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A Retrospective Comparative Analysis of Mixed Reality Integration in General Dentistry and Oral Surgery

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Abstract

Mixed reality (MR), encompassing augmented reality (AR) and virtual reality (VR) technologies, is an emerging tool in clinical dentistry that enables digital information to be displayed directly within the clinician's field of view. Modern dental practice relies heavily on electronic health records, radiographic imaging, and computer-assisted diagnostic and surgical systems, often requiring clinicians to divert attention away from the operative field. These interruptions can disrupt workflow and increase cognitive load. This study aimed to quantify computer dependence across common general dentistry and oral surgery procedures and to evaluate which clinical discipline may benefit most from MR integration into dental loupes. A retrospective observational analysis was conducted on fifty patients treated by a single general dentist, with ten patients included in each procedure category: Extraction(s), Root Canal Treatment(s), Crown(s), Filling(s), and Prophylaxis. An additional fifty patients were treated by two oral surgeons across six procedure categories, with ten patients per category except for implant procedures, which included five patients each: Surgical Extraction(s) with IV Sedation, Implant without Assisted Reality Glasses, Implant with Assisted Reality Glasses, Bone Graft with IV Sedation, Bone Graft with Local Anesthesia, and Biopsy. Computer usage was quantified as seconds per interaction with digital devices during active treatment. A two-sample t-test demonstrated a statistically significant difference in computer usage between general dentistry and oral surgery procedures ($p < 0.001$), with oral surgery exhibiting more frequent digital interactions and greater computer dependence. One-way ANOVA tests conducted independently within each discipline revealed significant variation in computer usage among procedure types. These findings suggest that targeted MR integration may be particularly beneficial in oral surgery workflows, where frequent consultation of digital systems is essential. Prioritizing MR and assisted reality technologies in high-dependence procedures may reduce attention shifts, lower cognitive load, and enhance clinical efficiency.

Keywords: Mixed reality, Augmented reality, Head-mounted displays, Digital workflow, General dentistry, Oral surgery.

INTRODUCTION

Advances in digital technology continue to reshape the delivery of dental care, with increasing emphasis on tools that enhance precision, efficiency, and clinician focus. As dental workflows become more digitally dependent, practitioners are required to frequently interact with electronic health records (EHRs), radiographic imaging, intraoral scanners, navigation systems, and patient monitoring devices during active treatment. While these technologies improve diagnostic and procedural accuracy, they also introduce workflow interruptions that can increase cognitive load and divert visual attention away from the operative field. Mixed reality (MR) technologies have emerged as a potential solution to these challenges by enabling real-time access to digital information without requiring clinicians to disengage from patient care.

Mixed reality represents a spectrum of immersive technologies that includes virtual reality (VR), augmented reality (AR), and assisted reality (aR). Virtual reality fully immerses the user in a simulated digital environment, typically isolating them from the physical world and is therefore most commonly applied in dental education, simulation training, and procedural rehearsal. Augmented reality overlays digital information such as anatomical landmarks, radiographic guidance, or navigation cues onto the real-world environment, allowing simultaneous interaction with both physical and virtual elements. Assisted reality, a simplified subset of AR, presents essential digital information within the user's field of view without spatial anchoring or complex interaction. In clinical dentistry, aR is often more practical due to its lower cognitive demand and compatibility with existing workflows.

Adoption of MR-related technologies across healthcare has expanded rapidly in recent years, driven by the need to reduce reliance on external monitors and improve real-time decision-making. Dentistry, however, has been comparatively slower to integrate these tools into daily clinical practice. One key barrier is the widespread use of dental loupes, which remain the standard for magnification and ergonomic visualization. The lack of seamless integration between loupe systems and MR displays has historically limited adoption. Nevertheless, recent innovations in AR-enabled loupes and head-mounted displays (HMDs) have demonstrated the feasibility of combining optical magnification with digital overlays, opening new opportunities for clinical application.

In general dentistry, procedures such as surgical extractions, endodontic therapy, and complex restorative treatments require repeated consultation of radiographs, working length measurements, intraoral scans, and patient records. During root canal therapy, for example, clinicians often alternate between the operative field, apex locator displays, digital radiographs, and rotary system interfaces. These repeated gaze shifts can disrupt procedural flow and increase mental workload, particularly in complex or multi-rooted cases. AR-based overlays displaying working length, canal anatomy, or reference radiographs directly within the clinician's field of view have been explored as a means of maintaining continuous focus while improving procedural efficiency.

Virtual reality has also found a role in general dentistry, particularly in patient management and anxiety reduction. VR-based distraction therapy has been shown to decrease perceived pain and anxiety during procedures such as restorations, prophylaxis, and extractions, especially in pediatric and anxious adult patients. While VR does not directly reduce clinician computer usage, it highlights the broader role of immersive technologies in improving the dental care environment. Additionally, VR simulation platforms are increasingly used in dental education to improve procedural competence before clinical exposure, reinforcing the relevance of immersive technologies across the dental continuum.

Oral surgery presents an even greater demand for digital interaction due to the complexity of procedures and the reliance on advanced imaging, navigation systems, and physiologic monitoring. Beyond implant dentistry, AR and MR technologies are being applied in third molar surgery, orthognathic procedures, trauma management, and pathology assessment. In surgical extractions, AR systems have been used to project cone beam computed tomography (CBCT) data onto the operative field, assisting surgeons in visualizing the proximity of impacted teeth to vital structures such as the inferior alveolar nerve or maxillary sinus. This real-time anatomical guidance has the potential to reduce complications and improve surgical confidence.

In maxillofacial trauma and reconstructive surgery, MR has been explored for preoperative planning and intraoperative guidance. Surgeons can rehearse fracture reductions or osteotomies in VR environments and then utilize AR overlays during surgery to align bone segments according to preplanned trajectories. These applications demonstrate how immersive technologies can support both planning accuracy and intraoperative execution, while also reducing dependence on external screens.

Another important application of AR in oral surgery involves real-time navigation systems used during complex procedures. These systems rely heavily on continuous visual feedback from external monitors displaying three-dimensional imaging, spatial orientation, and instrument positioning. Surgeons must repeatedly shift their gaze between the patient and the screen, increasing cognitive load and potentially prolonging treatment time. Integrating navigation data into aR HMDs allows critical information such as angulation, depth, and positional alerts to be displayed directly within the surgeon's line of sight. This approach minimizes visual disengagement and supports more efficient hand–eye coordination.

Procedures performed under intravenous (IV) sedation further highlight the need for streamlined digital access. Oral surgery procedures such as complex extractions, bone grafting, biopsies, and implant placement frequently involve IV sedation to enhance patient comfort and cooperation. Sedation requires continuous monitoring of vital signs, including oxygen saturation, blood pressure, heart rate, respiratory rate, and end-tidal CO_2. These parameters are typically displayed on monitors positioned outside the surgeon's immediate field of view, requiring frequent checks during surgery. Missed or delayed recognition of vital sign changes can compromise patient safety, particularly in longer or more invasive procedures.

Head-mounted displays with aR capabilities offer a promising solution by projecting real-time vital sign data directly into the clinician's visual field. This allows surgeons to maintain focus on the operative site while continuously monitoring patient status. Similar systems have already been adopted in hospital operating rooms and anesthesia workflows, demonstrating improved situational awareness and reduced response time. Translating these technologies into dental and outpatient surgical settings could significantly enhance safety and efficiency, particularly in high-acuity cases.

Bone grafting procedures exemplify the cumulative digital demands placed on oral surgeons. These procedures are foundational to implant dentistry and are commonly performed for ridge augmentation, sinus elevation, and socket preservation. Bone grafting often involves multiple imaging checks, material preparation steps, and, when performed under IV sedation, continuous physiologic monitoring. The combination of surgical complexity and digital reliance makes bone grafting an ideal candidate for MR or aR integration aimed at reducing workflow interruptions.

Despite the expanding body of research comparing accuracy and outcomes across different digitally assisted surgical techniques, fewer studies have focused on quantifying workflow efficiency and computer dependence during routine dental procedures. Many existing investigations prioritize surgical accuracy or implant survival rates, while overlooking the practical impact of repeated computer interaction on clinician performance and procedural flow. Understanding how frequently clinicians disengage from the operative field to interact with digital devices is essential for identifying where MR technologies may offer the greatest benefit.

The present study addresses this gap by quantifying computer usage across common general dentistry and oral surgery procedures. By measuring the duration and frequency of digital interactions during active treatment, this analysis aims to identify patterns of computer dependence and determine which procedures are most disrupted by current digital workflows. Rather than evaluating clinical outcomes alone, this approach emphasizes operational efficiency and cognitive ergonomics factors that directly influence both provider performance and patient experience.

By identifying procedures with the highest reliance on external digital systems, this study provides a rationale for targeted implementation of MR and aR technologies. Strategic integration of these tools in high-dependence workflows has the potential to reduce unnecessary screen shifts, lower cognitive burden, and enhance procedural efficiency. As dentistry continues to evolve toward increasingly digital practice models, understanding how and where immersive technologies can be most effectively applied will be critical to maximizing their clinical value.

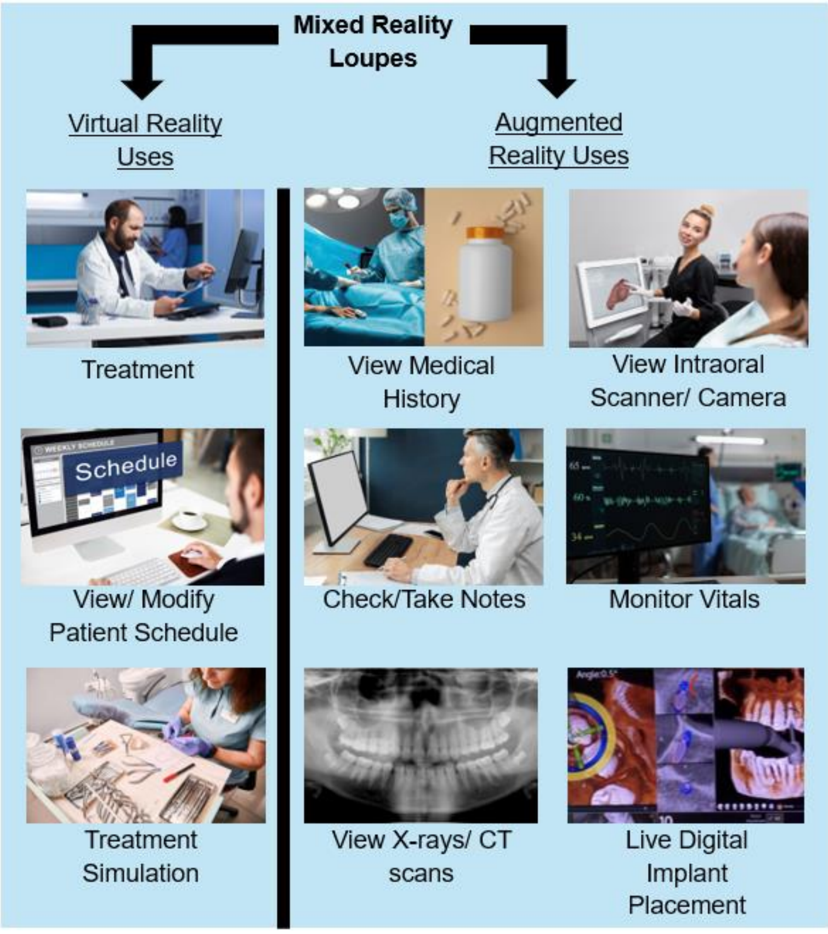

Figure 1: Examples of Mixed Reality Loupes Usage. The figure shows the Virtual Reality Uses (a) and Augmented Reality Uses (b), through images (designed by Freepik) and captions

EXPERIMENTAL SECTION/MATERIALS AND METHODS

2.1 Study Design and Clinical Setting

This retrospective observational study was conducted across two private dental practices: one general dentistry office and one oral surgery office. The study included procedures performed by one general dentist (n = 50 patients) and two oral surgeons (n = 50 patients collectively). Informed consent was obtained from the participating clinicians, and patient consent and authorization were granted prior to data collection. All procedures were performed as part of routine clinical care, with no alterations to standard treatment protocols.

2.2 Treatment Selection and Data Categorization

2.2.1 Classification of Treatment Types

Five categories of general dentistry procedures were analyzed: Extraction(s), Root Canal Treatment(s), Crown(s), Filling(s), and Prophylaxis. Ten patients were included in each category.

Oral surgery procedures were categorized as follows: Surgical Extraction(s) with IV Sedation, Implant without Assisted Reality Glasses, Implant with Assisted Reality Glasses, Bone Graft with IV Sedation, Bone Graft with Local Anesthesia, and Biopsy. Ten patients were included in each oral surgery category, except for the two implant groups, which included five patients each due to provider-specific workflow preferences.

The designation "(s)" indicates that a patient may have undergone one or multiple procedures within a given category (e.g., single-tooth or multiple-tooth extractions). Minor, uncommon procedures, as well as routine examinations and consultations, were excluded. Total treatment time was recorded for all procedures to account for variability in procedural duration, as longer treatments were anticipated to involve increased digital interaction.

2.2.2 Strategies to Minimize Sampling and Operator Bias

To reduce procedural bias within the Crown(s) category, five cases involved crown preparations and five involved crown seatings, ensuring balanced representation of workflows with differing digital demands.

To minimize bias related to provider experience and procedural variability in oral surgery, five patients per non-implant treatment category were treated by each oral surgeon. For implant procedures, data for "Implant without Assisted Reality Glasses" were collected exclusively from one surgeon, while data for "Implant with Assisted Reality Glasses" were collected exclusively from the second surgeon. This distribution reflects established clinical preferences and avoided introducing workflow changes for the purpose of the study.

2.2.3 Patient Care and Data Collection

Data collection was designed to be non-intrusive and observational. Clinicians treated their regularly scheduled patients, and eligible procedures were identified prospectively. The oral surgeon using assisted reality glasses was already incorporating this technology into routine practice prior to the study. No modifications were made to patient care, and all data was collected through direct observation during standard clinical workflows.

2.3 Measurement of Computer Usage

2.3.1 Definition and Calculation of Treatment Time

Treatment time was defined as the period during which the dentist or surgeon actively provided care. To minimize extraneous discussion during procedures, patient examinations and consultations were conducted on separate dates when possible. Timing began after the patient was prepared by a registered dental assistant and the clinician entered the operatory.

An Apple Watch stopwatch function was used to record treatment time with millisecond precision. Interruptions unrelated to active care such as radiograph acquisition or temporary departure from the operatory were documented, and timing was paused and resumed accordingly.

2.3.2 Identification and Recording of Digital Interactions

Digital interactions were defined as any instance in which the treating clinician visually engaged with a digital device during active treatment. Recorded devices included operatory computer screens, digital imaging systems, vital sign monitors, and the X-Guide navigation monitor during implant procedures. Interactions performed by dental assistants were excluded.

For implant procedures utilizing assisted reality glasses, interactions with the glasses themselves were not counted as computer usage. However, any instance in which the surgeon disengaged from the HMD to consult an external monitor was recorded as a digital interaction.

2.3.3 Quantifying Computer Usage

Computer usage was calculated by dividing total treatment time (in seconds) by the number of recorded digital interactions for each patient. Lower values indicate higher computer dependence, reflecting more frequent digital interactions relative to procedure duration.

2.4 Statistical Analysis

2.4.1 Data Visualization

Computer usage data were categorized by treatment type and analyzed using Microsoft Excel. Box-and-whisker plots were generated to illustrate distributions of seconds per interaction, including minimum, first quartile (Q1), median (Q2), third quartile

(Q3), and maximum values. Treatment duration and computer usage metrics are summarized in Table 1.

Figure 4 presents a conceptual design of future dental loupes with integrated mixed reality, created using artificial intelligence software, highlighting potential clinical applications in both general dentistry and oral surgery.

2.4.2 Analysis of Variance Across Treatment Types

One-way ANOVA tests were conducted independently for general dentistry and oral surgery to determine whether computer usage differed significantly among procedure types. The F-value from the test was used to calculate a corresponding p-value, with a significance level of 0.05, to determine whether significant differences in computer usage existed across treatment types.

2.4.3 Comparative Statistical Testing Between Disciplines

A two-sample t-test was performed to compare computer usage across general dentistry procedures and across oral surgery procedures. The corresponding p-value was recorded to assess statistical significance.

RESULTS AND DISCUSSION

3.1 Overview of Computer Usage Patterns

Analysis revealed substantial variability in computer usage across both general dentistry and oral surgery procedures. Differences were influenced by procedural complexity, duration, sedation requirements, and reliance on diagnostic or navigational technologies. For example, third molar extractions frequently required increased consultation of radiographic data compared to simpler anterior extractions.

3.2 Procedural Differences Within Each Discipline

3.2.1 General Dentistry

A one-way ANOVA demonstrated a statistically significant difference in computer usage among general dentistry procedures ($F(4, 45) = 13.68$, $p < .001$). Median computer usage values were lowest for Extraction(s) and Root Canal Treatment(s), indicating the highest frequency of digital interaction during these procedures. Restorative and preventive treatments showed comparatively lower dependence on digital devices during active care.

3.2.2 Oral Surgery

A separate one-way ANOVA revealed significant differences in computer usage across oral surgery procedures ($F(5, 54) = 72.84$, $p < .001$). Implant procedures performed without assisted reality glasses exhibited the highest computer dependence, whereas implants performed with assisted reality glasses demonstrated reduced reliance on external monitors, highlighting the workflow impact of aR integration.

3.3 Comparison Between General Dentistry and Oral Surgery

A two-sample t-test comparing all general dentistry and oral surgery procedures revealed a statistically significant difference in computer usage (General Dentistry: M = 237.4 s/interaction, SD = 99.1; Oral Surgery: M = 414.6 s/interaction, SD = 172.3; $t(98) = -6.30$, $p < .001$).

General dentistry procedures demonstrated more frequent digital interactions, reflecting workflows that require continuous charting, verification, and imaging. Oral surgery procedures, while longer and more technologically complex, were characterized by longer uninterrupted clinical intervals. The large effect size ($d = 1.26$) underscores a fundamental divergence in digital workflow patterns between the two disciplines.

3.4 Procedure-Specific Trends and Implications

3.4.1 Computer Usage Across General Dentistry Treatment Types

Computer usage for each general dentistry procedure was quantified by dividing total treatment time (in seconds) by the number of recorded digital interactions. Under this metric, lower values indicate greater computer dependence, reflecting more frequent interactions with digital systems relative to procedural duration. As shown in Figure 2, median computer usage values were 112 seconds per interaction for Extraction(s), 147 for Root Canal Treatment(s), 257 for Crown(s), 312.5 for Filling(s), and 303.5 for Prophylaxis.

These results demonstrate marked variability in digital device reliance across general dentistry procedures. Surgical and endodontic treatments specifically extractions and root canal therapies exhibited the highest frequency of computer interactions, consistent with their reliance on radiographic verification, working length confirmation, and procedural documentation during active treatment. In contrast, restorative and preventive procedures, including fillings, crowns, and prophylaxis, showed lower computer dependence, as these workflows typically require fewer real-time digital consultations once treatment has begun.

When ranked from highest to lowest computer usage (i.e., lowest to highest seconds per interaction), general dentistry procedures followed the order: Extraction(s), Root Canal Treatment(s), Crown(s), Prophylaxis, and Filling(s). This ranking highlights the procedure-specific nature of digital workflow demands and suggests that MR-enabled dental loupes or head-mounted displays may offer the greatest efficiency gains in surgical and endodontic procedures by reducing visual disengagement from the operative field.

3.4.2 Computer Usage for Treatment Types for Oral Surgery

For oral surgery procedures, computer usage was calculated using the same metric: total treatment time divided by the number of recorded digital interactions. As illustrated in Figure 2, lower values correspond to higher computer dependence. Median computer usage values were 230.5 seconds per interaction for Surgical Extraction(s) with IV Sedation, 102 for Implant without Assisted Reality Glasses, 340 for Implant with Assisted Reality Glasses, 255.5 for Bone Graft with IV Sedation, 520.5 for Bone Graft with Local Anesthesia, and 559 for Biopsy.

Substantial variability in computer usage was observed across oral surgery procedures, reflecting differences in procedural complexity, sedation requirements, and reliance on navigation or monitoring systems. Implant procedures performed without assisted reality glasses demonstrated the highest computer dependence, indicating frequent consultation of external navigation displays. In contrast, implant procedures utilizing assisted reality glasses showed reduced reliance on external monitors, supporting the potential of aR technology to streamline digital workflows.

When oral surgery procedures were ranked from lowest to highest computer usage, the order was: Biopsy, Bone Graft with Local Anesthesia, Implant with Assisted Reality Glasses, Bone Graft with IV Sedation, Surgical Extraction(s) with IV Sedation, and Implant without Assisted Reality Glasses. This trend underscores the workflow benefits of assisted reality integration in technologically intensive surgical procedures and highlights opportunities for broader MR adoption in oral surgery to reduce cognitive load and improve procedural efficiency.

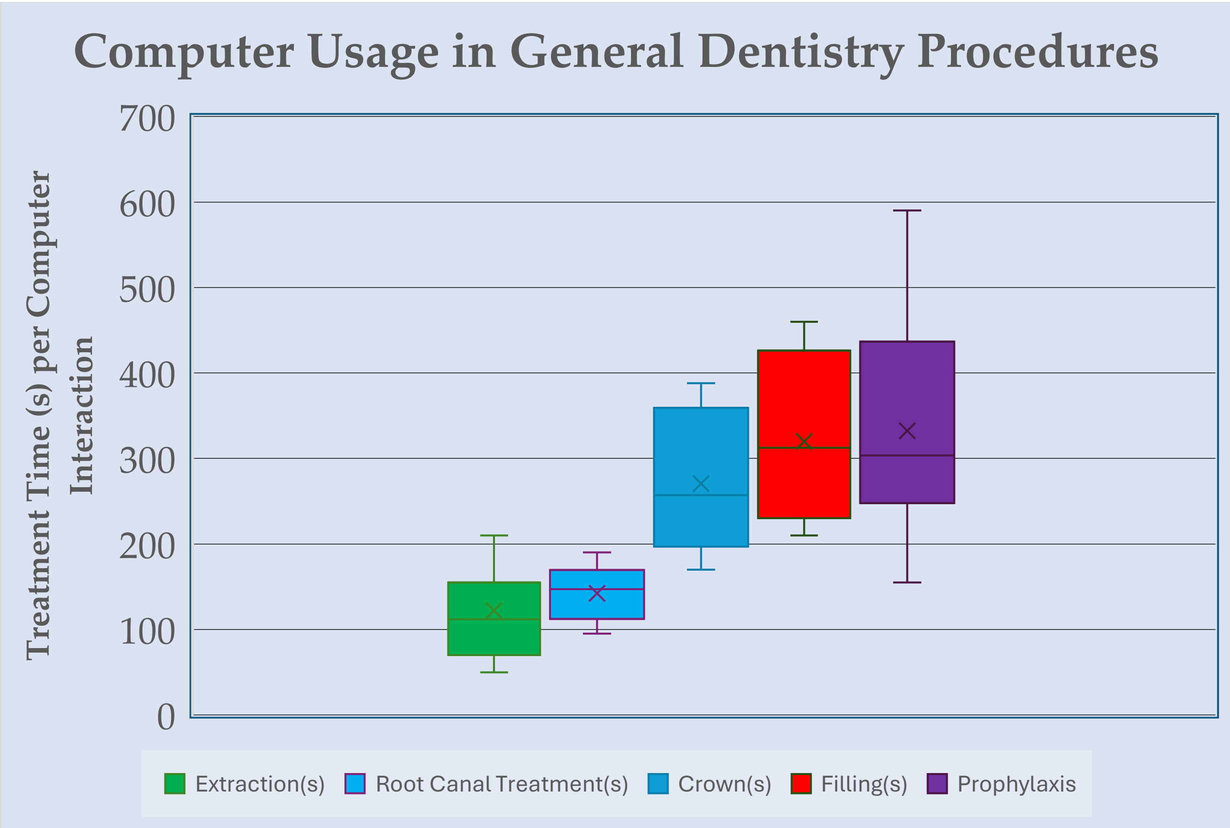

Figure 2: Box-and-Whisker Plot of Computer Usage in General Dentistry Procedures

Each data point represents an individual patient. The central line within each box indicates the median seconds per digital interaction, while the lower and upper boundaries of the box represent the 25th (Q1) and 75th (Q3) percentiles. Whiskers extend to the 10th and 90th percentiles. Lower median values indicate greater dependence on digital devices, reflecting more frequent interactions during active treatment.

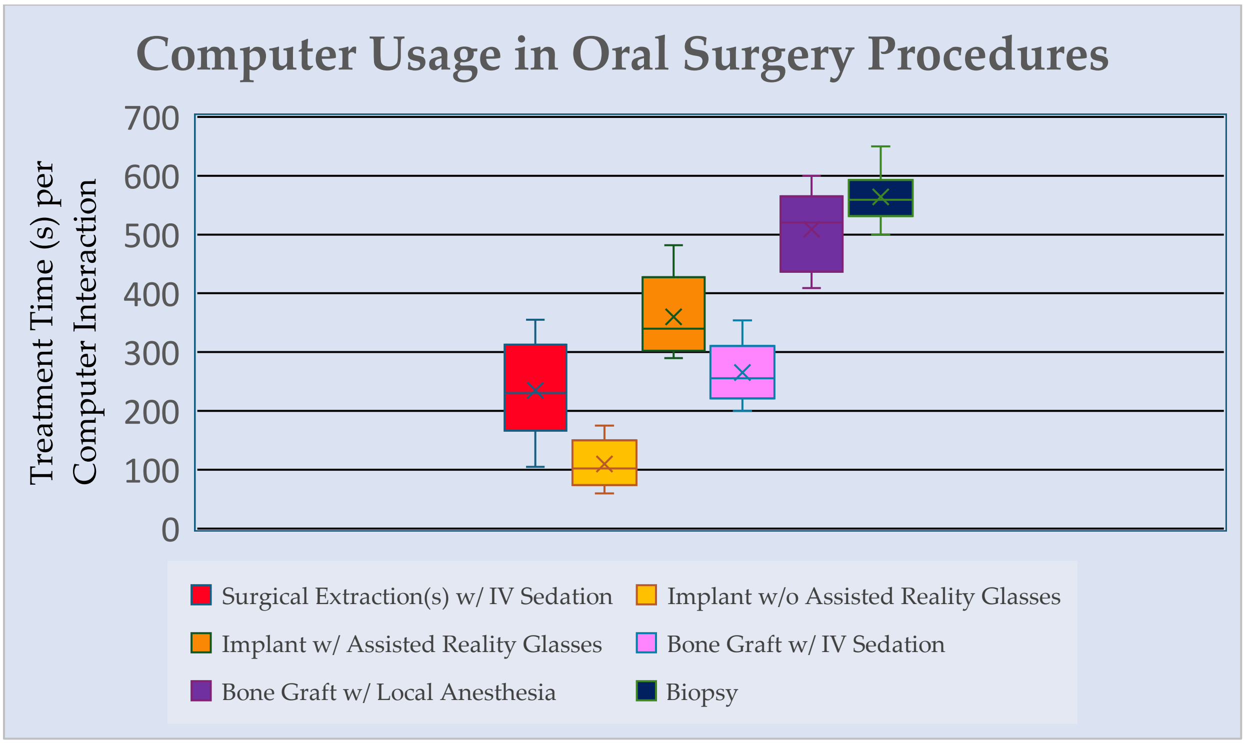

Figure 3: Box-and-Whisker Plot of Computer Usage in Oral Surgery Procedures

Each data point corresponds to an individual patient undergoing an oral surgery procedure. The median seconds per digital interaction are shown by the central line, with the box representing the interquartile range (25th–75th percentiles) and whiskers extending to the 10th and 90th percentiles. Lower median values denote higher computer dependence, indicating more frequent digital interactions during treatment.

Table 1: Treatment Duration and Computer Usage in General Dentistry Procedures

Treatment Types	Average Treatment Time(min)	Average Computer Usage	Sample Size(n)
Extraction(s)	8.73	122	10
Root Canal Treatment(s)	28.24	142	10
Crown(s)	29.5	271	10
Filling(s)	19.1	320	10
Prophylaxes	19	332	10
Average/ Total	20.91	237.4	50

This table summarizes treatment duration and computer usage across the five general dentistry procedure categories analyzed. "Average Treatment Time (min)" represents the mean procedure duration, while "Average Computer Usage" reflects mean seconds per digital interaction. Each treatment group included ten patients. Aggregate averages are provided in the final row to facilitate comparison across procedures.

Table 2: Treatment Duration and Computer Usage in Oral Surgery Procedures

Treatment Types	Average Treatment Time(min)	Average Computer Usage	Sample Size(n)
Surgical Extraction(s) w/ IV Sedation	28.94	253	10
Implant w/o Assisted Reality Glasses	26.92	111	5
Implant w/ Assisted Reality Glasses	20.73	360	5
Bone Graft w/ IV Sedation	27.49	265	10
Bone Graft w/ Local Anesthesia	25.95	520	10
Biopsy	11.31	564	10
Average/ Total	28.15	414.6	50

This table summarizes treatment duration and computer usage across the oral surgery procedure categories analyzed. "Average Treatment Time (min)" represents the mean procedure duration, while "Average Computer Usage" denotes mean seconds per digital interaction. Each treatment group included ten patients, except for implant procedures, which included five patients per group. Aggregate averages are provided in the final row to facilitate comparison across procedure types.

Figure 4: Conceptual Mixed Reality Head-Mounted Display and Clinical Applications in Dentistry

This figure presents a conceptual design of mixed reality–enabled dental loupes (a), generated using OpenArt, along with illustrative applications of mixed reality technology in third molar extractions (b), crown seating procedures (c), and root canal treatments (d), highlighting potential use cases across both surgical and restorative dental workflows.

3.5 Data Evaluation

3.5.1 Procedure-Specific Computer Dependence

Analysis of oral surgery procedures demonstrated that implant placements performed without assisted reality glasses exhibited the highest frequency of digital interactions. This elevated computer dependence reflects the need for repeated consultation of radiographic data, navigational guidance, and treatment planning software to verify anatomical landmarks, instrument positioning, and procedural accuracy. Compared with other oral surgery and general dentistry procedures, these implant workflows required more frequent visual engagement with external digital displays, whereas less technologically intensive procedures relied primarily on direct visualization and tactile feedback, resulting in fewer workflow interruptions.

3.5.2 Implications for Mixed Reality Integration

The statistically significant difference in computer usage observed between general dentistry and oral surgery procedures ($p < 0.001$) indicates that MR integration may yield particularly meaningful efficiency gains in oral surgery workflows. Head-mounted MR systems integrated with dental loupes have the capacity to project radiographs, navigational cues, and procedural metrics directly into the clinician's line of sight. By reducing the need for repeated screen checks, MR technology may preserve operative focus, improve hand–eye coordination, and decrease the likelihood of errors associated with frequent visual disengagement from the surgical field (Barteit *et al.,* 2021; Qian *et al.,* 2022).

3.5.3 Workflow and Cognitive Considerations

Frequent shifts of attention away from the patient to consult digital devices contribute to increased cognitive load and may disrupt procedural flow. MR-enabled loupes offer a potential solution by centralizing access to multiple data streams such as radiographic images, navigation feedback, apex locator measurements, and charting interfaces within a single, hands-free display. This consolidation may enhance ergonomic efficiency, reduce mental fatigue, and support uninterrupted workflow continuity. These advantages are especially relevant in high-precision procedures, including surgical extractions and endodontic therapy, where sustained focus is critical to clinical accuracy and efficiency (Bhugaonkar *et al.,* 2022; Worlikar *et al.,* 2023).

3.5.4 Limitations and Sources of Bias

Several limitations should be acknowledged when interpreting these findings. First, contemporary dental workflows involve multiple digital platforms, and MR systems must effectively integrate these data sources without introducing new cognitive or technical burdens. Second, the single-practitioner design in general dentistry and limited number of surgeons in oral surgery restrict the generalizability of the results, as individual practice patterns and familiarity with digital tools may influence computer usage. Despite these constraints, the observed benefits of MR-assisted workflows are consistent with trends reported in other surgical disciplines, where head-mounted displays have been shown to streamline information access, reduce cognitive load, and support improved procedural performance (Monterubbianesi *et al.,* 2022; Fahim *et al.,* 2022).

CONCLUSION

This study systematically evaluated computer usage across a range of general dentistry and oral surgery procedures to characterize procedure-specific digital dependence and identify workflows most likely to benefit from mixed reality (MR) integration. Quantitative analysis demonstrated statistically significant differences in computer usage both across treatment types within each discipline and between general dentistry and oral surgery overall. These findings confirm that digital interaction is not uniform across dental procedures and is strongly influenced by procedural complexity, reliance on imaging and navigation systems, and real-time documentation requirements.

Procedures such as extractions, root canal treatments, and implant surgeries exhibited the highest frequency of digital interactions, reflecting sustained dependence on radiographs, apex locator measurements, navigation software, and treatment planning tools during active care. In contrast, restorative and preventive procedures including fillings, crown seatings, prophylaxis, and biopsies required fewer real-time digital consultations once treatment commenced. This distinction highlights that MR technology is unlikely to provide uniform benefits across all dental procedures, but rather offers the greatest potential value when strategically deployed in workflows characterized by frequent screen consultation and iterative digital verification.

4.1 Clinical Implications and the Emerging Role of Mixed Reality

This study highlights the procedure-specific nature of computer dependence in general dentistry and oral surgery. Implants, extractions and root canal treatments demonstrated the highest frequency of digital interactions, reflecting their reliance on radiographs, apex locator readings, and treatment and implant planning software. Restorative and preventive procedures, such as crown preparations, fillings, and prophylaxis as well as treatments that do not require heavily radiographic usage, such as biopsies, exhibited significantly lower computer dependence, indicating that MR integration would be most impactful in workflows requiring frequent digital consultation. These findings provide strong evidence for the potential role of mixed reality (MR) technologies in optimizing high-dependence procedures by overlaying digital information directly into the clinician's line of sight (Barteit *et al.,* 2021; Qian *et al.,* 2022).

4.2 Barriers to Widespread Adoption

The results of this study support the growing recognition that MR and assisted reality technologies may play a transformative role in digitally intensive dental workflows. By projecting essential information such as radiographic data, navigation guidance, and procedural metrics directly into the clinician's field of view, MR systems have the potential to reduce repeated attention shifts between the patient and external monitors. This capability is particularly relevant in oral surgery and endodontics, where maintaining continuous visual and tactile engagement with the operative field is critical to precision and safety.

Importantly, implant procedures performed without assisted reality glasses demonstrated the highest computer dependence among all procedures analyzed, while those utilizing assisted reality technology showed reduced reliance on external monitors. This finding provides practical evidence that hands-free digital visualization can meaningfully alter workflow dynamics in technologically demanding procedures. Similar benefits have been reported in other surgical specialties, where head-mounted displays have improved situational awareness, ergonomic efficiency, and intraoperative decision-making.

4.3 Cognitive and Workflow Advantages

From a cognitive ergonomics perspective, the frequent disengagement required to interact with external digital devices introduces mental fatigue and increases the risk of workflow disruption. MR-enabled loupes and head-mounted displays offer a potential solution by centralizing critical data streams within the clinician's line of sight. This approach may enhance procedural continuity, reduce mental load, and improve efficiency, particularly during high-precision procedures where even brief interruptions can compromise accuracy.

The alignment of these findings with existing literature from both dental and medical surgery suggests that MR integration may represent a natural evolution of digital dentistry rather than a disruptive innovation. As dental workflows continue to grow more technologically complex, tools that preserve focus while maintaining access to essential information will become increasingly important.

4.4 Future Directions

Future research should prioritize larger, multi-practitioner studies across diverse clinical environments to validate these findings and better quantify the impact of MR on efficiency, accuracy, and patient safety. Investigations comparing procedure time, error rates, ergonomic outcomes, and clinician fatigue with and without MR assistance would further strengthen the evidence base for adoption. Additionally, continued development of loupe-integrated MR systems will be essential to ensure clinical feasibility and acceptance.

4.5 Final Remarks

In summary, this study demonstrates that computer dependence in dentistry is highly procedure-specific and that mixed reality technologies hold the greatest promise for workflows with intensive digital interaction, particularly in oral surgery and endodontics. By reducing reliance on external monitors and preserving clinician focus, MR has the potential to improve workflow efficiency, enhance ergonomics, and support safer, more precise care. With continued technological refinement and targeted implementation, mixed reality may become an integral component of the next generation of digitally optimized dental practice.

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Patient Consent Statement: Informed consent was obtained from the participating general dentist, two oral surgeons, and all patients involved in data collection.

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