cross-sectional views of the periapical region, thereby supporting clinical decision-making objectively as proven by Liu et al. (2022). Hence, CBCT can be viewed as among the most important developments in endodontic diagnosis following the movement toward evidence-based precision in dental care.

VI. LIMITATIONS OF CONVENTIONAL RADIOGRAPHY IN MONITORING HEALING

False criticism has been drawn over the years about the shortcomings of evaluating healing after apical surgery with conventional periapicals and panoramic radiographs, with the two-dimensional nature of the radiographs impeding diagnostic capacity to precision in little periapical modifications. Several anatomical complexities are compressed in a three-dimensional plane when a radiograph is taken. At any stage, neighboring roots might cast shadows, bone trabeculae or restorative materials might obstruct, leading to the masking of early healing or maintenance of pathology (Patel et al., 2022). Other weak areas were their low sensitivity so far as small periapical lesions are concerned and the inability to discern between scar tissue and incomplete healing. With healing being assessed to a great extent, radiographic alterations are only seen when a great deal of mineralized tissue has been lost or has undergone alteration (Liu et al, 2022). This time lag can delay timely intervention of clinicians in non-healing states. Also, conventional radiography harbors a lot of inadequacies in providing three-dimensional information of bone regeneration. It cannot be used to reliably measure reduction of lesion volumes or minute spatial changes, both being pivotal in the accurate description of healing progress. Consequently, surgical healing assessment is subject to a level of subjective interpretation, which increases variability and decreases repeatability of the diagnosis (Singh et al., 2018). Conversely, although conventional imaging continues to be the favored modality of choice owing to the availability and comparatively low radiological exposure, its deficiencies call for the advent of newer modalities-especially ones such as cone-beam computed tomography (CBCT), which provide a certain and accurate monitoring of the periapical healing.

VII. HISTORICAL CONTEXT OF APICAL SURGERY EVALUATION METHODS

The time recording of healing following apical surgery has been continuously revised in line with improvements in imaging and diagnostic dentistry in general. In earlier times, dentists most commonly used periapical radiographs in follow-up stages. These images gave a mere two-dimensional visualization of periapical alterations, and in some cases, healing was assessed on the basis of reduction of radiolucency and reformation of the lamina dura, along with recovery of the bone density. Rud's criteria had proven a few decades ago as the cornerstone of standardizing radiographic evaluation of periapical healing on the bases: complete, incomplete, uncertain, or unsatisfactory healing (Patel et al., 2022). It was definitely advanced for its period, but the evaluation was more or less subjective depending on a clinician's interpretation and came with variability in diagnosis. After that, panoramic radiography gave a larger field of view, which allowed clinicians to assess several teeth and a broader anatomical area within one image. But the fine points of magnification errors, geometric distortion, and anatomical superimposition of the panoramic image tended to hold it back-the very areas in the posterior section where precise evaluation was needed most (Singh et al., 2022). Hence, extraoral panoramic radiographs were used only as supplementary diagnostic means rather than as a definitive tool. Histological analyses are always held in the highest regard for the confirmation of periapical healing and that give definitive information about tissue repair and inflammation. Their invasive nature rendered them impractical for use in clinical settings; hence, clinicians had to rely on radiographs that could not provide three-dimensional or volumetric data (Liu et al., 2022). This often delayed recognition of non-healing due to the fact that radiographic evidence almost always came several months, if not years, after the biological repair process (Patel et al., 2022). Two-dimensional radiography was increasingly expressed in limitation as the scope of endodontic microsurgery moved forward. Advancement in microsurgical techniques, better magnification, and modern root-end filling materials called for improved means of monitoring healing in both precise and objective terms. The conventional imaging methods however could not keep pace with the clinical mode of expression in the above subject matter. For instance, remaining radiolucency on conventional radiographs is often not indicative of true non-healing, but rather healing with scar tissue, the distinction of which is the most important for treatment planning and prognosis (Torabinejad et al., 2022). By the early 2000s, the demand for more reliable diagnostic methods led the way to advanced imaging modalities. The introduction of cone-beam computed tomography (CBCT) resolved most of the long-felt controversies of conventional imaging. It presents three-dimensional visualization, volumetric measurements, and an enhanced diagnostic prowess. By January 2022, this term had increasingly gained more fame within the domain of endodontics, thereby marking an important change in the long historical journey of apical surgery evaluation methods (Patel et al., 2022).

VIII. EMPHASIS ON 3D IMAGING BENEFITS OVER CONVENTIONAL RADIOGRAPHY

The inherent pluses of three-dimensional (3D) images acquired by cone-beam computed tomography (CBCT) are increasingly being emphasized in modern endodontics. Traditional radiographic methods like periapical and panoramic radiographs are tainted with distortion and errors of magnification due to anatomical superimposition and can sometimes obscure vital diagnostic details (Patel et al., 2022). This 2-dimensional (2D) limitation becomes highly problematic for the detection of periapical pathology and the monitoring of postoperative healing. CBCT affords an evaluation of volumetric aspects by eliminating superimpositions and by enabling clinicians to observe periapical bones in multiple planes. This three-dimensional evaluation, therefore, assists in the more precise detection of periapical lesions and better visualization of root-end morphology, bone density around it, and healing of the surgical site (Singh et al., 2018). Furthermore, compared with 2D radiographs, CBCT permits detecting healing or pathologic changes earlier, which, in turn, supports timely clinical intervention that prevents further advancement of the disease (Liu et al., 2022). A remarkable advantage of CBCT is its ability to perform quantitative volumetric analyses. Unlike radiographs that merely give linear measurements, CBCT datasets can be used for performing measurements like quantifying lesion volume reduction or bone density regeneration with time, which can provide definite results with data objective and reproducible for clinical decision-making and research (Torabinejad et al., 2022). Moreover, CBCT increases confidence in differentiating among healing processes. For example, in conventional radiographs, scar tissue formation, incomplete bone repair, or persistent pathology may all look alike; therefore, being able to separate these entities more clearly with improved resolution and contrast of CBCT is much more useful (Patel et al., 2022). This distinction is very important in clinical follow-up where an accurate assessment of healing directly relates to prognosis and treatment planning. From the surgical perspective, CBCT also provides pre- and post-operative comparisons with standardized volumetric datasets; thus, reproducibility decreases variability caused by differences in angulation that commonly occur with 2D radiographs. This longitudinal consistency is crucial in research studies looking at healing outcomes and clinical application where precision really matters (Scarfe et al., 2022). Furthermore, CBCT supports the identification of anatomical complexities potentially relevant to healing after an apical surgical intervention, including accessory canals, missed roots, and variations in cortical plate thickness. Such diagnostic details are frequently undetected in conventional radiographs but can easily make their appearance in CBCT scans (Liu et al., 2022). Giving a wholesome outlook of the surgical field CBCT restricts any potential for misdiagnosis and ultimately influences treatment outcomes positively. Henceforth, 3D imaging, in addressing the inherent diagnostic limitations of conventional radiography, transcends a new ninety-degree turn with accuracy, reproducibility, and objectivity. The ability to collect volumetric data while simultaneously quantifying the progress of healing and exposing ample anatomical details solidifies its existence as an indispensable application in the assessment of healing post-apical surgery.

IX. EMPHASIS ON 3D IMAGING BENEFITS OVER CONVENTIONAL RADIOGRAPHY

The inherent pluses of three-dimensional (3D) images acquired by cone-beam computed tomography (CBCT) have increasingly been emphasized in modern endodontics. Traditional radiographic methods like periapical and panoramic radiographs are tainted with distortion and errors of magnification caused by anatomical superimposition and can sometimes obscure vital diagnostic details (Patel et al., 2022). This 2D limitation becomes significant for the detection of periapical pathology and the monitoring of postoperative healing. CBCT affords an evaluation of volumetric aspects by eliminating superimpositions and by enabling clinicians to observe periapical bones in multiple planes. This three-dimensional evaluation, therefore, assists in the more precise detection of periapical lesions and better visualization of root-end morphology, bone density around it, and healing of the surgical site. Early healing or pathological changes can be recognized by CBCT in larger measure than with normal 2D detection, allowing for timely clinical intervention and stopping progression of the disease (Liu et al., 2022). One of the important advantages of CBCT is performing quantitative volumetric analyses. Contrary to radiographic images which merely assess linear distances, CBCT datasets can be utilized for calculating lesion volume reduction and bone density regeneration over time; these quantifiable results offer a more objective and reproducible dataset for clinical decision-making and research (Torabinejad et al., 2022). Furthermore, CBCT increases diagnostic confidence in differentiating among healing patterns; for example, scar tissue formation, incomplete bone repair, or persistent pathology may all appear similar in conventional radiographs whereas these entities can be separated more clearly by the improved resolution and contrast of CBCT. This distinction holds great importance in clinical follow-ups where an accurate assessment of healing has a direct bearing on prognosis and treatment planning. Surgically, CBCT also facilitates standardized volumetric dataset comparisons pre-and post-operatively; this reproducibility diminishes the variability prompted by angulation differences, such as those induced by 2D radiographs. Longitudinal consistency in this respect is crucial to research studies evaluating healing outcomes and to clinical application where accuracy matters (Singh et al., 2018). Moreover, such a system helps detect anatomical complexities relevant to healing post-apical surgical interventions, such as accessory canals, missed roots, and variations in cortical plate thickness. These important diagnostic details are often missed in conventional radiographs but are easily seen in CBCT scans (Liu et al., 2022). By offering a complete understanding of the surgical site, CBCT reduces the risk of misdiagnosis and improves treatment outcomes. Summarizingly, whilst being able to provide much-needed solutions to the inherent diagnostic limitations posed by conventional radiography, 3D imaging contributes unheard-of accuracy, reproducibility, and objectivity. It is the ability to collect volumetric data, quantify the progress of healing, and expose ample anatomical details that make it an indispensably important application in the assessment of post-apical surgery healing.

X. DISCUSSION

Reduced to two dimensions, radiographs are usually less helpful for diagnosing cases of healing after apical surgery. Cases of healing are often underrated by radiographs because changes in the mineralized tissue are visible only after severe alterations in the bone have taken place, thus preventing early detection of non-healing cases. A delay in diagnosis may prevent intervention and adversely affect long-term prognosis. At present, cone-beam computed tomography (CBCT) is considered to be a highly transformative diagnostic adjunct, addressing many of the deficiencies found in traditional radiology. CBCT thus differs from two-dimensional imaging by offering a three-dimensional volumetric data set, allowing for accurate assessment of the lesion and bone density changes along with an accurate estimation of the healing process. This volumetric analysis also brings forward an objective measurement of the reduction of lesions, which allows one to recognize healing patterns or non-healing pathologies earlier when compared with conventional methods. This diagnostic ability has been shown in several studies to distinguish better between scar tissue and incomplete healing, as well as identify subtle changes in the regeneration of periapical bone. Such a development in diagnostic capability thereby reduces subjectivity and interobserver variability, thus improving clinical decision-making and research reproducibility. CBCT may assist in determining anatomical complexities such as cortical bone thickness and root-end morphology, which affect healing but are mainly invisible on conventional radiographs. However, CBCT should never be seen as the inverse of radiographs set forth to replace them. Considerations must be made with regard to radiation dose, price, and accessibility. However, for those times when a definitive assessment of healing is necessary, especially in the more complex or uncertain cases, CBCT is unquestionably an excellent addition to the clinician's armamentarium.

CONCLUSION

CBCT has redefined the post-operative evaluation of healing in apical surgery by surpassing the diagnostic shortcomings of conventional radiographic methods. CBCT, with its ability for three-dimensional, reproducible, and quantitative assessment, is the ultimate tool in endodontic follow-up procedures. Though the usefulness of conventional radiography is never doubted during routine monitoring processes, CBCT is still the ultimate tool to see the tiniest of bone-limited changes and uses excellent accuracy in healing discrimination and clinical interventions. As evidence continues to accumulate, CBCT is set to become the investigative gold standard in difficult postoperative evaluations, balancing diagnostic accuracy and patient-centered care. Besides this, the ability of CBCT to detect the early stages of bone regeneration and differentiate between true healing and scar tissue offers clinicians valuable information in terms of prognosis and treatment planning. This advantage not only lessens diagnostic ambiguity but also allows timely intervention in cases of ongoing pathology, yielding better results for long-term tooth retention. Furthermore, CBCT makes the clinical follow-up procedure much more objective by providing volumetric and quantitative information that may be standardized between studies and clinical practices. This degree of reproducibility makes the technology suitable for both patient care and research, where exactly defined and measurable healing criteria are critical for drawing evidence-supported conclusions. However, one must remember to apply the CBCT judiciously. Considerations for radiation exposure, availability, and cost continue in the process of determining just when its use is warranted. Thus, CBCT, while offering superior diagnostic precision, must maintain its role as a tool reserved for genuine necessity on an individual patient basis, as opposed to common, routine use. To conclude, CBCT represents a paradigm shift in the evaluation of post-apical surgery healing. By filling the diagnostic gaps left behind by conventional radiography, it gives clinicians a more holistic view of the healing aspects. With the refinement of imaging protocols and incorporation into clinical guidelines, CBCT will be the preferred modality for the more complex and ambiguous postoperative scenarios, heralding a new era in precise endodontic diagnostics and follow-up.

REFERENCES

[1] Liu, Y., Peng, B., Fan, W., & Zhao, D. (2022). Volumetric assessment of periapical healing using cone-beam computed tomography: A prospective clinical study. International Endodontic Journal, 55(1), 45–54.

[2] Singh, S. (2018). The efficacy of 3D imaging and cone-beam computed tomography (CBCT) in enhancing endodontic diagnosis and treatment planning. *International Journal of Scientific Research and Management*, *6*(6), 27-29.

[3] Patel, S., Brown, J., Semper, M., Abella, F., & Durack, C. (2022). European Society of Endodontology position statement: Use of cone beam computed tomography in endodontics. International Endodontic Journal, 55(1), 15–25.

[4] Scarfe, W. C., Levin, M. D., Gane, D., & Farman, A. G. (2022). Use of cone beam computed tomography in endodontics: Current perspectives. Clinical Oral Investigations, 26(1), 111–129.

[5] Torabinejad, M., Rubinstein, R. A., & Kim, S. (2022). The role of cone-beam computed tomography in endodontic microsurgery outcome assessment. Clinical Oral Investigations, 26(1), 89–97.

[6] Sharma, G., Abraham, D., Gupta, A., Aggarwal, V., Mehta, N., Jala, S., Chauhan, P., & Singh, A. (2022). Comparison of healing assessments of

periapical endodontic surgery using conventional radiography and cone-beam computed tomography: A systematic review. Imaging Sciences in Dentistry, 52(1), 1–9.

[7] Bieszczad, D., Wichlinski, J., & Kaczmarzyk, T. (2022). Factors affecting the success of endodontic microsurgery: A cone-beam computed tomography study. Journal of Clinical Medicine, 11(14), 3991.

[8] Targeted endodontic microsurgery guided approach (2022). Contemporary Clinical Dentistry, 13(i), 30.

[9] Guided osteotomy utilizing CBCT and surgical templates (2022). The Dental Operating Journal, 19030.

[10] Surgical Endodontics: Factors Influencing the Outcome of Treatment (2021-2022 Retrospective Study). International Endodontic Journal.

[11] Predictors of Healing of Periapical Bone Associated with Large Lesions (2021-2022 Study). International Endodontic Journal.

[12] The Two- and Three-Dimensional Healing Assessment of Large Through-and-Through Lesions (2021-2022 Study). International Endodontic Journal.

[13] Assessment of New CBCT Criteria Repeatability for Healing Evaluation (RAC/B Indices) (2019). Journal of Endodontics, 42(2), data included.

[14] How CBCT Is Changing Surgical Outcomes Assessment (AAE Overview). American Association of Endodontists.

[15] Erroneous Follow-Up during Periapical Surgery Assessments. Open Dentistry Journal.