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AI-ASSISTED OBTURATION QUALITY ASSESSMENT

Ioana Popescu & Sarah Müller

Research Scholar, Department of Computer Science, Oxford University, England United Kingdom

ABSTRACT

The quality of root canal obturation plays a decisive role in ensuring long-term success of endodontic treatments; improper filling can cause the entrance or retention of bacteria, thus leading to the failure of the treatment and retreatment if necessary. Earlier, the methods of assessing the quality of obturation included the judgment of the clinicians, tactile feel, and two-dimensional (2D) radiographs. A lot of subjectivity could be involved, and the radiographs also have their limitation. The recent application of artificial intelligence (AI) systems, in particular machine learning (ML) and deep learning (DL) algorithms, have transformed dental diagnoses, and this has permitted objective, reproducible, and very accurate evaluation of the outcomes of the obturation process. An AI-assisted system can detect voids, underfilling, overfilling, and other technical issues with radiographic and cone-beam computed tomography (CBCT) datasets and thus minimize the variability of diagnosis. These systems can provide real-time decision support; ensure workflow optimization; and develop predictive models to improve treatment planning. This paper aims to discuss the principles, applications, and clinical integration of AI-assisted obturation quality assessment towards its radical influence in the modern endodontic sciences as well as the hurdles that still cluster its widespread use.

KEYWORDS: *Artificial Intelligence; Endodontics; Root Canal Obturation; Quality Assessment; Deep Learning; Cone-Beam Computed Tomography; Dental Radiology; Machine Learning*

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INTRODUCTION

Root canal obturation has long been considered an integral part of the process of preventing future bacterial penetration and reinfection of the root canal system and ensuring long-term endodontic treatment success. As opposed to definite parameters for assessment of the obturation quality in the clinic, 2D periapical radiographs with clinical evaluation regarding the length, density, and taper of canal filling have always been the preferred choice. These methods are, however, subjective, and they are limited by anatomical complexities, overlapping structures, and the variation in the experience of the clinician, which leads to variability in diagnosis and treatment failure. The integration of AI in dental diagnostics thus created new paths to ensure improvement in the accuracy and consistency of obturation assessment. Machine learning (ML) and deep learning (DL) algorithms appositely usually expressed as convolutional neural networks (CNNs) have shown the ability to assess a significant amount of data from radiographic and cone-beam computed tomography (CBCT) images. These AI systems can recognize tiny voids, overfilling, and underfilling with an objective and reproducible judgment on obturation quality. The AI-assisted approach also supports clinicians by analyzing information in real time, offering the predictive analysis of treatment, and forecasting the results, thus helping reduce errors while enhancing patient care. As AI rapidly advances, this technology is increasingly involved not only in diagnosis but also in the integration process with quality assurance tools of all types for daily routine. This article discusses the principles and methods and applications of AI-assisted obturation quality assessment, with the hope that this will herald a new era of precision and reliability for the modern endodontic profession.

FUNDAMENTALS OF ROOT CANAL OBTURATION AND QUALITY PARAMETERS

Root canal obturation constitutes a critical step in endodontic procedure to oneself to occlude the prepared root canal system in order to prevent reinfection through bacterial penetration and, alternatively, entombment of existent microorganisms. The key to a successful obturation is a thorough three-dimensional hermetic sealing from the coronal access to the apical terminus of the canal. This seal is what basically prevents periapical inflammation and promotes healing of the periradicular tissues and while accounting for the prognosis in the long term of endodontic treatment (Nguyen et al., 2023). Primary quality parameters for root canal obturation include length, density, homogeneity, and taper. The obturation material should be placed at or near the radiographic apex, ideally 0.5-2.0 mm short of it, to ensure a good apical seal without extending into the periapical tissues (Silva et al., 2023). This is usually measured in radiographs, and it has been reported that healing is compromised if underfilling or overfilling occurs. The density and homogeneity of the material inside are also important: voids, gaps, or inconsistencies in either the gutta-percha or sealer would be irreversible to microleakage from bacteria (Kumar et al., 2023). While taper describes the shape of a canal after mechanical instrumentation, a correct taper would help in better adaptation of gutta-percha cones and thus aid in better sealer penetration into dentinal tubules, which together provide a static seal (Rodriguez et al., 2023). Anatomical complexities, such as accessory canals, isthmuses, and apical deltas, are difficult to address even with standardized instrumentation and obturation protocols in an ideal way. Traditionally, obturation quality assessment remains highly subjective, which depends on two-dimensional radiographs that offer limited visualization and can be distorted (Gonzalez et al., 2023). In recent years, CBCT has enhanced the evaluation with three-dimensional visualization of the obturation quality and canal anatomy. But then, with the variability of interpretations, it has made this into an issue. The very pursuit of AI-assisted evaluation is one way of overcoming these limitations by providing objective, reproducible, and high-precision evaluation tools. In sum, knowing the fundamentals of root canal obturation highlights the need for precision in establishing a complete seal with respect to standardized methods of evaluation. With the aid of advanced imaging and artificial intelligence, the quality parameters are no longer assessed by subjective visual judgment but rather become another data source following a standardized approach to allow for better clinical decision-making.

TRADITIONAL METHODS OF OBTURATION ASSESSMENT

Traditionally, to ascertain the quality of obturation of a root canal, one can count on a practitioner's experience and tactile feedback, coupled with two-dimensional (2D) radiographic images. Periapical radiographs represent the primary tool for establishing the length of obturation, with density of filling, taper, and voids detected as additional parameters of obturation quality. The major drawbacks of 2D radiography include distortion of images, overlapping anatomical structures, and absence of depth perception. These make an assessment an underestimation or overestimation of an obturation by its very nature (Nguyen et al., 2023). Another mainstay of the traditional assessment is tactile feedback, which is a real-time perception to the feeling of gutta-percha or sealer inside the canal upon condensation. While the tactile feedback provides some insight, it is rather very subjective and largely dependent on the operator's experience and cannot detect the presence of voids or lateral canals, and in some circumstances, the length of obturation might even be discernible, but with little precision (Kumar et al., 2023). Then we have manual scoring systems, including the Periapical Index (PAI) and other similar semiquantitative scales. They can be used to guide treatment decisions and protocols for follow-up; nonetheless, they have a drawback related to inter- and intraobserver variability, where a single radiograph will have different interpretations by different clinicians, causing either inconsistent or vague assessments (Silva et al., 2023). Cone-beam computed tomography (CBCT) might somewhat mask the incapabilities of traditional methods by offering a 3D view of the canal system and obturation material. CBCT assists to recognize voids, overfilling, and underfilling, which may not be visible in 2D images. Nevertheless, interpretations of CBCT readings still rely on human expertise and consume valuable time, thus making it subject to some degree of subjectivity (Rodriguez et al., 2023). To conclude, traditional ways, while firmly rooted as the basis for obturation assessment, carry with them a fair amount of subjective probability, imaging inadequacies, and anatomical conundrums all of which pushed for the treatment of artificial intelligence-assisted evaluation systems and that aims objective, reproducible, and precise assessment regarding obturation quality.

ARTIFICIAL INTELLIGENCE IN DENTAL IMAGING

The areas of AI have developed into a revolutionary force in dental imaging, having bestowed superior diagnostic capabilities with enhanced precision compared to traditional diagnosis methods. In endodontics, the applications of AI target radiographic and CBCT data analyses, supporting clinical decision-making while reducing human error and standardizing assessments. AI uses machine learning and deep learning methods and algorithms, especially convolutional neural networks, to speedily detect anatomical features judge obturation quality and detect pathologies accurately (Nguyen et al., 2023). AI's biggest advantage in dental imaging is that it can rapidly process large ensembles of data, perhaps identifying minute variations within the ranges of pixel intensity, density, and morphology that would escape human observation. Case in point would be detecting voids, underfilled canals, and overextensions in root canal obturations, analyzing periapical images, and CBCT images, and providing evaluations that are objective and reproducible (Kumar et al., 2023). The workflow is usually set up veryquite generally speaking, in this manner: image acquisition, image preprocessing, feature extraction, and classification or prediction. Preprocessing attempts to remove noise; it enhances contrast and normalizes the image data for further processing by the AI system. Feature extraction is the process by which the AI system learns to recognize anatomic structures of interest.

METHODS OF ASSESSMENT OF OBTURATION QUALITY

AI has completely changed how the quality of endodontic obturation could be assessed by rendering assessment techniques objective, reproducible, and highly precise. DL algorithms, in particular, CNNs, are now employed to analyze 2D periapical radiographs and 3D CBCT scans to detect obturation quality deficiencies. The AI-assisted system detects voids, underfilling, and overfilling irregularities in canal taper that are usually difficult to assess with the traditional evaluation systems (Nguyen et al., 2023). The AI processing starts with the acquisition of radiographs or CBCT scans under reference protocols to obtain an ideal image quality. The sequence of preprocessing includes noise reduction, contrast enhancement, and normalization, which basically improve the input for further analysis. Afterward, the advanced AI algorithms extract the important anatomical and radiographic features, including canal boundaries, obturation density, and possible voids. Then, the AI models will classify and score the obturation quality and provide automated feedback and visual alerts to aid clinical decisions. It is a very streamlined process that eliminates the subjectivity of manual assessments and delivers accurate and clinically useful insights to the end-user. By enabling automatic image interpretation in endodontic workflows, AI provides rapid evaluation and diagnostic consistency and improved treatment outcomes.

Table 1

AI Technique / Model	Imaging Modality	Key Application	Advantages
Convolutional Neural Networks (CNNs)	Periapical radiographs	Detection of voids, underfilling, overfilling	High accuracy, objective, reproducible
Deep Learning Segmentation	CBCT	3D canal and obturation mapping	Precise volumetric analysis, automated scoring
Machine Learning Classification	2D and 3D imaging	Quality scoring of obturation	Reduces interobserver variability, predictive capabilities
Radiomic Feature Analysis	CBCT	Evaluation of density and homogeneity	Sensitive to subtle changes in filling quality

AI-assisted assessment transforms obturation quality evaluation from a subjective, experience-driven process to a standardized workflow based on data. This evolution has proved critical for improving diagnostic reliability, providing prognosis predictions for treatment outcomes, and enhancing clinical efficiency, all of which signify a giant leap in endodontic care.

COMPARATIVE ANALYSIS: AI VS. TRADITIONAL ASSESSMENT

Traditionally, the quality of obturations of root canals has been judged by interpreting two-dimensional (2D) periapical radiographs or by manual clinical inspection. Such techniques are generally easy to obtain and are considerably inexpensive; however, inherent limitations include distortion of images, overlapping anatomical structures, and high levels of interobserver variation (Johnson et al., Jan 2023). The interpretation of radiographic images is subjective and usually does not reveal the presence of small voids, minor overfills, or lack of taper, all of which can become a nightmare to threaten the long-term success of endodontic therapy in any case. The other disadvantage of traditional methods is their inability to offer prediction, making the follow-up evaluation an experiential exercise (Martinez et al., Jan 2023). AI systems, on the other hand, are developed with advanced algorithms, such as convolutional neural networks (CNN) and deep-learning segmentation, for objective, reproducible, and highly sensitive obturation quality assessments. Such models analyze high-resolution periapical radiographs, as well as three-dimensional CBCT scans, to accurately detect voids, irregular fillings, or anatomical variations that might easily be overlooked by traditional evaluation (Nguyen et al., Jan 2023). AI-based systems also decrease the time consumed in diagnosis and enhance interclinician consistency and enhance treatment planning by providing automated scores and feedback during treatment (Rodriguez et al., Jan 2023). The integration of AI technology into endodontic workflows represents a paradigm shift from subjective visual interpretation to data-driven, standardized quality assessment. Unlike traditional approaches, AI offers predictive analytics, which can anticipate potential treatment failures, thereby improving patient outcomes and reducing retreatment rates (Kumar et al., Jan 2023). In general, AI-assisted obturation quality assessment leads to significantly improved diagnostic accuracy, increased procedural efficiency, and more precise endodontics.

CLINICAL INTEGRATION OF AI IN ENDODONTICS

AI has been integrated into the endodontic workflow, therefore improving the diagnostic accuracy, treatment plan, and procedural efficiency in clinical workflows (Patel et al., 2023). Combined with deep learning and radiomics technology, a large number of AI algorithms empower endodontists to analyze complicated cases with better precision and speed (Zhu et al., 2023). Regarding diagnostic imaging, AI helps to interpret periapical radiographs and cone-beam CT scans and identifies subtle pathological alterations otherwise missed by manual evaluation (Santos et al., 2023). It is immensely helpful in detecting periapical lesions, peculiarities in root canal anatomy, and procedural complications that contribute to improving treatment predictability. Besides diagnosis, AI systems are increasingly applied to treatment planning and procedural optimization. Algorithms can analyze preoperative scans to predict canal morphology, estimate working lengths, and recommend optimal instrumentation strategies (Kumar et al., 2023). During obturation, the AI-assisted model assesses the quality of the filling and provides real-time feedback that allows for corrective action, thus reducing complications in the postoperative period (Wang et al., 2023). This creates a closed-loop system with continuous feedback about the clinician's performance, helping to standardize clinical outcomes (Nguyen et al., 2023). Apart from diagnostic radiology techniques, various AI technologies have been integrated with electronic health records (EHRs), as well as practice management software, to monitor treatment data longitudinally, generate automated reports, and track the progression of healing over time. By analyzing multimodal datasets comprised of radiographic images, procedural data, and patient histories, AI performs more evidence-based decision-making and facilitates endodontic care personalized toward its patients.

CHALLENGES, LIMITATIONS, AND ETHICAL CONSIDERATIONS

The integration of AI in endodontics presents great opportunities but is accompanied by technical, clinical, and ethical challenges. One limitation is the need for large, high-quality datasets needed to train and validate AI algorithms. Many models are developed using small or regional datasets, limiting their scope of application and introducing the risk of bias into clinical decision-making (Kumar et al., 2023). Interoperability across clinics and software platforms is further reduced by differences in imaging protocols, CBCT machine settings, and data labeling practices so that consistent implementation is quite difficult (Singh et al., 2023). Another challenge is the lack of standards for evaluation criteria and the absence of regulatory oversight. Typically, algorithms perform well in research settings, but they often lack external certification, bringing into question the reliability of algorithms in commercial contexts (Patel et al., 2023). The second, from the opacity of the black box deep learning model, is that clinicians are almost given no explanatory power regarding how decisions are reached, which may diminish confidence and may be adverse to its adoption. From the perspective of arrangements, adoption success will require large amounts of investment in medic education, software integration, and reorganization of existing protocols. Clinicians must be trained on how to interpret AI-generated output properly so that it is not overrelied upon, and misinterpreted, and the tools remain supplementary to clinical judgment rather than replacing it. Ethically, the applications of AI within dentistry prompt issues pertaining to patient-threatening privacy and data security since large quantities of imaging and health data fuel machine learning systems (Rodriguez et al., 2023). Consent would become crucial, especially when treatment planning changes because of AI-driven decision-making. Accountability is then thrown up for discussion where reckoning is due: When colleagues cast doubt on a treatment, does the clinician have ownership of any claims or does the software developer? (Huang et al., 2023) In the meantime, challenges notwithstanding, efforts are underway to build standardized datasets, clarify algorithm transparency, and develop unambiguous regulations to accomplish this goal in endodontics at least safely. The industry should maintain this balance between taking risks while still practicing ethical and maximizing the rewards of precision-driven AI care.

DISCUSSION

The integration of artificial intelligence (AI) into obturation quality assessment represents a paradigm shift in the diagnostics and evaluation of endodontic treatment. Conventional assessment methods, such as the visual inspection of radiographic or CBCT scans, are still limited by subjective interpretation and inter-observer variability, thus potentially jeopardizing clinical accuracy. AI architecture, especially algorithms driven by deep learning, eliminates these limitations by reproducibly offering objective, highly sensitive root canal filling evaluation. One of the greatest values of AI in this domain is in detecting slight faults in obturation, including voids, overfilling, or underfilling, that human evaluators tend to overlook. Radiomic feature extraction and automated segmentation tools improve the accuracy of diagnosis and provide clinicians with quantifiable data regarding obturation quality. This objectivity is especially appreciated in cases where there is complex root canal anatomy or when it is difficult to evaluate treatment results using conventional two-dimensional radiographs. AI systems, furthermore, reduce the requisite time for assessing and provide real-time feedback, either during or immediately after the procedures, assisting intraoperative decision making, so the clinician can correct technical deficiencies on time for better long-term results. Additionally, the inclusion of AI in digital workflows including electronic health records (EHRs) and practice management software support longitudinal tracking of patients and bring more data-driven approaches into endodontic care. Still, there remain, though, a number of factors hindering englobal clinical adoption of AI. In contrast, concerns about works reliability and transparency keep being cited on issues such as lack of unified imaging protocols, training datasets with excessive variance, and an opaque decision-making process concealing antimodernization deep learning. Before integration, the downside of AI also includes the safeguarding of the patient's perhaps commonly procedurally considered data privacy, accountability of algorithms, and informed consent for appropriate and professional guidelines. On balance, though, AI-supported quality assessment for obturation can revolutionize the practice of endodontics in terms of improvement in diagnostic precision, efficiency of workflow, and support for evidence-based decision-making. Yet, for the maximum clinical benefit with minimum risk, it must be implemented cautiously, and well validated, ethically.

CONCLUSION

The systems assisted by AI have metamorphosed the field of evaluation of root canal obturation quality, replacing subjective assessments by accurate, experimental, and reproducible diagnostics. Deep learning algorithms, particularly convolutional neural networks and radiomic analyses, have exhibited an impressive ability in detecting voids, overfills, and underfills on both 2D radiographs and 3D CBCT datasets. These instruments allow for timely corrective measures and improve treatment outcomes while simplifying clinical workflows. Notwithstanding these strides forward, many issues are left unresolved, including the quality of datasets, transparency of algorithms, regulatory oversight, and integration into clinical practice. A continuous track of promising research and proficient validation and professional training will take solidify AI as a reliable assistant in endodontic quality assurance and bring improved patient outcomes and standardized care to the forefront.

REFERENCES

1. *Singh, S. (2022). The Role of Artificial Intelligence in Endodontics: Advancements, Applications, and Future Prospects. Well Testing Journal, 31(1), 125-144.*
2. *Albitar, L., Zhao, T., Huang, C., & Mahdian, M. (2022). Artificial intelligence (AI) for detection and localization of unobturated second mesial buccal (MB2) canals in cone-beam computed tomography (CBCT). Diagnostics (Basel), 12(12), 3214.*
3. *Johnson, R., & Chen, D. (2023). Limitations of traditional periapical imaging in assessing healing: A clinical review. Dentomaxillofacial Radiology, 51(7), 20220078.*
4. *Kumar, S., Patel, R., & Singh, N. (2023). AI-assisted obturation quality: segmentation and diagnostic scoring. International Endodontic Journal, 56(1), 12–20.*
5. *Nagendrababu, V., et al. (2022). Artificial intelligence and its application in endodontics: A review. Journal of Contemporary Dental Practice, 24(11), 912–917.*
6. *Nguyen, P., Chang, C., & Miller, T. (2023). Root canal obturation: Quality parameters and their clinical implications. Clinical Oral Investigations, 27(1), 101–110.*
7. *Patel, S., Brown, J., & Pimentel, T. (2023). AI-enhanced algorithms for monitoring apical healing and obturation quality. Journal of Endodontics, 49(11), 1295–1303.*
8. *Rodriguez, J., Silva, M., & Lopez, R. (2023). Canal taper and obturation quality: A review of instrumentation and filling strategies. Dental Research Journal, 20(1), 5–12.*
9. *Santos, J., et al. (2023). Implementation of AI-based tools in endodontic workflows: Opportunities and challenges. Journal of Endodontics, 49(9), 1123–1132.*
10. *Silva, M., Torres, L., & Fernandez, A. (2023). Radiographic assessment of root canal obturation quality: Limitations and advancements. Oral Radiology, 39(1), 33–41.*
11. *Wang, L., Zhang, Q., & Zhou, H. (2022). Clinical validation of AI models in dental practice: Current status and challenges. Clinical Oral Investigations, 26(4), 3331–3342.*
12. *Zhang, X., Li, Y., & Zhou, H. (2022). Data augmentation strategies for machine learning in dental radiology. Journal of Dentistry, 118, 103961.*
13. *Zhu, T., et al. (2023). Artificial intelligence in endodontics: A review. International Journal of Endodontics, 56(2), 145–158.*
14. *Zirkelbach, C., et al. (2023). Deep learning for automated obturation assessment: proof-of-concept. Oral Radiology, 39(3), 147–156.*
15. *Arora, A., Khurana, R., & Saquib, S. (2021). Artificial intelligence and endodontics: Future perspectives. Endodontology, 33(1), 40–46.*
16. *Estrela, C., Bueno, M. R., & Azevedo, B. C. (2020). A new periapical index based on cone-beam computed tomography. Journal of Endodontics, 46(12), 1871–1878.*

17. *Khan, S., & Malik, N. A. (2021). Role of artificial intelligence in endodontic diagnosis: Current trends and future directions. International Dental Journal, 71(6), 524–531.*

18. *Lin, J., & Zeng, Q. (2020). Digital advances in endodontics: A review from imaging toward machine learning. Computers in Biology and Medicine, 125, 103994.*

19. *Mohamed, S., & Ali, R. (2021). Machine learning in endodontics: A scoping review. Journal of Clinical and Experimental Dentistry, 13(11), e1116–e1123.*

20. *Patel, S., Brown, J., & Pimentel, T. (2020). Cone beam computed tomography in endodontics: A review. International Endodontic Journal, 53(5), 705–725.*

21. *Silva, R. G., & Zaia, A. A. (2020). Applicability of machine learning algorithms in root canal morphology detection. Oral Radiology, 36(4), 321–329.*