TWO CUTTING EDGES: HARD AND SOFT SKILLS IN DENTAL IMPLANTOLOGY TRAINING AND THE INFLUENCE OF MODERN TECHNOLOGIES

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LIST OF ABBREVIATIONS

3D	3 dimensional
AI	Artificial Intelligence
AFFECT	Affective emotional and physiological states detection and recognition
AR	Augmented Reality
CAD	Computer-aided design
CAM	Computer-aided manufacturing
CBCT	Conebeam Computer Tomogram
CT	Computer Tomography
DICOM	Digital Imaging and Communications in Medicine
DL	Deep Learning
FER	Facial emotion recognition
HMD	Head Mounted Device
IOS	Intraoral Scan
ML	Machined Learning
MR	Mixed Reality
MRI	Magnetic Resonance Imaging
NTS	Non-technical Skills
OR	Operating Room
STL	Standard Template Diary
TS	Technical Skills
VACID	Video Assisted Clinical Instruction
VR	Virtual Reality

1. INTRODUCTION

This extended abstract synthesizes the content and contributions of the PhD thesis presented here, which interrogates the need of soft and hard skills for oral and maxillofacial surgeons and how immersive technologies - virtual reality (VR), augmented reality (AR), and mixed reality (MR) - together with artificial intelligence (AI), are reshaping both the technical and the humanistic dimensions of dental implantology and oral surgery. The thesis is structured around four central questions: the role and future capabilities of immersive technologies in dental surgery; the fulfilled promises and remaining potentials of AR in implant training; the perceptions and ethical expectations of the next generation of clinicians regarding AI; and the search for a durable balance between hard (technical) and soft (relational, ethical) skills in training and practice.

The thesis combines conceptual analysis, literature review, and empirical work including a proof-of-concept clinical implementation of MR during implant surgery and a multitopic survey on AI ethics among university students to assemble a comprehensive picture of the current inflection point in digital dentistry. The thesis demonstrates that MR can support intraoperative visualization and remote teaching, AR/VR meaningfully augment pre-clinical and postgraduate education under blended-learning models, and that students are prepared to engage with AI provided that robust safeguards are implemented, like explainability, privacy, fairness and accountability. Across these strands, the thesis argues that the durability of digital transformations will ultimately be judged by their compatibility with, and reinforcement of, soft skills: empathy, communication, teamwork, and ethical judgement.

Beyond cataloguing technologies, the thesis proposes an integrative framework for training that deliberately couples data-driven precision with humane clinical care. It advances new observations from clinical MR trials and detailed survey findings on data stewardship preferences and access controls, while offering actionable guidance for educators and policy-makers.

2. AIMS

The research is organized around four aims that together define the scope of the thesis:

1) Clarify the roles and plausible near-term capabilities of immersive technologies in dental surgery, with attention to what can be responsibly implemented today versus what remains aspirational.

2) Evaluate the promises of AR in dental implant training, distinguishing genuine educational value from novelty effects, and identify where AR best complements established methods.

3) Elicit and analyze the expectations and worries of future clinicians regarding AI in dentistry, particularly around data governance, explainability, responsibility, and patient dignity.

4) Articulate a principled approach to balancing hard and soft skills in curricula and in practice, proposing practical levers for educators, trainers, and institutional leaders.

3. BACKGROUND

Dentistry has long demanded dexterity and clinical foresight, but contemporary practice is increasingly mediated by digital systems that reconfigure diagnosis, planning, and the conduct of surgical procedures. High-resolution 3D imaging (CBCT, CT, MRI), intraoral scanning, computer-aided design and manufacturing (CAD, CAM), and intelligent software pipelines now furnish surgeons with rich datasets and decision support at every stage of care. Immersive interfaces like VR, AR, MR extend this trajectory by placing patient-specific models, plans, and guidance into the surgeon's field of view and by enabling interactive teaching at a distance. Simultaneously, AI promises pattern recognition and predictive power across imaging, diagnostics, and logistic, while raising profound questions about oversight, liability, privacy, and the preservation of clinical empathy.

The thesis contends that the full value of these technologies cannot be realized without sustained attention to the interplay of hard and soft skills. Where hard skills are sharpened by digital data and simulation, there is a countervailing risk of eroding soft skills. Those human competencies that ground trust and shared decision-making. The challenge, therefore, is neither to slow innovation nor to fetishize it, but to embed technology within an explicitly ethical, person-centered practice.

4. METHODS AND EVIDENCE BASE

The MR clinical proof-of-concept adopted standard implant planning with intraoral scanning and CBCT. Data fusion yielded STL models that were curated for MR visualization. During surgery, HMDs supplied direct access to models and PDF-based drill protocols within the sterile field. Remote avatars were piloted to explore telementoring. Observational measures included feasibility, ease of use, fidelity of alignment, and qualitative utility for orientation and education.

The AI ethics survey instrument canvassed attitudes across multiple domains: acceptable purposes for data use, preferred loci for data storage (professional bodies, WHO, EU, national, UN), granularity of collection (limited, large-scale, comprehensive), and stakeholder roles in access decisions. It captured demographic variation (region, gender, level of study) and applied exact tests to evaluate group differences. Results showed differentiated preferences, like greater support among some cohorts for WHO-run or professional-body data pools, stricter limits on industrial use, and a tendency for younger respondents to endorse more comprehensive storage in certain institutional settings, while consistently elevating patient roles in governance.

5. IMMERSIVE TECHNOLOGIES IN DENTAL SURGERIES

The opening pillar positions VR, AR, and MR within surgical education and operative workflows. VR immerses the user in a fully synthetic environment for rehearsal and concept acquisition. AR overlays digital objects onto the real world to enrich perception and communication. MR enables bidirectional interaction between the real environment and digital artefacts, such that the surgeon can interrogate, manipulate, and share patient-specific models during a procedure.

A proof-of-concept clinical implementation tested MR under real operating conditions. The workflow began with acquisition of intraoral scans and CBCT data, which were fused for prosthetically driven implant planning. Planning outputs like STL models of the jaw anatomy, proposed implant positions, and 2D reports were prepared for intraoperative visualization. During cases, the surgeon and an assistant wore head-mounted displays (Hololense 2, Microsoft, USA) or used see-through tablets (apple, USA) to access holographic models, cross-sectional views, drill sequence reports, and pre-operative plans in the sterile field. Remote participants could join as avatars for consultation and teaching, observing the surgeon's perspective in real time.

The experience demonstrated multiple advantages: enhanced spatial orientation for the surgeon through persistent 3D context, hands-free access to key documents (e.g., drilling protocols) without turning away from the patient and a novel educational modality in which trainees and external experts could visualize and discuss the same holographic objects while the case proceeds.

Figure 1: MR devices during surgery. Surgeon wearing an HMD.

Figure 2: See-through devices during surgery. View of the surgery and the adjusted virtual model.

It also exposed technical constraints that currently limit direct, navigation-grade applications: anchoring holograms to moving anatomy with true-to-scale fidelity remained imprecise, adding or recombining complex 3D layers on the fly tended to break registration and automatic alignment of the virtual model to the intraoral situation was not yet robust enough for clinical reliance.

The discussion distills six concrete use-cases where mixed reality already shows value:

(1) preoperative visualization of bony structures and pathologies to inform plans.

(2) three-dimensional communication among the therapeutic team and with the patients.

(3) intraoperative visualization of patient-specific models to guide orientation.

(4) remote consultation and tele-mentoring through shared holograms.

(5) creation of a transparent record that can support quality assurance and medico-legal review.

(6) scaffolding of new training paradigms that blend observation with interaction.

In this framing, MR augments the surgeon's situational awareness and the team's collective cognition, even as industry works toward higher precision tracking and seamless data integration.

Figure 3: PDF based drilling protocol in a virtual presentation.

6. POTENTIALS OF AR IN DENTAL IMPLANT TRAINING

The second pillar surveys educational impacts. The pandemic catalyzed the adoption of blended and remote instruction, forcing faculties to re-imagine how to impart three-dimensional anatomical understanding and procedural fluency without traditional cadaveric labs or in-person clinics. In this context, AR/VR tools gained traction because they enable repeated practice and perspective-taking, support spatial reasoning, and can be integrated with computerised phantom heads and video-assisted clinical instruction (VACID).

Synthesizing available studies, the thesis identifies where these tools are the strongest: concept acquisition in anatomy, pre-operative planning exercises, and rehearsal of procedural sequences. Students frequently report better comprehension of 3D relationships and value the ability to pause, replay, and explore from multiple vantage points. Nevertheless, limitations are recurrent: lack of tactile realism, occasional hardware and latency issues and the risk of attenuating the social learning and mentorship that occur in shared physical spaces. Surveyed cohorts often state a preference for keeping VR/AR as a complement rather than a substitute for conventional training, a position endorsed by the thesis' analysis of outcomes and face validity.

On the implementation side, the work proposes practical patterns for curriculum design like the beginning with model-based training to build dexterity, to layer in VR modules that stress spatial reasoning and the use of AR/MR to connect pre-operative plans to observed or simulated procedures. Standardized assessment rubrics and structured debriefs remain essential, both to validate competence and to keep soft skills (communication, teamwork, reflection) in scope. Early data suggest that the time required for accurate implant planning can be reduced when learners have access to integrated VR/AR environments, though the thesis cautions against over-generalization until controlled comparisons are more widely available.

Figure 4: External team members. Visualization of an avatar of an external team member during surgery.

7. AI IN DENTISTRY – ETHICS AND PERCEPTIONS

AI applications now span imaging analysis, treatment planning, triage, and administrative automation. Yet the literature review reveals a misalignment between the pace of technical publications and the maturity of ethical discourse. Across more than fifteen hundred articles screened for the period 1999–2020, fewer than two hundred were retained for relevance, and among those the proportion explicitly addressing ethical implications has stagnated despite rising volume. The thesis therefore foregrounds a structured ethical analysis using principles of beneficence, non-maleficence, autonomy, justice, privacy, accountability, and transparency.

With the multi-topic student survey the empirical component probes attitudes on data governance, access controls, locus of oversight, and stakeholder roles in decision-making processes. Respondents generally support access to personal data for diagnostic, therapeutic and scientific purposes under controlled conditions, and oppose access for industrial or marketing purposes. Preferences vary by region, gender, and stage of study. There is comparatively stronger support for international or professional-body stewardship (e.g., WHO) and for EU-level frameworks than for unbounded national or UN pools. A sizeable contingent assigns patients an important or exclusive role in decisions about the use of their own data. Students also voice clear expectations for explainability and for legal clarity in liability when AI tools inform clinical decisions.

Complementing attitudes, the thesis examines technical, and governance challenges associated with big data in healthcare: the difficulty of ensuring high-quality or bias-resistant datasets, the need for robust documentation and traceability of models, and the design of oversight mechanisms, both institutional and regulatory, that can detect mis-specification or corruption in training data. 'Explainability' is treated not merely as a model property but as an interdisciplinary requirement that implicates clinical communication, informed consent, jurisprudence, and societal trust.

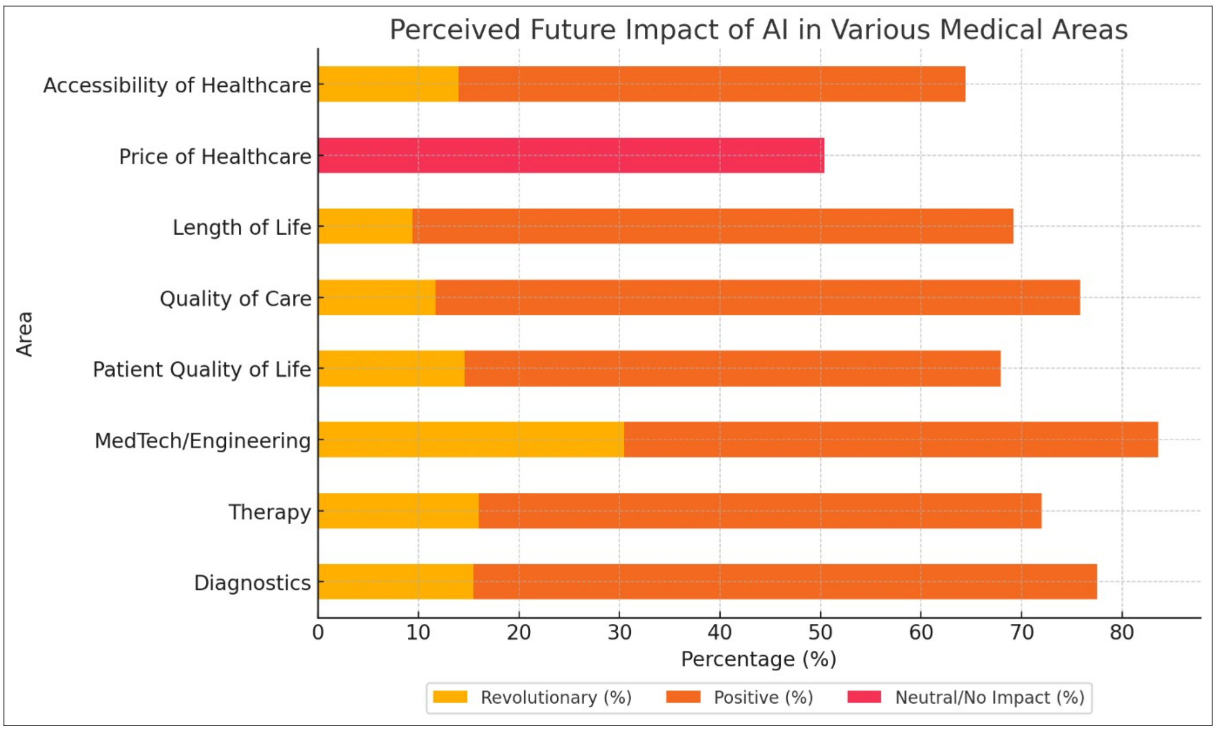

Table 1: Perceived future impact of Ai in various medical and dental areas

8. BALANCING HARD AND SOFT SKILLS

The fourth pillar articulates the dual competency model. Hard skills like anatomical knowledge, guided-surgery workflows, instrument handling, and quality assurance are necessary for a safe, and effective implantology. Soft skills like empathy, narrative competence, communication, teamwork, and ethical reasoning are equally necessary for a humane and patient-centered care. The thesis argues that digital transformation increases the salience of soft skills because technology can distance clinicians from patients' lived experiences even as it streamlines procedures.

Drawing on professionalization theory, the work re-states five structural characteristics of medical action: attending to the patient's concern, helping without patronizing, maintaining appropriate professional distance while seeing the whole person, and adapting general knowledge to the specifics of the case. In this light, an AI capable of classifying affect or forecasting risk may assist, but it does not replace the clinician's responsibility to situate data within the person's values and context. Case material on mesiodens underscores the point by juxtaposing evidence-based protocols with sensitivity to aesthetics, identity, and the meaning patients attach to treatment trajectories.

9. RESULTS, IMPLICATIONS AND LIMITATIONS

9.1. Results

Taken together, the four pillars yield a coherent set of findings:

- Immersive technologies are already fit for purpose as visualization, communication, and teaching tools in implantology and oral surgery. They extend the surgical cockpit with context-rich data and enable new forms of collaboration and mentorship.

- AR/VR are pedagogically potent for spatial understanding and rehearsal and should be embedded where they add demonstrable value. They cannot supplant tactile, supervised training and the tacit knowledge transmitted through apprenticeship.

- AI enjoys cautious enthusiasm among future clinicians, conditioned on substantive safeguards. Ethical lacunae in the literature should be closed by interdisciplinary teams who co-design tools and guardrails from the outset.

- The soft-skills agenda must be elevated, not eclipsed, by digital progress. Empathy, communication, and shared decision-making are not 'nice-to-have' complements. They are core to safety, adherence, patient satisfaction, and just care.

9.2. Implications

Education: Embed immersive tools in a spiral curriculum that progresses from conceptual visualization to procedural rehearsal to guided clinical observation, with consistent assessment of both technical proficiency and communicative competence. Provide faculty development so instructors can orchestrate VR/AR/MR sessions that are psychologically safe, pedagogically intentional, and inclusive.

Clinical Practice: Use MR as an adjunct for preoperative briefings and intraoperative orientation in well-selected cases where it can streamline access to critical information. Establish protocols for data preparation, device sterilization, and team roles. Treat MR/AR displays as shared cognitive artefacts to support situational awareness without overloading attention.

Policy and Governance: Translate the survey's ethical expectations into concrete institutional policies: clarified responsibility for AI-assisted decisions, routine documentation of model lineage and performance, patient-centered consent pathways, and robust oversight of data quality. Encourage multi-stakeholder forums including students to iteratively refine guidelines as capabilities and norms evolve.

9.3. Limitations and directions for future research

The MR clinical pilot was not powered for outcome comparisons and did not include navigation-grade alignment. The results should be interpreted as feasibility insights rather than efficacy claims. Hardware constraints and movement artifacts limited the precision. Future work should evaluate landmark-based registration and dynamic tracking approaches that can tolerate patient and operator motion without losing scale fidelity.

The survey reflects specific institutional and regional cohorts and topics, and the generalization requires replication and extension. Future modules should probe explainability preferences in more depth, test comprehension of AI outputs in clinical vignettes, and experiment with deliberative formats that bring patients and trainees into shared conversations about acceptable AI use.

10. CONCLUSIONS AND FINDINGS

The thesis makes the case that digital dentistry will be judged not only by accuracy metrics and throughput gains, but by how well it preserves the human texture of care. Immersive technologies and AI can and should be harnessed to strengthen rather than weaken clinical relationships. Achieving this outcome requires deliberate design of tools, pedagogy, and governance. The framework and findings assembled here provide a path forward for educators, clinicians, and policy-makers committed to technically excellent, ethically grounded implantology.

As a result, the following new observations and contributions to already existing scientific knowledge can be drawn:

1.) First-hand demonstration that MR can be integrated into live implant surgery to provide surgeons and observers with persistent, manipulable 3D context and on-demand access to key documents in the sterile field.
2.) Validation of avatars/remote presence as a viable extension of surgical education and consultation, opening pathways for resource-efficient tele mentoring and just-in-time expertise sharing.
3.) Empirical mapping of student attitudes toward AI governance that differentiates among purposes, storage loci, and stakeholder roles as a granularity that can guide institutional data policy and national-level frameworks.
4.) A training blueprint that binds technical excellence to humanistic competence, offering practical levers to maintain empathy and shared decision-making amid accelerating digitization.

11. LIST OF PUBLICATIONS RELATED TO THE DISSERTATION

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12. OTHER PUBLICATIONS

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