EGYPTIAN DENTAL JOURNAL
www.eda-egypt.org
VOL. 72, 1287:1295, APRIL, 2026
PRINT ISSN 0070-9484 • ONLINE ISSN 2090-2360
ORAL MEDICINE, X-RAY, ORAL BIOLOGY AND ORAL PATHOLOGY
Submit Date : 22-12-2025 • Accept Date : 08-01-2026 • Available online: 01-04-2026 • DOI : 10.21608/edj.2026.452578.3723

CLINICAL UNCERTAINTY IN DENTISTRY: NAVIGATING DIAGNOSTIC AND THERAPEUTIC GRAY ZONES

Lubna Ahmad Amro*

ABSTRACT

Background: Clinical uncertainty, caused by biological variability, imperfect diagnostic tools, and incomplete or conflicting evidence ,is a feature of dental practice and a major driver of variability in diagnosis, treatment planning, and clinician stress.

Aim: This narrative review synthesizes the possible reasons uncertainty arises across dental diagnosis and treatment planning, it's influence on clinical decision-making, and examines educational & practice strategies can help clinicians navigate diagnostic and therapeutic gray zones more safely and transparently.

Methods: A search of dentistry focused uncertainty and clinical decision making literature, including scoping review evidence, studies on interpretive variability, guideline/evidence limitations, and emerging work on artificial intelligence (AI) in oral diagnosis and education was performed using PUBMED,SCOPUS, and WEB OF SCIENCE including 43 studies.

Results: Uncertainty is sustained by heterogeneous disease natures and borderline clinical findings, further complicated by interclinician variability and gaps in high quality evidence; thus increasing reliance on experience, and risk tolerance, contributing to inconsistent recommendations. Educational approaches that explicitly teach uncertainty management such as case-based learning, reflective practice, mentorship, and bias-awareness, support more resilient clinical reasoning. AI may reduce some diagnostic uncertainty, but also introduce new concerns about transparency, calibration, and safe deployment.

Conclusion: Instead of being disregarded, uncertainty should be anticipated, communicated, and managed. Structured educational frameworks, standardized diagnostic calibration, shared decision-making, and cautious integration of validated AI tools can improve consistency, safety, and clinician confidence.

KEYWORDS: Clinical reasoning; Diagnostic variability; Decision-making under ambiguity; Treatment planning strategies; Cognitive bias in healthcare; Dental education and training

* Department of Oral Medicine, Periodontology and Oral Diagnosis, Faculty of Dentistry, October University for Modern Sciences and Arts, Giza, Egypt

INTRODUCTION

Certainty in clinical practice is not merely a convenience, rather a fundamental aspect of decision-making; influencing patient management, treatment outcomes, and the psychological well-being of practitioners [1]. Therefore, inherent ambiguity calls for a deeper exploration of its sources, impact on various dental disciplines, and the strategies clinicians employ to navigate these gray zones effectively[2]. This narrative review aims to comprehensively investigate the underlying process of decision making under uncertainty in clinical dentistry and the factors that influence individual clinicians during diagnosis and treatment planning[2]; examining both the limitations of current diagnostic modalities and the interpretive variability in clinical assessments [2]. Furthermore, educational frameworks and emerging technologies, such as artificial intelligence, may improve the experience of uncertainty for dental professionals and trainees [3,2]. Such an investigation is critical given that diagnostic and treatment planning errors, frequently compounded by uncertain conditions, can lead to significant patient harm, such as reports of wrong tooth extractions [2]. Ultimately, an enhanced understanding of clinical uncertainty can foster more resilient clinical reasoning, optimal patient care, and a more supportive professional dental environment.

Sources of Clinical Uncertainty

Several fundamental factors contribute to clinical uncertainty in dentistry, stemming from the biological complexities of the oral cavity and limitations in current diagnostic and prognostic monitoring tools. Biological variability, for instance, involves a wide spectrum of individual host responses, disease progression rates, and healing capacities, leading to diverse outcomes even among patients with seemingly similar clinical presentations. Hence, establishment of universally applicable protocols and often necessitates individualized treatment strategies, introducing an element of professional judgment and inherent uncertainty [2]. Diagnostic limitations further compound this uncertainty, as current imaging techniques and clinical tests often yield imperfect or borderline findings, requiring clinicians to interpret ambiguous data without absolute thresholds [4]. Furthermore, the lack of definitive diagnostic criteria can lead to significant inter-clinician variability in interpretation and subsequent treatment recommendations.

Oftentimes, conventional radiographic techniques may fail to identify incipient carious lesions until a substantial loss of mineral content has occurred, creating a critical diagnostic gap of when early preventive interventions could be most effective [4]. Moreover, subjective interpretation of diagnostic indicators, such as probing depths or lesion color changes, can introduce additional layers of uncertainty, necessitating careful consideration of contextual factors and clinician experience. Evidence gaps and conflicting guidelines further exacerbate uncertainty by providing limited high quality research sources for common clinical scenarios and allowing for varied interpretations among practitioners [5] ; often resulting in reliance on clinician experience and judgment, which, while valuable, can introduce cognitive biases, potentially leading to suboptimal decisions [6,2].

Biological Variability

Biological variability is a core reason why dentistry has so many "gray zones," even when clinicians follow the same guidelines and use the same diagnostic thresholds. Patients differ in their host inflammatory phenotype, systemic health, and environmental exposures; these differences can meaningfully change disease behavior and treatment response in ways that are hard to predict using routine chairside data alone [7]. A clear illustration is periodontitis, comparable clinical measurements may not reflect comparable future risk. Two patients can present with similar probing

depths and radiographic bone loss, yet show very different progression rates. The 2018 staging and grading framework explicitly acknowledges this by incorporating grade modifiers notably smoking and glycemic control in diabetes, because these factors shift the expected rate of progression and likely response to therapy [8]. A patient with similar periodontal destruction who is a heavy smoker or a poorly controlled diabetic may be classified as higher risk of rapid progression than an otherwise similar nonsmoker without metabolic dysregulation, even if the current clinical presentation is the same [8].

Biological variability also explains why outcomes diverge after what appears to be identical treatment. In endodontics, post-treatment healing is not fully determined by technical quality alone; systemic and behavioral factors can influence periapical healing and long-term tooth survival. Evidence syntheses report that tobacco smoking is associated with worse post-endodontic outcomes , namely, increased risk of persistent apical pathology and increased possibility extraction of root-filled teeth, supporting the idea that host and exposure-related differences can modify healing capacity and prognosis [9]. Similarly, the evidence on diabetes and endodontic outcomes has been uncertain/ heterogeneous pointing to variability in metabolic control, host response, and study populations as drivers of mixed clinical outcomes [10].

Many prognostic approaches in dentistry remain limited: often relying on static thresholds and population averages, while real-world disease trajectories are dynamic and individualized. The shift toward precision dentistry requires shifting from association only thinking toward prediction focused models that integrate multiple patient-level dimensions ,biological, behavioral, and contextual, rather than assuming uniform treatment responses from similar baseline findings [7].

Diagnostic Limitations

Diagnostic uncertainty in dentistry is frequently driven by the limitations of available diagnostic tools and the common occurrence of borderline or equivocal findings. Many routine diagnostic methods such as conventional radiography, periodontal probing, and visual/tactile examination lack sufficient sensitivity and specificity, particularly in the early or transitional stages of disease. Consequently, clinicians are often required to make decisions in situations where diagnostic findings neither clearly confirm disease nor confidently exclude it, complicating clinical decision making [4].

Furthermore, radiographic changes, lesion boundaries, probing depth measurements, and soft-tissue characteristics are rarely absolute, and their interpretation is influenced by clinician experience, training background, and perceptual judgment. Even when evaluating identical clinical or radiographic findings, dentists may arrive at different conclusions regarding disease presence, severity, or the need for intervention, reflecting the absence of universally accepted diagnostic thresholds in many areas of dental practice [11]. Such interpretive variability becomes particularly evident in image-based diagnostics and emerging AI-assisted tools, where discrepancies may arise between human interpretation and algorithmic output.

Inconsistent interpretation of diagnostic findings can lead to considerable variation in treatment recommendations, ranging from premature intervention to delayed or missed diagnoses ; especially critical in conditions where early detection influences prognosis, such as incipient carious lesions, early periodontal breakdown, or potentially malignant oral disorders. Evidence examining interobserver agreement consistently demonstrates that, without structured calibration and standardized diagnostic criteria, agreement among clinicians remains limited, even among experienced practitioners [12].

As a result, diagnostic decision making in dentistry often extends beyond objective test results and

relies heavily on clinical judgment, contextual patient information, and risk assessment. While calibration exercises, continuing professional development, and standardized diagnostic frameworks can reduce unwarranted variability, a degree of diagnostic uncertainty remains unavoidable. Highlighting the importance of reflective clinical reasoning, cautious interpretation of diagnostic findings, and transparent communication with patients when decisions are made under conditions of imperfect information [4,11,12].

A common example of diagnostic uncertainty arises when a patient presents with an early proximal radiolucency detected on bitewing radiographs, accompanied by an intact enamel surface and no symptoms. One clinician may interpret this finding as an early carious lesion requiring operative intervention, citing the risk of lesion progression and patient compliance concerns. Another clinician, reviewing the same radiograph and clinical findings, may recommend non-operative management with enhanced preventive measures and periodic monitoring, particularly if the patient demonstrates good oral hygiene and low overall caries risk. Both approaches can be clinically justifiable, yet they reflect different interpretations of imperfect diagnostic data rather than clear differences in disease status. The radiograph alone cannot reliably determine lesion activity or predict progression, and adjunctive diagnostic tools may provide limited additional certainty. This vignette illustrates how diagnostic limitations, coupled with clinician judgment and risk perception, can lead to divergent management decisions despite identical clinical information, underscoring the inherent uncertainty embedded in routine dental diagnosis [4,11,12].

Evidence Gaps and Conflicting Guidelines

A lack of high quality scientific evidence for prevalent clinical scenarios, coupled with conflicting or nonexistent guidelines, leaves dentists without clear directions for optimal care [13]. Therefore , clinicians often tend to rely on intuition, personal experience, or anecdotal evidence, introducing subjective elements into decision making [2]. The limited number of clinically relevant publications in dentistry, combined with the often contradictory findings in the scientific literature, further exacerbates this problem, challenging practitioners to identify and apply the most efficacious treatments [14,15]. Clinicians are often forced to rely on clinical judgment and, at times, intuition, particularly in complex situations where data are insufficient [16]. This leads to inconsistencies in treatment recommendations, as evidenced by studies highlighting how individual clinician perspectives and non-evidence based factors often influence decision making [2]. Furthermore, the development of predictive models is hampered by the scarcity of data for rare events, resulting in models that are not entirely useful, even with high performance metrics [7]. In this regard, integrating advanced analytics and artificial intelligence could potentially bridge some of these evidence gaps by identifying subtle patterns and relationships within vast datasets that human analysis might miss [17]. However, the integration of AI in dentistry also introduces new forms of uncertainty, such as the potential for AI models to produce hallucinations or depart from established clinical protocols [18].

Clinical Uncertainty in Diagnosis

In the diagnostic phase, dentists frequently encounter borderline findings that do not fit neatly into established disease categories, necessitating a delicate balance between active intervention and watchful monitoring. This often arises from the inherent limitations of current diagnostic tools, which may not possess sufficient sensitivity or specificity to distinguish definitively between health, early disease, or stable pathological conditions, thereby contributing to clinical uncertainty [19]. Diagnostic ambiguity compels clinicians to engage in complex risk assessments, weighing the potential benefits of early intervention against the risks of overtreatment or the consequences of delayed action, particularly

in conditions with variable histories. Decisions regarding whether to monitor or intervene are complicated by the risks associated with both under treatment and over treatment [2].

Determining the restorability of a tooth presents a significant challenge, as the assessment is highly subjective and heavily influenced by the clinician's experience and knowledge, often leading to difficulties for less experienced practitioners [20]. Moreover, the introduction of artificial intelligence in dentistry, while promising for enhanced diagnoses and treatment planning, also presents a novel layer of uncertainty concerning its reliability, transparency, and integration into existing clinical workflows [21,22,23]. Rigorous independent assessments by expert healthcare professionals are crucial to ensure the accuracy, validity, and safety of AI applications in patient care [22]. The interpretability of AI algorithms remains a significant challenge, as dentists need to comprehend the underlying rationale behind AI-driven diagnoses and treatment recommendations to foster trust and ensure accountability [17]. The opaque nature of many AI decision making processes, with potential inconsistencies in judgment, raises questions about the validity and reliability of AI-driven tools, highlighting the necessity for robust calibration techniques and expert oversight [24,25].

Clinical Uncertainty in Treatment Planning

Treatment planning in dentistry is frequently characterized by the availability of multiple acceptable treatment options for the same clinical presentation, a situation that often arises from the subjective interpretation of diagnostic data and the diverse philosophies within dental practice. The presence of several viable approaches necessitates a decision making process that extends beyond mere technical proficiency, to incorporate elements of clinical judgment, ethical considerations, and patient specific considerations[26]. The influence of clinician experience, training background, and individual risk tolerance further complicates the situattion, leading to variations in preferred treatment modalities even among highly skilled practitioners [26]. Variability among clinicans can lead to differing recommendations for similar cases, potentially impacting patient trust and the perceived consistency of care. Moreover, patient-related modifiers such as expectations, financial considerations, compliance, and anxiety significantly shape treatment choices, often diverting from purely evidence-based pathways toward options that accommodate individual circumstances [2].

The dynamic interplay between clinical efficacy and patient preferences highlights the need for shared decision making models, where the clinician acts as a facilitator, guiding the patient through complex choices. A collaborative approach acknowledges the inherent uncertainty in treatment outcomes and aims to align therapeutic interventions with patient values and realistic expectations. Furthermore, conservative versus aggressive treatment philosophies, often rooted in different schools of thought or individual practitioner biases, further contribute to the heterogeneity of treatment plans, especially in scenarios lacking definitive evidence based guidelines. The divergent approaches highlight the challenge of achieving consensus in dental practice, particularly when confronted with the many subjective and objective factors influencing clinical decisions. Practice variations, even for similar clinical conditions, underscore the judgmental nature of dental treatment and the absence of universally superior interventions [27]. Differences in clinical judgment and treatment decisions are common across various dental disciplines, such as orthodontics, restorative dentistry, and periodontics [28,29].

Teaching and Learning Under Uncertainty

Dental education faces a critical challenge in moving beyond teaching fixed answers to nurture clinicians capable of navigating the ambiguous and contradictory nature of real world clinical scenarios [30]. Calling for a shift towards structured exposure to uncertainty during training, allowing students to

develop critical thinking, adaptability, and resilience when confronted with diagnostic and therapeutic gray zones [1]. Emphasizing the development of clinical judgment over strict adherence to protocols, thereby fostering an environment where students learn to justify their actions based on contextual understanding rather than rigid guidelines [31]. Integrating discussions on the limitations of diagnostic tools and the probabilities of prognoses, prepares future dentists to articulate these complexities to patients effectively [2]. Moreover, incorporating case based learning scenarios that present ambiguous findings and multiple plausible solutions can help students develop the capacity for critical appraisal and nuanced decision making, moving beyond a "one-right-answer" mentality [32].

This shift is crucial for fostering clinical expertise, which involves complex integration of experiential, narrative, and evidence-based data to inform decision making, particularly in situations of ambiguity [6]. The role of mentorship and reflective clinical practice is therefore paramount in guiding students through these gray zones, enabling them to develop their own decision-making frameworks while learning from experienced practitioners. The inability of dental interns and recent graduates to make independent decisions highlights gaps in current learning outcomes and graduate attributes [33]. The discrepancies in faculty opinions and the varying interpretations of clinical findings among educators can further complicate students' ability to discern correct answers and develop consistent clinical judgment [30]. This often leaves students struggling to rationalize ambiguity, as they seek definitive treatment plans in complex clinical situations [34]. Further compounded by the perception among students that educators sometimes prematurely intervene, hindering the development of independent decision making skills [34].

Managing Uncertainty in Daily Practice

Educational strategies that intentionally expose students to the complexities of clinical uncertainty and provide frameworks for navigating ambiguous situations rather than simply seeking definitive solutions are needed now more than ever [35]. Furthermore, strong mentorship programs and peer support mechanisms can significantly aid students in processing these ambiguous situations, promoting a collaborative learning environment where experiences are shared and diversified perspectives are considered [36]. These support systems can help relieve the emotional and cognitive burdens associated with uncertainty, allowing students to develop resilience and self-reflection [36]. Equipping students with strategies to recognize and mitigate cognitive biases, such as confirmation and anchoring bias, becomes essential for sound clinical judgment in orthodontics and other specialties [36].

Confirmation bias refers to the tendency to seek, interpret, or recall information in ways that reinforce an initial diagnostic impression, while discounting evidence that challenges it. In dental practice, this may occur when a clinician forms an early assumption,such as attributing radiolucency to caries or periodontal breakdown,and subsequently focuses on findings that support this assumption, while minimizing contradictory signs such as patient history, lesion stability, or absence of clinical symptoms. Under conditions of diagnostic uncertainty, confirmation bias can narrow clinical reasoning and increase the risk of overdiagnosis or inappropriate intervention [37,6].

Anchoring bias, occurs when clinicians rely too heavily on an initial piece of information, such as a preliminary radiographic interpretation, referral diagnosis, or an automated AI output, and fail to adequately adjust their judgment as new information emerges. For example, a dentist may anchor on an initial radiographic impression of caries or periapical pathology and persist with that diagnosis even after subsequent clinical examination or follow up imaging suggests a non-progressive or alternative condition. Anchoring is particularly problematic in dentistry because early diagnostic cues are often subtle rather than definitive, increasing the

likelihood of initial impressions disproportionately influencing final decisions [38,39].

Both confirmation and anchoring biases are likely to exert influence in diagnostic "gray zones," where objective evidence is limited and multiple interpretations are possible. These biases may be further reinforced by time pressure, clinical workload, previous experiences, and the growing use of decision support technologies that present confident appearing outputs. Recognizing the presence of these cognitive biases is therefore essential for improving diagnostic accuracy and consistency. Strategies such as reflective practice, deliberate consideration of alternative diagnoses, peer discussion, and structured calibration exercises can help clinicians counteract biased reasoning and support a more balanced decision making process under uncertainty [37,6].

While extensively studied in other fields, uncertanity remains an underexplored area within dental healthcare [2]. Therefore, developing robust educational frameworks that explicitly address how to manage cognitive biases and equip future practitioners with advanced decision making tools is imperative for enhancing patient care and reducing clinical errors [36]. Certainty , daily practice involves adopting a multidisciplinary approach, that incorporates robust communication strategies with patients, continuous professional development, and reflective practice to refine clinical judgment and adapt to evolving evidence.

Future Perspectives

Further research is needed to develop and validate models that effectively integrate uncertainty management into dental curricula, moving beyond traditional, protocol-driven instruction to cultivate adaptable and resilient practitioners. Exploring the potential of artificial intelligence in education, promises to enhance clinical decision making and reduce patient harm by augmenting diagnostic and management processes [2]. However, these AI tools should be viewed as complementary aids, supporting rather than replacing the clinical judgment crucial for complex cases [40]. The successful integration of AI into dental education, however, requires addressing practical and ethical challenges, such as limited faculty training, technical infrastructure deficits, and potential resistance from educators [41]. Ultimately, longitudinal studies are crucial for evaluating the long-term impact of AI on clinical competence and patient outcomes, to ensure that technological advancements truly support and enhance dental education [42].

CONCLUSION

In conclusion, the pervasive nature of clinical uncertainty in dentistry demands a paradigm shift in both educational approaches and daily practice, moving beyond a simple, protocol driven mindset ,to embrace the true complexity of patient care. Developing critical thinking, adaptability, and resilience among practitioners is vital to navigate diagnostic and therapeutic gray zones effectively [43]. This evolution is essential for cultivating a new generation of dental professionals capable of making evidence informed decisions in the face of ambiguity, to improve patient outcomes and mitigating clinician stress. As well as commitment to person centred care, and acknowledging patient's unique biological and psychological factors that influence treatment outcomes [13]. Moreover, understanding and managing uncertainty effectively also requires recognizing that, at times, certain ambiguities may be irreducible, and should be accepted rather than forced resolution [3].

Ethics approval and consent to participate

Not applicable (No study participants)

Consent for publication

Not applicable.

Data availability statement

Not Applicable

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

No funding was received for this research.

REFERENCES

1. Pigg M, Brodén J, Fransson H, Vareman N, EndoReCo and the Foresight Research Consortium. How do we and how should we deal with uncertainty in endodontics? Int Endod J. 2022;55(4):282–289. doi:10.1111/iej.13679
2. Murdoch AIK, Blum J, Chen J, et al. Decision-making under uncertainty in dentistry: a scoping review. Diagnostics (Basel). 2023;13(6):1076. doi:10.3390/diagnostics13061076
3. Fransson H, Bjørndal L, Dawson V, Frisk F, Kvist T, Markvart M, et al. EndoReCo – a research consortium for endodontics. Int Endod J. 2022;55(10):911–914. doi:10.1111/iej.13784
4. Salem H, Elbaz M, Soliman R, Hafez ME, Elkhatib M. Artificial intelligence–assisted caries detection: diagnostic performance and clinical implications. Sci Rep. 2025;15(1):21923. doi:10.1038/s41598-025-21923-5
5. El-Wakeel N, Ezzeldin N. Diagnostic errors in dentistry: opinions of Egyptian dental teaching staff. BMC Oral Health. 2022;22(1):565. doi:10.1186/s12903-022-02565-9
6. Feller L, Lemmer J, Nemutandani MS, Ballyram R, Khammissa RAG. Judgment and decision-making in clinical dentistry. J Int Med Res. 2020;48(11):0300060520972877. doi:10.1177/0300060520972877
7. Schwendicke F, Krois J. Precision dentistry—what it is, where it fails, and how it may succeed. Clin Oral Investig. 2022;26(6):4421–4428. doi:10.1007/s00784-022-04420-1
8. Tonetti MS, Greenwell H, Kornman KS. Staging and grading of periodontitis: framework and proposal of a new classification and case definition. J Periodontol. 2018;89(Suppl 1):S159–S172. doi:10.1002/JPER.18-0006
9. Cabanillas-Balsera D, Segura-Egea JJ, Jiménez-Sánchez MC, et al. Cigarette smoking as a risk factor for periapical periodontitis and endodontic outcomes: a systematic review and meta-analysis. J Endod. 2020;46(7):944–953. doi:10.1016/j.joen.2020.03.016
10. Nagendrababu V, Segura-Egea JJ, Fouad AF, et al. Impact of diabetes on the outcome of root canal treatment: an umbrella review. Int Endod J. 2020;53(4):455–466. doi:10.1111/iej.13230
11. Pradhan P. Accuracy of ChatGPT-3.5, GPT-4 and Gemini in diagnosing oral potentially malignant lesions based on clinical case reports and image recognition. Med Oral Patol Oral Cir Bucal. 2025;30(2):e224–e231. doi:10.4317/medoral.26824
12. Wafaie K, Basyouni ME, Bhattacharjee T, et al. Inter-observer variability and calibration in AI-assisted dental diagnostics. BMC Oral Health. 2025;25(1):960. doi:10.1186/s12903-025-06960-w
13. Apelian N, Vergnes JN, Bedos C. Humanizing clinical dental decision making: a qualitative study. Int J Whole Person Care. 2014;1(2). doi:10.26443/ijwpc.v1i2.2
14. Łabno P, Łabno A, Chałas R. Assessment of original dental diagnostic programs in the opinion of dentists. J Stomatol. 2020;73(5):231–236. doi:10.5114/jos.2020.100597
15. Scott I, Doust J, Keijzers G, Wallis K. Coping with uncertainty in clinical practice. Med J Aust. 2023;218(9):418–423. doi:10.5694/mja2.51925
16. Nalliah RP. Clinical decision making – choosing between equally acceptable options. Br Dent J. 2016;221(12):752. doi:10.1038/sj.bdj.2016.942
17. Lin H, Chen J, Hu Y, Li W. Explainability and transparency of artificial intelligence in oral diagnosis. Med Oral Patol Oral Cir Bucal. 2024;29:e180–e187. doi:10.4317/medoral.26679
18. Raj M, Ravindran V, Arthanari A. Reliability and ethical challenges of generative artificial intelligence in dentistry. J Clin Exp Dent. 2025;17:e631–e637. doi:10.4317/jced.63136
19. Barber S, Jones A, Patel V, Ashley M. Involving patients in decisions when there is uncertainty. Br Dent J. 2023. doi:10.1038/s41415-023-6328-1
20. Aldowah O. The ability of dental interns and freshly graduated dentists to assess tooth restorability: a multicenter cross-sectional study. Clin Cosmet Investig Dent. 2022;14:337–352. doi:10.2147/CCIDE.S386676
21. Babu A, Andrew J, Sagayam KM. Artificial intelligence in dentistry: a review. E3S Web Conf. 2021;297:01074. doi:10.1051/e3sconf/202129701074

22. Lal A, Nooruddin A, Umer F. Concerns regarding deployment of artificial intelligence-based applications in dentistry. BDJ Open. 2025;11(1):31. doi:10.1038/s41405-025-00319-7

23. Hassanein FEA, Ahmed Y, Maher SC, et al. Prompt-dependent performance of multimodal artificial intelligence in oral diagnosis. Sci Rep. 2025;15:22979. doi:10.1038/s41598-025-22979-z

24. Jeong H, Han S, Jung H, Lee W, Jeon KJ. Attitudes toward artificial intelligence among dental students and dentists. BMC Med Educ. 2024;24(1):5441. doi:10.1186/s12909-024-05441-y

25. O. DR, Rajan SD. Ethical considerations of artificial intelligence in healthcare. J Clin Rev Case Rep. 2025;10(2):1–6. doi:10.33140/jcrc.10.02.01

26. Hamer S, Kanagasingam S, Sonde N, Mannocci F, Patel S. Impact of the Dental Practicality Index on treatment planning. Br Dent J. 2021. doi:10.1038/s41415-021-2948-5

27. Grytten J. Practice variation in dentistry. Community Dent Oral Epidemiol. 2010;38(3):203–212. doi:10.1111/j.1600-0528.2009.00527.x

28. Ganhewa M, Lau A, Lay AMD, et al. Collective intelligence in dentistry: a pilot study. BMC Oral Health. 2023;23(1):3091. doi:10.1186/s12903-023-03091-y

29. Milosavljević A, Stavropoulos A, Descroix V, Götrick B. Decision-making variability across dental disciplines. Eur J Dent Educ. 2018;22(3). doi:10.1111/eje.12317

30. Lanning SK, Pelok SD, Williams BC, Richards PS. Student challenges with ambiguity in clinical dentistry. J Dent Educ. 2005;69(3):355–364. doi:10.1002/j.0022-0337.2005.69.3.tb03919.x

31. Caplin RL. Dentistry—art or science? Br Dent J. 2021;230(6):337. doi:10.1038/s41415-021-2726-4

32. Liew J, Abidin IZ, Cook N, Kanagasingam S. Case-based learning and uncertainty tolerance in dental education. Eur J Dent Educ. 2022;26(4):707–715. doi:10.1111/eje.12751

33. Aldowah O. Graduate decision-making readiness in dentistry. Clin Cosmet Investig Dent. 2022;14:337–352. doi:10.2147/CCIDE.S386676

34. Ray M, Milston A, Doherty P, Crean S. In the face of uncertainty: student perceptions. Br Dent J. 2018;225(4):340. doi:10.1038/sj.bdj.2018.646

35. Moffett J, Hammond J, Murphy P, Pawlikowska T. Teaching uncertainty in healthcare education. Adv Health Sci Educ. 2021;26:10028. doi:10.1007/s10459-021-10028-z

36. Lakshmikantha R. Teaching metacognition and bias awareness in healthcare education. BMC Med Educ. 2025;25:46. doi:10.1186/s12909-025-06645-6

37. Croskerry P. The importance of cognitive errors in diagnosis. Acad Med. 2003;78(8):775–780. doi:10.1097/00001888-200308000-00003

38. Kahneman D. Thinking, Fast and Slow. New York: Farrar, Straus and Giroux; 2011.

39. Hicks EP, Kluemper GT. Heuristic reasoning and cognitive bias in orthodontics. Am J Orthod Dentofacial Orthop. 2011;139(3):297–304. doi:10.1016/j.ajodo.2010.05.018

40. Ziaei S, Samani D, Behjati M, et al. Artificial intelligence in dental education. BMC Oral Health. 2025. doi:10.1186/s12903-025-06880-9

41. Baxmann M, Kárpáti K, Baráth Z. Integrating generative AI into dental education. BMC Oral Health. 2025;25. doi:10.1186/s12903-025-06070-7

42. Khalifah A, Alafaleg S. Long-term impact of artificial intelligence on dental competence. Dent Educ. 2025.

43. Fontana M, González-Cabezas C, de Peralta T, Johnsen DC. Dental education for a changing healthcare environment. J Dent Educ. 2017;81(8). doi:10.21815/jde.017.022