Beyond the Horizon in Endodontics

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KEYWORDS

- Artificial intelligence in endodontics • Regenerative endodontics
- Robotics in dentistry • Neural operators • Augmented reality
- Cone-beam computed tomography • Whole-tooth regeneration
- Future predictions in endodontics

KEY POINTS

- Endodontics is evolving rapidly with the integration of artificial intelligence (AI), robotics, and augmented reality/virtual reality (AR/VR), enhancing precision and efficiency.
- Neural operators and AI systems are driving innovations in diagnostics, treatment planning, and engineering solutions for endodontic challenges.
- Advancements in regenerative therapies hold promise for whole-tooth regeneration and functional restoration.
- Robotics and AR/VR technologies are transforming both clinical practice and education, offering immersive, data-driven environments for enhanced care.
- AI, robotics, regenerative medicine, and AR/VR will revolutionize precision, innovation, and patient outcomes in endodontics.

INTRODUCTION

Endodontics, a dental specialty dedicated to preserving natural teeth, has continually evolved through scientific advancements and technological innovation. From its early reliance on manual instrumentation to its current integration of cutting-edge technologies, the specialty has consistently adapted to improve diagnostic accuracy, treatment outcomes, and patient care. Each decade has brought transformative changes that have elevated the standard of care and expanded the scope of possibilities.

This evolution has been driven by the profession's ability to incorporate emerging technologies into practice. For instance, the introduction of nickel-titanium (NiTi) rotary files in the 1990s revolutionized canal preparation, enabling more precise shaping of complex root systems.[1] In the 2000s, cone-beam computed tomography (CBCT)

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Abbreviations	
AGI	artificial general intelligence
AI	artificial intelligence
AR	augmented reality
CBCT	cone-beam computed tomography
LIDAR	light detection and ranging
MIE	minimally invasive endodontics
NiTi	nickel-titanium
RCT	randomized controlled trial
USAG-1	uterine sensitization-associated gene-1
VR	virtual reality
3D	3-dimensional

provided clinicians with 3-dimensional (3D) imaging, transforming treatment planning, and enhancing diagnostic accuracy.[2] These milestones, along with innovations in irrigation, materials, and visualization, have defined modern endodontics, setting the stage for its next era of transformation.

The intersection of science and imagination has always played a role in shaping perceptions of the future, as evidenced by cultural phenomena like *Back to the Future*, *Star Wars*, *The Matrix*, *2001: A Space Odyssey*, and *Star Trek*. These works of fiction envisioned technologies that seemed impossible at the time but have become increasingly relevant in the twenty-first century. The idea of intelligent systems, robotic assistants, and advanced computational capabilities; common themes in these stories, are now being realized in fields such as health care and endodontics. Artificial intelligence (AI) and machine learning, once the domain of speculative fiction, are now integral tools in modern practice. In 2018, a study titled *Automatic quantification framework to detect cracks in teeth* explored the application of machine learning for detecting cracks in CBCT images.[3] Dr Asma Khan, a contributing author, endodontist and neuroscientist, demonstrated how AI systems could enhance diagnostic accuracy, offering a glimpse into the future of endodontic practice. This early exploration of AI in dentistry exemplifies how innovation can transform clinical workflows. While many clinicians became aware of AI's potential with the release of tools like ChatGPT in 2022, the groundwork for its application in health care had been laid years earlier.

Endodontics today is at a critical inflection point. Advances in AI, robotics, augmented reality (AR), virtual reality (VR), and regenerative therapies are creating opportunities to redefine the specialty. AI-powered systems such as those used in crack detection and CBCT analysis are improving diagnostic precision while reducing human error.[4] As discussed earlier in Almira Isufi and colleagues' article, "On the Horizon: What's Next for Endodontics," in this issue AR and VR platforms are beginning to transform clinician training by offering immersive environments that accelerate skill acquisition. A recent study by Carpegna and colleagues further illustrated this potential, demonstrating how VR simulations can effectively support endodontic microsurgery training in a structured educational setting.[5] Looking ahead, innovations such as neural operators; a novel AI framework capable of solving complex engineering problems, are expected to optimize treatment protocols and material design in endodontics.[6] These technologies, combined with breakthroughs in regenerative medicine and bioengineering, may soon make whole-tooth regeneration possible; an idea once confined to the realm of science fiction.[7]

However, the rapid pace of technological advancement also raises important ethical and practical considerations. As AI systems become more sophisticated, concerns about over-reliance on technology, workforce implications, and data privacy are growing. Clinicians must navigate these challenges carefully, ensuring that innovation enhances, not replaces, the human element of patient care. Additionally, if decentralized systems like Web 3 and blockchain technologies are utilized to store patient data, questions surrounding its integration highlight the need for robust regulatory frameworks to maintain trust and compliance.[8]

Looking ahead, the future of endodontics promises a confluence of biological and technological innovation. The integration of AI, robotics, and regenerative medicine is not merely an evolution of existing practices but a transformation that could fundamentally redefine the specialty. This final segment explores these themes in depth, beginning with an examination of the historical evolution of endodontic technology, followed by an analysis of current trends and an exploration of what lies beyond the horizon. Each section is grounded in the understanding that innovation in endodontics is driven by a commitment to preserving natural teeth while enhancing the quality of care provided to patients.

THE EVOLUTION OF ENDODONTIC TECHNOLOGY

The field of endodontics has witnessed a remarkable transformation, driven by advancements in instrumentation, imaging, disinfection, and materials. These innovations have redefined clinical workflows, enhanced precision, and improved patient outcomes.

In the early twentieth century, stainless steel hand files dominated endodontic instrumentation. While effective for shaping canals, these tools were rigid and prone to procedural errors such as transportation and perforation.[1] The introduction of NiTi rotary files in the 1990s was a turning point, offering flexibility and efficiency, especially in curved or narrow canals.[9] In the 2010s, heat-treated NiTi files further enhanced performance, providing increased resistance to fatigue and allowing safer navigation of complex anatomies.[10]

Imaging technologies have also evolved dramatically. The 2-dimensional periapical radiographs, once the standard for diagnosis, were supplemented by digital radiography in the early 2000s, offering faster imaging with lower radiation exposure.[11] The introduction of CBCT provided 3D imaging, enabling precise visualization of root canal systems, periapical tissues, and anatomic landmarks.[2] CBCT has since become an indispensable tool for treatment planning and guided procedures.

Advances in disinfection technologies, such as laser, ultrasonic, and multisonic irrigation systems, have improved biofilm removal and enhanced outcomes in challenging cases.[12] Bioceramic materials, introduced for obturation and repair, provide superior sealing properties, biocompatibility, and regenerative potential.[13] These materials are now integral to treatments such as apexification and pulp capping.

Together, these advancements have propelled endodontics into the modern era, setting the stage for the transformative innovations discussed in previous sections (**Fig. 1**).

CURRENT TRENDS IN ENDODONTIC RESEARCH AND PRACTICE

Endodontics is experiencing a surge of innovation as advanced technologies continue to reshape clinical practice and education. These current trends are enhancing precision, efficiency, and outcomes, reflecting the specialty's commitment to adopting cutting-edge solutions (**Fig. 2**).

Guided dynamic navigation systems are transforming nonsurgical and surgical endodontics. By integrating real-time imaging and 3D modeling, these systems

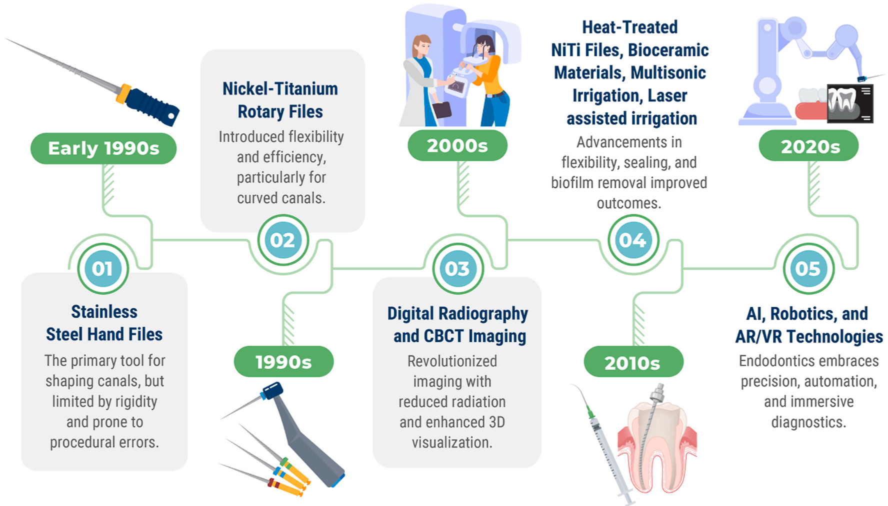

Fig. 1. Timeline of endodontic technology: from hand files to AI.

enable precise access to the pulp chamber and accurate root resection during apical surgeries.[14] These advancements reduce procedural errors, minimize damage to surrounding structures, and improve success rates, particularly in challenging cases.

The growing emphasis on preserving tooth structure has driven the adoption of minimally invasive techniques.[15] While this approach was once ahead of its time, advancements in technology have made it practical and effective. Early attempts at minimally invasive endodontics (MIE) faced limitations, as traditional irrigation methods and rigid instruments struggled to disinfect and shape canals effectively with smaller access cavities.

Today, innovations like multisonic irrigation, laser-assisted systems, and bioceramic materials have revived MIE as a viable approach. These technologies promise improved disinfection and sealing while preserving dentin and enamel integrity, aligning with modern dentistry's goal of extending tooth longevity.

Effective disinfection remains a cornerstone of successful endodontic treatment. Multisonic systems like GentleWave use acoustic streaming and cavitation to enhance biofilm removal, while laser-assisted irrigation offers improved penetration into dentinal tubules.[16] Emerging systems, such as ODNE Clean and nanotechnologies, are further expanding options for more efficient and predictable irrigation.[17]

AI is playing an increasingly prominent role in diagnostics and clinical decision support. AI-powered computer vision tools, such as Overjet, analyze radiographs and CBCT to detect anatomic structures, caries, periapical lesions, and other anomalies with remarkable accuracy.[18] Clinical decision support systems are also guiding treatment planning, offering real-time insights that augment clinician expertise.[19]

AR, VR, and 3D printing are revolutionizing dental training and education. AR and VR platforms provide immersive simulations for mastering complex techniques, while 3D-printed models enable hands-on practice.[5] AR can overlay CBCT data onto the patient in real time, allowing clinicians to visualize hidden anatomic structures and precisely guide apical surgeries.[20] These technologies are accelerating skill acquisition and improving confidence among students and clinicians.

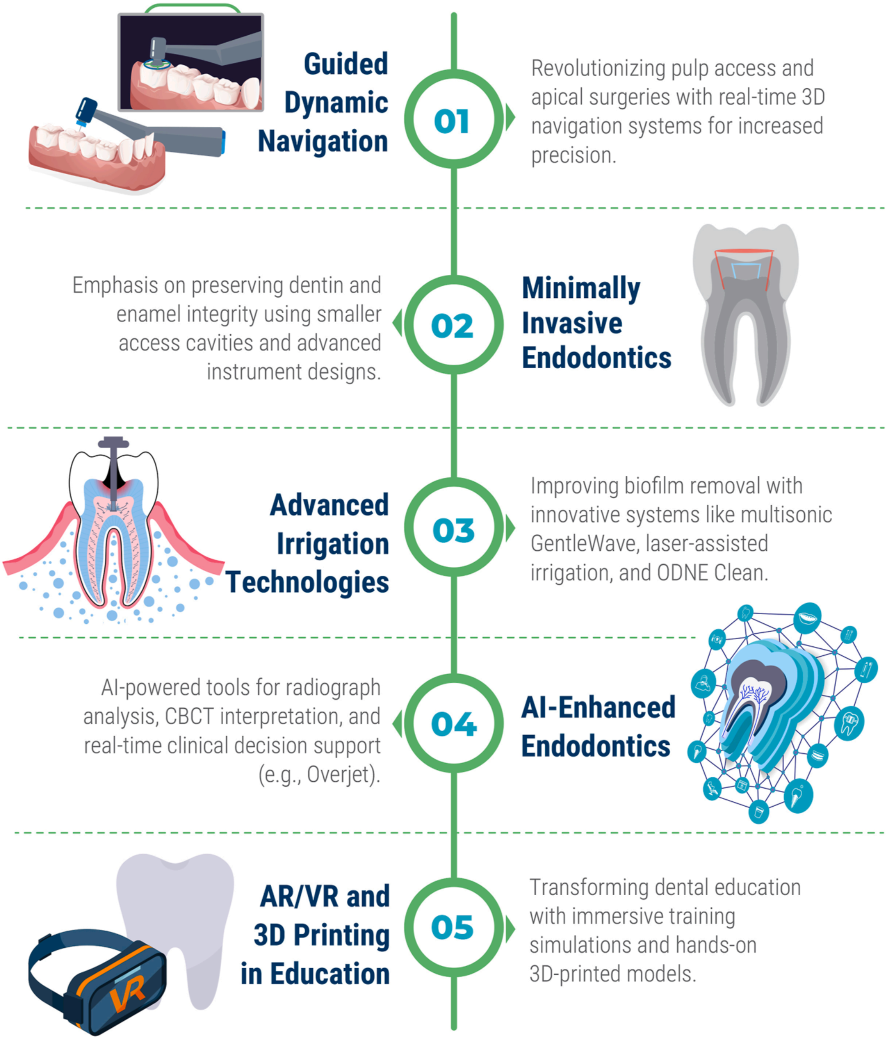

Fig. 2. Current trends in endodontics.

BEYOND THE HORIZON IN ENDODONTICS

Endodontics is entering an unprecedented era of transformation, driven by rapid advancements in robotics, AR, VR, regenerative medicine, and AI. These innovations are redefining what is possible in diagnostics, treatment, and patient care. While technologies such as CBCT, bioceramics, and advanced irrigation have brought significant progress, what lies ahead promises to fundamentally reshape the field. As technologies converge in endodontics, the horizon stretches into realms that challenge even the boldest imagination.

Technologies on the Horizon: Near-Term Breakthroughs

Several technologies are poised to transition from experimental phases to clinical application, fundamentally altering how endodontic procedures are performed and taught (Fig. 3).

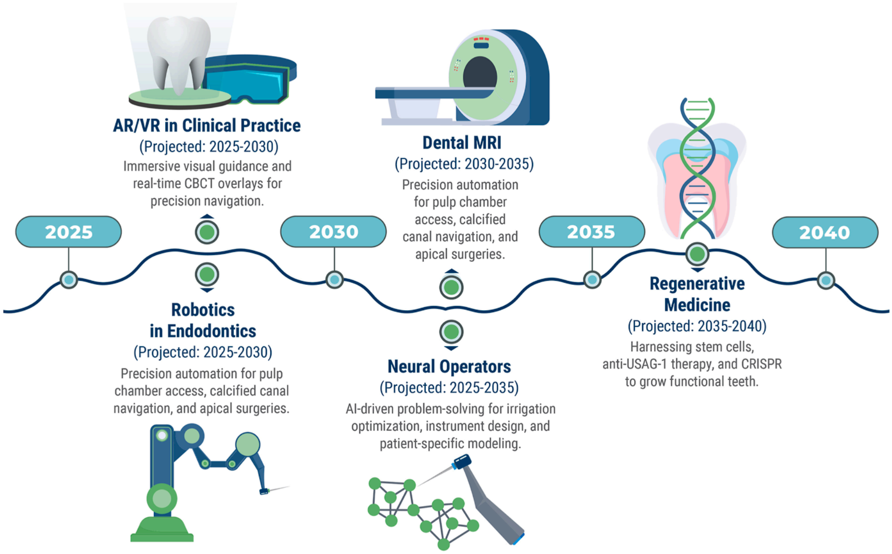

Fig. 3. Technologies on the horizon.

Robotics in endodontics

Robotics has already demonstrated its potential across various dental specialties, including implantology and oral surgery, but its application in endodontics is only beginning to take shape. As discussed in Nadasinee Jaruchotiratanasakul and colleagues' article, "Microrobotics in Endodontics: A Revolutionary Approach to Root Canal Treatment and Nanozymes," in this issue, robots designed for root canal therapy can locate and access calcified canals with a level of precision that exceeds human capability. Similarly, guided robotic apical surgery has emerged as a highly effective and precise approach for complex procedures.[21] These systems help mitigate the risks of perforation and missed canals, which remain significant challenges in complex cases. In apical surgeries, robots are expected to assist with root-end resections, delivering millimeter-level accuracy while preserving adjacent anatomic structures. Looking ahead, the integration of robotics with nanotechnology may further revolutionize endodontics, with nanobots potentially navigating the intricate root canal system with unparalleled precision and efficiency.

It is projected that robotic systems will soon be developed to automate repetitive tasks, such as instrument sterilization, chair-side assistance, and turn-over of clinical rooms. These innovations promise to streamline workflows, reduce clinician fatigue, and enhance procedural efficiency. While still in their infancy, robotic systems are anticipated to become integral to modern endodontic practices within the next decade.

Dental MRI: a radiation-free imaging modality

MRI has long been a staple in medical diagnostics, but its application in dentistry remains limited due to the high costs and size of traditional MRI machines. However, advancements in miniaturization of MRI systems tailored for dental use have the potential to revolutionize imaging in endodontics.[22] Unlike CBCT, which exposes patients to ionizing radiation, MRI provides detailed soft tissue contrast without radiation exposure, making it ideal for assessing pulp vitality, visualizing periapical pathologies, and evaluating complex root canal systems. These capabilities could replace or complement existing imaging modalities, providing clinicians with new tools for diagnosis and treatment planning. Incorporating MRI into endodontic practice presents significant challenges. Compared with CBCT, dental MRI has lower spatial resolution, making it less reliable for detecting fine structures such as microcracks or small canals. Metallic restorations can cause artifacts, reducing image clarity. MRI systems are costly, require specialized infrastructure, and are generally unavailable in dental offices, necessitating off-site referrals that disrupt workflow. Scan times are longer, and patient discomfort or motion can compromise image quality. Moreover, most endodontists lack training in MRI interpretation, and integration requires adherence to strict safety protocols uncommon in dental settings. These factors limit the current feasibility of dental MRI in routine endodontic care.[22]

Augmented reality/virtual reality and wearable technologies

AR and VR technologies are already transforming dental education, offering immersive training environments for mastering complex procedures. In their current state, VR systems simulate highly realistic clinical settings, allowing dental students and clinicians to practice procedures such as pulp access, obturation, and even apical surgery in a completely risk-free environment.[5] These systems often incorporate haptic feedback, enabling users to experience tactile sensations that mimic the resistance of dentin or the delicate maneuvering required for root-end resections. Such innovations accelerate skill acquisition and improve confidence before clinicians perform these procedures on patients.

As AR and VR technologies evolve, their clinical applications are set to expand significantly. Future AR glasses, equipped with cameras, light detection and ranging (LIDAR) sensors, and neural tracking capabilities, could revolutionize how clinicians approach real-time treatment. By projecting 3D CBCT data directly onto a patient's anatomy, these devices would allow endodontists to see hidden structures, such as canals, accessory pathways, or vital anatomic landmarks, superimposed over the patient's physical appearance during treatment. This real-time overlay enables precise guidance in locating calcified canals, performing apical surgeries, or navigating complex root anatomies. The ability to dynamically align and scale CBCT images ensures that clinicians have a constantly updated, accurate view of their operative field.[20]

Moreover, these AR devices could interact with AI-powered agents that analyze real-time data during procedures. For instance, an AI system might identify and flag anatomic landmarks, highlight potential errors such as perforations, or even suggest alternative approaches when encountering unexpected challenges. By serving as a collaborative partner, the combination of AR and AI enhances decision-making and minimizes the risk of complications.

The miniaturization of AR/VR systems will further drive adoption, as devices become smaller, lighter, and more practical for everyday clinical use. Rather than bulky headsets, clinicians will likely use AR glasses that resemble traditional safety eyewear, seamlessly integrating into their workflows. These tools could be paired with other technologies, such as robotic systems or AI-enhanced microscopes, to provide an augmented view of the operative field with hands-free control.

Beyond clinical applications, VR is poised to play an increasingly central role in education and training, as discussed in Tun-Yi Hsu and colleagues' article, "Shaping the Clinician I: Virtual Reality and Augmented Reality Use in Teaching Endodontics"; and Nauman R. Chatha and colleagues' article, "Shaping the Clinician II: Artificial Intelligence-Taught Endodontic Skills," in this issue. Dental schools and continuing education programs can leverage VR to create patient-specific simulations based on actual CBCT scans, enabling clinicians to rehearse complex cases before performing them in real life. Additionally, VR platforms could incorporate gamification elements to enhance engagement, track skill development, and provide real-time feedback to support continuous improvement.

Looking further ahead, AR and VR technologies may even integrate with wearable sensors that monitor the clinician's movements and ergonomics. These systems could provide real-time coaching to ensure optimal positioning and technique, reducing operator fatigue and improving outcomes. The convergence of AR, VR, AI, and robotics represents a paradigm shift in how endodontics is practiced and taught, promising unprecedented precision, efficiency, and innovation.

Regenerative and genetic therapies

Regenerative medicine is perhaps the most transformative area of research in endodontics, offering the potential to restore lost dental tissues and even grow entirely new teeth. Anti-uterine sensitization-associated gene-1 (USAG-1) therapy, developed by Dr Takahashi and his team, represents a groundbreaking approach to dental regeneration.[23] By inhibiting USAG-1, this therapy enhances bone morphogenetic protein signaling, promoting the formation of functional dentin-pulp complexes and, in preclinical models, even supernumerary teeth.[24] This discovery could pave the way for biologically based alternatives to traditional restorative methods, eliminating the need for implants and prosthetics.

CRISPR-based gene editing further expands the possibilities of regenerative endodontics. By targeting genes involved in tooth development, researchers aim to address congenital anomalies such as tooth agenesis and stimulate the regeneration of functional dental structures. These therapies, while still in experimental stages, represent a paradigm shift from preserving teeth to fully restoring them.[25]

Neural operators: a new frontier in artificial intelligence for endodontics

AI has already made significant inroads into endodontics, with computer vision systems analyzing radiographs and CBCT scans to identify cracks, periapical lesions, and other pathologies. However, neural operators developed by Dr Anima Anandkumar's laboratory at Caltech, represent a new class of AI with the potential to solve complex engineering problems and model dynamic physical systems.[26] Neural operators extend the capabilities of traditional AI by enabling real-time predictions and optimizations, even in systems with highly variable conditions.

Catheter development and its relevance to endodontics

One of the most compelling applications of neural operators has been in the development of advanced catheters that suppress bacterial contamination. Neural operators were used to design a novel geometric design with anti-infection properties allowing for prolonged use of the catheter while reducing urinary tract infections.[6] With this AI model, the time from design to prototyping an improved medical device was significantly decreased. These simulations enabled rapid prototyping and optimization of catheter designs, reducing the time and cost required for development.

In endodontics, similar challenges exist in navigating the complex anatomy of root canal systems. Neural operators could simulate the behavior of irrigants under various flow conditions, identifying the optimal parameters for disinfection. They could also model the mechanical properties of rotary files and other instruments, informing the design of tools that are more durable, flexible, and effective in complex canals. Additionally, neural operators could assist in regenerative endodontics by modeling how bioengineered scaffolds interact with pulp tissues, guiding the development of materials that promote faster and more predictable healing.

Broader applications and future potential

The ability of neural operators to generalize across different systems makes them ideal for addressing a wide range of challenges in endodontics. For example, these systems could predict the outcomes of various treatment approaches, enabling clinicians to tailor their protocols to individual patients. They could also be used to simulate long-term outcomes, such as the stability of endodontically treated teeth under different restorative scenarios, providing insights that inform clinical decision-making.

One particularly promising application is the use of AI models to simulate randomized controlled trials (RCTs). Traditional RCTs, though considered the gold standard for generating evidence-based knowledge, are often costly, time-consuming, and logistically challenging, particularly in dentistry where funding and large sample sizes are limited. This scarcity of high-quality trials has left gaps in the dental literature. Neural operator-driven AI systems could fill this void by using large datasets from electronic health records, prior clinical studies, and real-world treatment outcomes to create virtual populations. These simulations can replicate the structure of traditional RCTs, generating comparative data for different treatment approaches under controlled conditions, without the need for expensive, lengthy trials. Furthermore, AI-simulated trials could analyze variables and outcomes that are challenging to study in conventional research, such as rare conditions or long-term success rates, significantly expanding the scope of endodontic research. While these simulations may not fully replace clinical studies, they represent a critical tool for advancing evidence-based practice and bridging the gaps in our current knowledge base.

By enabling precise modeling of clinical scenarios, predicting outcomes, and simulating trials, neural operators have the potential to revolutionize research, refine treatment protocols, and improve patient-specific care in endodontics.

LEVELS OF ARTIFICIAL INTELLIGENCE AND THEIR IMPACT ON ENDODONTICS

AI is currently at the level of narrow intelligence, designed to perform specific tasks like analyzing radiographs or assisting in treatment planning. However, the future promises the emergence of more advanced AI paradigms, each with distinct implications for endodontics (**Fig. 4**).

Artificial general intelligence (AGI) will likely act as a collaborative partner in the clinic, capable of integrating data from multiple sources, such as CBCT scans, medical histories, and even genetic information, to provide real-time, context-sensitive insights during procedures.[27] With AGI's computational power, clinicians would receive personalized recommendations for treatment approaches, including optimal techniques and materials, tailored to the unique anatomic and biological characteristics of each patient. Complex cases, like calcified canals or anatomic variations, could be navigated with unprecedented precision, improving treatment outcomes and reducing procedural risks.[28]

Theory of Mind AI, which understands human emotions, intentions, and psychological states, could fundamentally enhance patient communication and experience.[29] This level of intelligence would allow AI systems to detect anxiety or hesitation in patients and respond with empathy, tailoring explanations, and reassurances to their specific needs. Such systems could act as mediators, bridging gaps between patients and clinicians to foster trust and ensure patients feel understood and valued during their care.

When AI reaches the level of artificial superintelligence, endodontics could enter a realm of possibilities previously unimaginable. Superintelligent systems may autonomously develop groundbreaking materials and therapies, such as bioengineered teeth, regenerative scaffolds, or self-healing biomaterials, in a fraction of the time

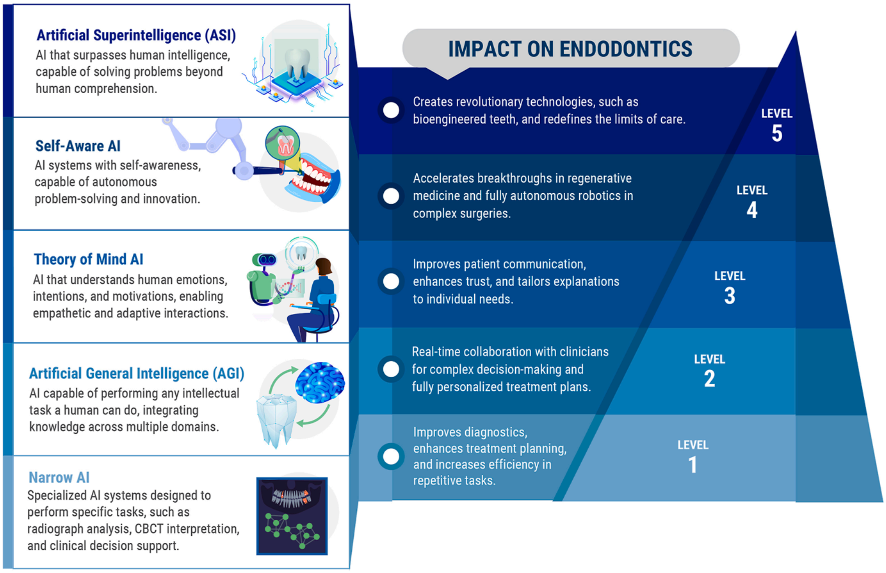

Fig. 4. The levels of AI in endodontics.

currently required by human researchers.[30] Fully autonomous robots, guided by superintelligence, could perform complex endodontic procedures with flawless precision, even in the most challenging anatomic scenarios. Entire dental practices might one day operate with minimal human intervention, from patient triage to execution of intricate surgeries. While the promise of superintelligence brings hope for eliminating tooth loss and pain altogether, it also introduces serious ethical considerations. Issues such as over-reliance on machines, data privacy, and the necessity for human oversight to maintain alignment with patient-centered values must be addressed; concerns explored in Michael McCarthy and Nanette Elster's article, "Artificial Intelligence and Ethics in Endodontics," in this issue. The convergence of AGI, Theory of Mind AI, and superintelligence could herald a new paradigm for endodontics, one marked by unprecedented innovation but also by profound ethical and practical challenges.

ETHICAL CONSIDERATIONS AND WORKFORCE IMPLICATIONS

The integration of emerging technologies like AI, robotics, and AR raises important ethical and societal questions. While these tools promise enhanced precision, efficiency, and improved outcomes, they also pose challenges that require careful consideration.

Workforce displacement is a significant concern, as automation may reduce the demand for certain roles within dental teams, leading to professional and economic disruptions. Ensuring these technologies complement rather than replace human expertise will preserve the essential human element in patient care.[28] Data privacy also remains critical, as AI systems rely on large datasets. Safeguards must address the ethical collection, storage, and use of patient information, with robust consent processes and compliance with regulations like the Health Insurance Portability and Accountability Act (HIPAA). Patients should retain ownership of their data, and transparency in AI usage is essential.[31]

Over-reliance on AI poses additional risks. While these systems enhance decision-making, clinicians must retain their diagnostic and critical-thinking skills to identify errors or limitations within AI recommendations. The "black box" nature of some algorithms could obscure flaws, underscoring the need for balanced integration where technology augments human expertise.[32]

Accountability is another challenge. In the event of errors by autonomous systems, determining liability, whether it lies with clinicians, institutions, or developers remains unresolved. Clear guidelines are vital for fostering trust in these innovations.[33]

Lastly, equitable access to these advancements must be prioritized. Without efforts to address affordability, disparities in care may widen, leaving underserved communities behind. Proactively addressing these issues ensures technological integration enhances patient outcomes while maintaining ethical integrity.

THE CONVERGENCE OF TECHNOLOGIES: THE INFINITE HORIZON

The convergence of robotics, AI, regenerative medicine, and other disruptive technologies marks a pivotal moment for endodontics. The integration of neural operators, anti-USAG-1 therapy, and CRISPR-based gene editing exemplifies how these innovations can work together to redefine the field. As these technologies mature, the possibilities for endodontics are virtually limitless. The challenge lies in navigating this transformation responsibly, ensuring that the benefits of innovation are realized while minimizing potential risks.

SUMMARY

The future of endodontics is both thrilling and uncertain. While we can outline potential advancements and speculate on emerging technologies, the reality is that we cannot predict the exact trajectory of innovation. What we can do, however, is dream and imagine. Science fiction literature and films, from *Star Trek* to *2001: A Space Odyssey*, have long served as a source of inspiration, envisioning technologies that once seemed fantastical but are now becoming reality. These stories remind us that progress often outpaces imagination, pushing the boundaries of what we think is possible.[30,34]

Perhaps the most transformative moment in human history, not just in endodontics but across all fields, will occur when AI surpasses human intelligence. This event, known as the Singularity, was once considered a distant, almost mythical possibility. However, recent projections suggest that it could occur within this decade, a timeline far shorter than previously imagined.[28] Such an inflection point would mark the convergence of disruptive technologies: AI, robotics, regenerative medicine, and bioengineering, accelerating innovation to speeds we cannot yet comprehend.[27] The implications for endodontics and health care as a whole are boundless, from autonomous agents providing real-time clinical guidance to AI-driven breakthroughs in tissue engineering and personalized care.

While we should be excited about this future, we must also proceed with caution. Human oversight will be critical to ensure that these technologies serve the greater good. Ethical considerations, accountability, and the preservation of human-centered care must guide our progress.[29] By embracing this balance of innovation and responsibility, endodontics can not only adapt to the future but also actively shape it, creating a world where the impossible becomes possible.

CLINICS CARE POINTS

- *Embrace Artificial Intelligence (AI)-powered Diagnostics*: AI tools, such as computer vision for radiograph analysis, can enhance diagnostic accuracy and streamline treatment planning.

- *Explore Minimally Invasive Techniques*: Preserving tooth structure with smaller access cavities and advanced tools ensures better long-term outcomes and reduces procedural risks.
- *Consider Dynamic Navigation*: Guided navigation systems improve precision during pulp access and apical surgeries, minimizing complications and enhancing procedural success.
- *Prepare for Augmented Reality/Virtual Reality (AR/VR) Integration*: AR and VR technologies are transforming endodontic education and will soon become integral to real-time clinical workflows.
- *Stay Informed on Emerging Technologies*: Innovations such as regenerative medicine, neural operators, and robotics are on the horizon, promising groundbreaking advancements in patient care.

DECLARATION OF AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the author used *Claude* as an editing tool to improve readability. The author reviewed and edited the content as needed and takes full responsibility for the content of publication.

DISCLOSURE

The author has nothing to disclose.

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