OPEN ACCESS
Saudi Journal of Medicine
Abbreviated Key Title: Saudi J Med
ISSN 2518-3389 (Print) | ISSN 2518-3397 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com

Original Research Article

Mixed Reality Implementation in X-Guide Navigated Implant Surgeries: A Retrospective Analysis

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DOI: https://doi.org/10.36348/sjm.2025.v10i06.002 | **Received:** 07.05.2025 | **Accepted:** 12.06.2025 | **Published:** 16.06.2025

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Abstract

Virtual and augmented reality are both integrated into mixed reality, enabling users to interact with real or artificial environments based on their needs. Integrating mixed reality into dental loupes could reduce treatment time and minimize the need to constantly look away from patients to consult computer screens. This study aims to determine the impact of mixed reality adoption by examining digital screen usage in X-Guide navigated implant surgeries, and to evaluate whether newly adopted assisted reality for navigated implant surgeries reduces computer screen dependency. This retrospective analysis involves two oral surgeons with a total of 55 treated patients. Data from these practitioners will assess mixed reality implementation in dental loupes, measuring their interactions with digital computers based on the treatment type. All implant surgeries utilized X-Guide by X-Nav Technologies. Statistical analysis was conducted using two-sample t-tests to identify whether the usage of assisted reality glasses in implant surgeries reduces treatment time and computer usage. An ANOVA test revealed significant variance in computer usage, indicating that mixed reality benefits vary across oral surgical procedures. Two independent two-sample t-tests revealed a statistically significant 22.1% reduction in treatment time and an 66.7% reduction in computer usage in X-Guide implant surgeries utilizing assisted reality. The findings on computer usage indicated that oral surgery could benefit significantly from mixed reality adoption. Digital implant surgeries with mixed reality integrated loupes would be more advantageous for implant procedures by enabling hand interaction, a feature not available in the screen-mirroring assisted reality glasses used in this study.

Keywords: Dental implants, surgical navigation systems, computers, smart glasses, virtual reality, augmented reality.

INTRODUCTION

Mixed reality (MR), invented by Ivan Sutherland at Harvard University in 1968, seamlessly integrates virtual reality (VR) and augmented reality (AR). Globally, the use of VR/AR in the healthcare industry increased by 33.97% from 2023 to 2024, with the market share ranking third ahead of the gaming and automotive industries, which rank first and second, respectively (Virtual Reality in Healthcare Market: Revenue Statistics [2032], 2024). MR enables users to interact with artificial environments through VR capabilities or engage with the real-world environment through the AR features (Barteit, S. *et al.,* 2021).

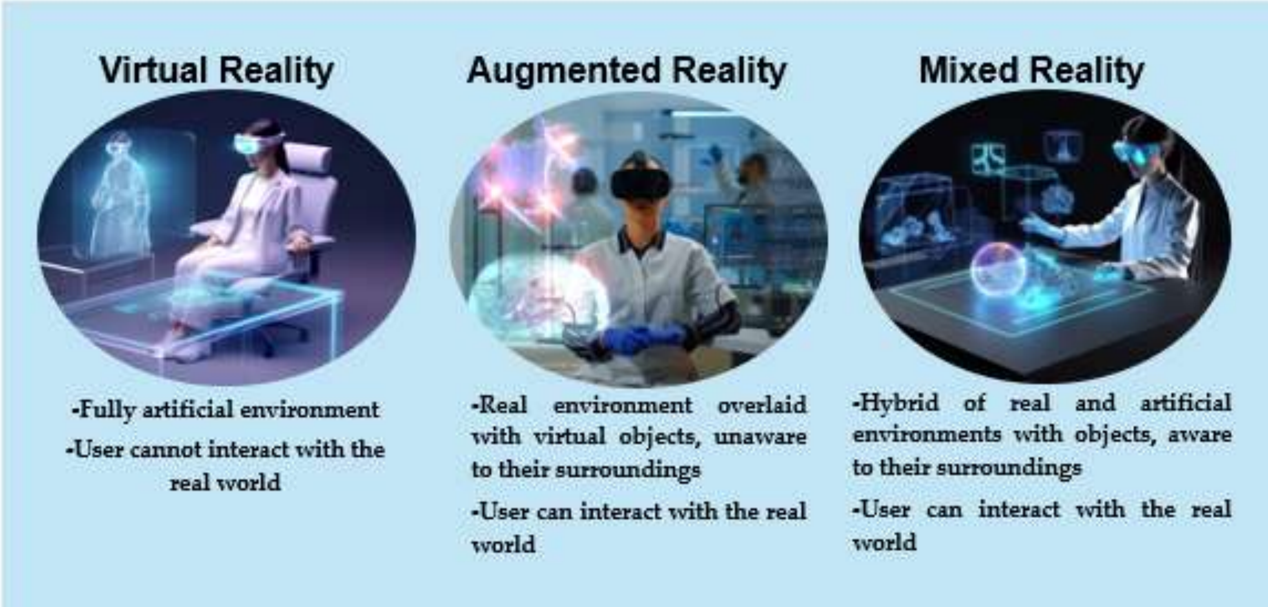

Figure 1: Comparing Different Types of Reality. The figure summarizes VR (a), AR (b), and MR (c), using images (designed by Freepik) and text noting the type of environment and user interaction

Recent advancements in reality technology have led to the gradual adoption of AR and other reality types in neurosurgical and cardiovascular procedures, such as brain, spine, and valve replacement surgeries. These surgeries demand high precision and concentration, and mixed reality technology can help to further minimize distraction by eliminating the need to consult external computers for crucial information during the procedures. In these surgeries, AR head-mounted displays (HMDs) overlay 3D reconstructions of a patient's organs in real-time on the display; surgeons interact with the HMD and rotate and manipulate images, allowing for enhanced visualization and decision-making (Bhugaonkar, K. *et al.,* 2022 and Bouraghi, H. *et al.,* 2023)

Currently, there are some challenges with integrating MR technology in the dental field. One obstacle in current medical-grade HMDs is the lack of integrated loupe magnification, which is critical for numerous dental and oral surgical procedures. Loupe magnification is utilized by 64.3% of general dentists, 60% of oral surgeons, and 80.38% of dental hygienists. The integration of loupe magnification in MR would be a breakthrough and could enable the widespread use of this technology in the dental and medical fields (Kharouba, J. *et al.,* 2022, Wei, C., 2018, and Brancheau, K., 2020).

Assisted reality (aR), a simpler version of AR, provides basic digital overlays without the complete immersion as seen in other more advanced reality types. Through aR, users can mirror the display of another digital device, such as a computer, onto the HMD. However, unlike AR, aR lacks hand tracking and gesture control, limiting its capabilities. Despite the lack of interaction, aR is still useful in the dental and medical professions, especially in surgeries requiring immediate access to digital information (Worlikar, H. *et al.,* 2023).

In the field of oral surgery, the soft adoption of aR technology is changing the profession, especially in digitally-navigated implant surgeries. In implant surgeries, there are three approaches: using traditional surgical guides, robot-assisted, or advanced navigation systems, such as X-Guide by X-Nav Technologies.

Traditional surgical guides are custom-made and patient-specific, created using the patient's CBCT (cone beam computed tomography) to make 3D-printed models. Then, the surgical guides are fabricated and delivered for implant surgery. These guides come with pre-made holes that direct the handpiece (drill) during implant surgery, enabling the implant to be placed at a correct depth and angle, which is critical to the longevity and effectiveness of the implant. The guides provide accurate implant placement and are more cost-effective than investing in digital implant technology. However, the surgical guides are delivered prior to the implant surgery; therefore, if any surgical complications arise or if the CBCT needs to be retaken, there will be a setback because the guide cannot be adjusted. Furthermore, surgeries using traditional guides involve significant computer interaction. Surgeons might frequently consult CBCT scans, intraoral images, and vital sign monitors during the procedure (Yang, Y. *et al.,* 2022). Despite this, this study did not include traditional guide-based implant surgeries, as the oral surgery office did not utilize this technology.

Robot-assisted implant systems offer a more advanced alternative. These systems feature a handpiece attached to the robotic machine, which automatically adjusts the direction and location of the handpiece based on a preoperative CBCT scan. A built-in computer displays real-time progress, allowing the surgeon to monitor and intervene if necessary. Like traditional guides, robot-assisted systems require significant computer interaction (Wang, M. *et al.,* 2024). Additionally, they provide enhanced accuracy and minimize iatrogenic mistakes through safety features, such as automatic adjustment of the handpiece to accommodate patient movement and the ability to stop the handpiece if needed or in emergency situations (Bahrami, R. *et al.,* 2024).

Another method of implant placement involves utilizing a machine with digital navigation software, such as X-Guide by X-Nav Technologies. The system offers real-time tracking and dynamic 3D imaging, which are projected on the computer attached to the machine. On the computer screen, critical values of the correct angle, position, and depth, to hold the handpiece are displayed while conducting the implant surgery. Therefore, dental professionals using the software must monitor the computer closely while constantly glancing in the patient's oral cavity. Additionally, the system notifies the surgeon when the correct depth is reached and has multiple features to prevent inaccurate implant placement (Nagata, K. *et al.,* 2024). Rather than relying on a pre-made surgical guide, X-Guide adjusts specifically to each patient in real-time, and changes to treatment plans can be made more quickly. To minimize external computer usage in X-Guide navigated implant surgeries, aR HMDs can be integrated into the procedures (Engelschalk, M. *et al.,* 2024). All implant surgeries analyzed in this study were performed using the X-Guide computer-assisted surgical system. This is because the oral surgery office where the study was conducted exclusively utilizes this technology for implant procedures.

Multiple systematic reviews and meta-analyses exist comparing the accuracy and efficiency of robot-assisted, computer-navigated, and traditional guide-based implant surgeries. In 2022, a meta-analysis involving 425 studies found that AR-assisted computer-navigated implant surgeries exhibited a significantly higher accuracy than traditional freehand methods and computer-navigated surgeries without AR ($p = < 0.001$) (Mai, H. *et al.,* 2023). However, a more recent study published in November 2024, which reviewed 45 studies, found no significant difference in implant accuracy across robot-assisted, computer-navigated, with and without AR, and traditional implant placement surgeries. That study also suggested that treatment time was generally longer for the robot-assisted and computer-navigated methods compared to traditional approaches (Miura, T. *et al.,* 2024). Numerous ongoing studies are comparing the efficiency of various implant surgery methods; therefore, this research article focused on the efficiency of using aR in a specific type of implant procedure, which is computer-navigated implant procedures conducted by X-Guide.

In digitally-navigated implant placement surgeries, aR can be crucial in lowering treatment time and external computer usage. Through the aR HMDs, which were used in the study, real-time X-Guide navigation software is displayed in the surgeon's field of view. Therefore, surgeons can be more focused on patient care by minimizing the need to shift their focus between the patient and external computers (Fahim, S. *et al.,* 2024).

To implement more advanced and immersive reality technology, like MR, in other oral surgical procedures, limitations preventing the widespread implementation of the technology should be addressed. For example, medical-grade MR HMDs lack loupe magnification, which is used by many oral surgeons and throughout the dental field. Therefore, many dental professionals cannot justify investing in this technology if it cannot be used in different treatment types. Another limitation is the inability to simultaneously monitor multiple computer screens, such as displaying live X-Guide navigation software and patient vital signs from two external computers simultaneously (Qian, L. *et al.,* 2022).

The potential applications of MR HMDs in oral surgery are vast, aiming to improve time efficiency, treatment accuracy, and facilitate virtual preoperative planning and training. To evaluate whether there is a necessity for MR HMDs in oral surgery, data on the usefulness of current assisted-reality use in digital implant surgeries should be analyzed (Monterubbianesi, R. *et al.,* 2022).

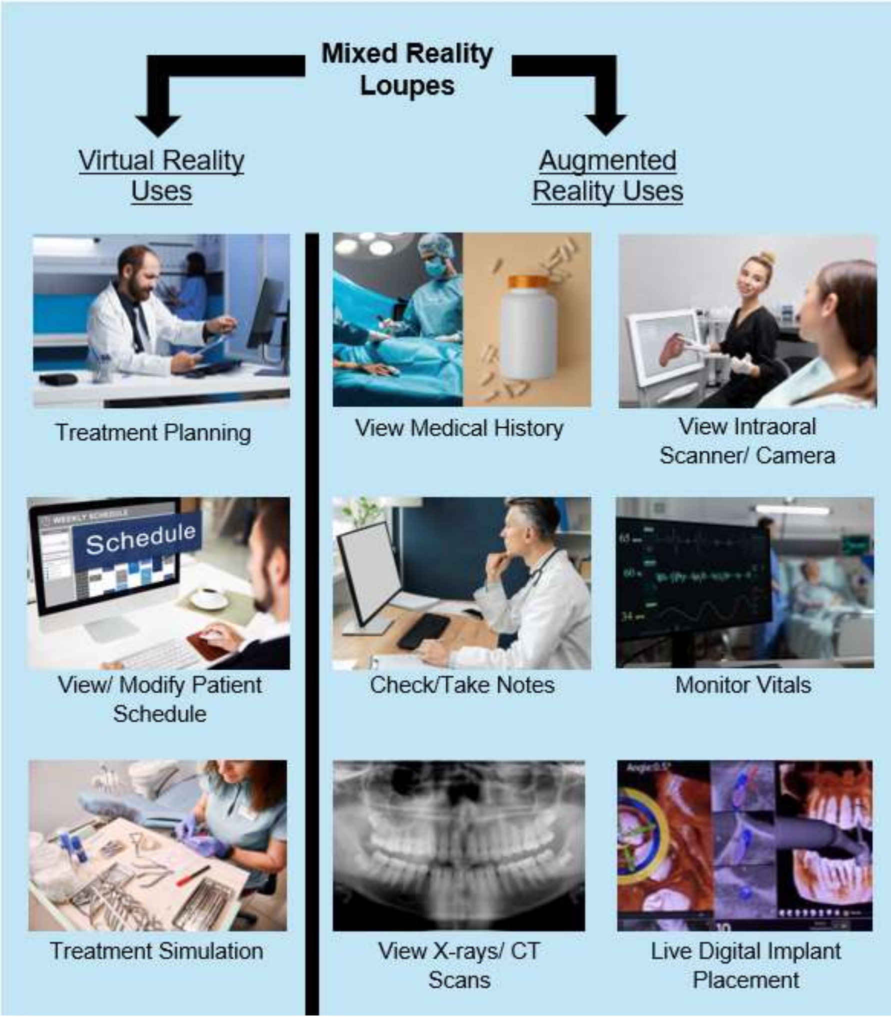

Figure 2: Examples of Mixed Reality Loupes Usage. The figure shows the Virtual Reality Uses (a) and Augmented Reality Uses (b), through images (designed by Freepik) and captions

Experimental Section/Materials and Methods

This retrospective analysis was conducted at a private dental office. The study included two oral surgeons practicing at the office, both of whom participated in the data collection involving a total of 50 patients they treated. Informed consent from the two oral surgeons, patient consent, and permission was granted to conduct the study.

2.1 Treatment Selection and Data Categorization

2.1.1 Treatment Types

The types of treatment recorded included: 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. Data from ten patients were collected for each treatment type, except for the two implant treatment groups, which involved five patients each. Treatments marked with “(s)” refer to instances where patients received one or multiple procedures (e.g., Surgical Extraction(s) with IV Sedation could include one or several extractions per patient). Treatment duration was recorded for each procedure to account for any variability in time, as longer treatments were expected to involve more frequent computer usage.

2.1.2 Minimizing Data Collection Bias

To minimize potential biases due to surgeon experience and variation in treatment time, five patients from each non-implant treatment type were treated by each oral surgeon, totaling ten patients per treatment. For the Implant treatments, data for “Implant without Assisted Reality Glasses” was collected from only one surgeon, while data for “Implant with Assisted Reality Glasses” was collected exclusively by the other. This allocation reflects each surgeon's preference, with one surgeon favoring assisted reality glasses and the other preferring the X-Guide machine’s external computer. Rare or minor dental procedures and dental exams/consultations were excluded from this study.

2.1.3 Patient Care Protocol

The study was designed to be non-intrusive, with data collected as part of routine patient care. The oral surgeons treated their regularly scheduled patients, and treatment types aligning with the study’s focus were selected. The surgeon performing Implant treatments with assisted reality glasses was already using this technology before the study, ensuring no modifications in patient care were necessary. As a result, the study did not interfere with patient treatment; data was collected solely through observation as the oral surgeons performed dental procedures on their patients.

2.2 Recording Data on Computer Usage in Oral Surgery Treatments

2.2.1 Treatment Time Calculation

Treatment time was defined as the duration the oral surgeon actively treated each patient. To optimize data accuracy, patient exams were conducted on separate dates to minimize time spent discussing procedures on the day of treatment. Once patients were prepped by registered dental assistants, treatment time began as the surgeon entered the operatory. Timing was managed using an Apple Watch, recording down to milliseconds. Any pauses in patient care (e.g., for x-rays taken or if the surgeon temporarily exited) were noted, with the stopwatch paused and resumed accordingly until patient treatment was completed.

2.2.2 Recording Computer Usage

Throughout each patient's treatment time, data was gathered on the number of interactions with digital devices by the treating surgeon only, excluding interactions by dental assistants. Devices tracked included computer screens, intraoral digital imaging systems, vital signs monitors, and the X-Guide monitor (for implant surgeries). For treatments using assisted reality glasses, interactions with the glasses themselves were not counted; however, if the surgeon looked away from the glasses, interactions with external screens were tallied.

2.2.3 Quantifying Computer Usage

Computer usage per patient was calculated by dividing treatment time (in seconds, converted from minutes and milliseconds) by the number of device interactions recorded.

2.3 Data Analysis and Statistical Tests

2.3.1 Graphical Representation of Data

In Figure 3, data on computer usage for each patient was categorized by treatment type in Excel, and box-and-whisker plots were generated to illustrate the distribution of seconds per interaction. Key values such as the minimum, Q1, Q2, Q3, and maximum were identified for each treatment group. Table 1 was created to show the collected data on treatment time and computer usage in the implants procedures with and without assisted reality. In Figure 4, a conceptual design of a future, improved alternative to assisted reality in oral surgery was created using an artificial intelligence software, showcasing mixed reality dental loupes and their application in third molar extractions.

2.3.2 ANOVA for Comparing Computer Usage Across Treatment

An ANOVA test was conducted to assess whether computer usage (treatment time in seconds divided by number of interactions with digital devices) varied significantly among various oral surgery procedures. Data from all treatment types, excluding Implant with Assisted Reality Glasses, were included. 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.

2.3.3 Comparative Statistical Tests for Implant Treatments

Two two-sample t-tests were conducted to compare implant procedures with and without Assisted Reality Glasses. The first test assessed whether aR reduced treatment time by comparing treatment times in minutes and seconds for both groups. The second t-test examined whether aR reduced the number of device interactions. For both tests, the p-value was recorded to determine the statistical significance of the results.

RESULTS AND DISCUSSION

The collected data on computer usage during oral surgery procedures revealed that the use of digital devices varies significantly by treatment type. Differences in computer usage appear to be influenced by both the complexity of the procedure and the patient's oral health status. For instance, in Surgical Extraction(s) with IV Sedation, a patient with impacted third molars may require more frequent reference to external digital resources, such as radiographs, compared to a patient with non-impacted molars.

3.1 Data Analysis Results

3.1.1 Comparison Across Oral Surgery Treatments

An ANOVA test was conducted to assess the variance in computer usage across oral surgery treatments without aR, excluding the Implant with Assisted Reality Glasses category (*F-value* $= 50.244$ *and* $p < 0.001$).

The p-value was well below the significance level of 0.05, indicating a statistically significant difference between the group means. This suggests that the observed differences are unlikely to be due to chance, and the null hypothesis (no difference in group means) was rejected. These findings demonstrate significant variance in computer usage across oral surgery procedures, indicating that certain procedures may benefit more from MR technology than others.

3.1.2 Computer Usage for Treatment Types

Computer usage for each treatment type was calculated by dividing treatment time (in seconds) by the number of computer interactions. Figure 3 shows that lower values correspond to higher computer usage, as interactions with digital devices are more frequent relative to the total treatment time. The median of computer usage for each treatment type was as follows: 230.5 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.

These results highlight considerable variation in computer usage across procedures and underscore the potential benefit of aR in implant surgeries. Ranking the treatments from lowest to highest computer usage, the order is as follows: 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.

3.1.3 Impact of Assisted Reality in Implant Procedures

For Implant procedures, two independent two-sample t-tests were conducted to evaluate the impact of aR on treatment time and computer interactions. Results showed a statistically significant reduction in treatment time by 22.1% with Assisted Reality Glasses in X-Guide implant surgeries compared to X-Guide implant cases without aR ($p = <0.001$). Additionally, Assisted Reality Glasses reduced computer interactions by 66.7%, a statistically significant difference ($p = <0.001$).

3.1.4 Figures Created to Represent Gathered Data

Two figures, Figures 3 and 4, and Table 1 were created to illustrate the findings. Figure 3 represents a box-and-whisker plot, which combines data from all oral surgery procedures, highlighting differences in computer usage and identifying procedures that may benefit more from mixed reality integration. Table 1 illustrates the difference in treatment time and computer usage between implant procedures with and without aR, emphasizing the technology's potential efficiency benefits. Figure 4 involves a conceptual illustration, showing a potential application of mixed reality loupes in oral surgery and demonstrating the convenience of integrated mixed reality technology in enhancing workflow.

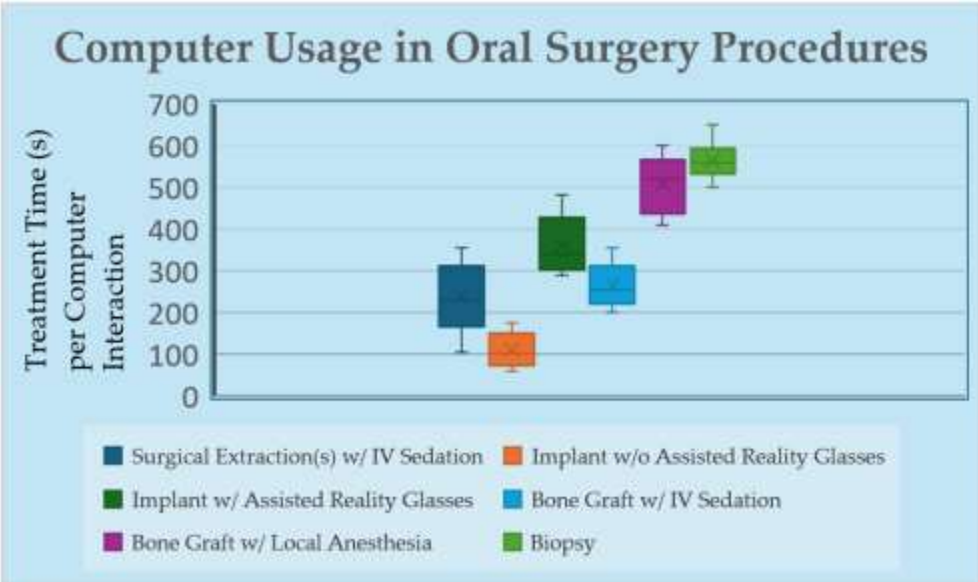

Figure 3: Box-and-Whisker Plot of Oral Surgical Procedures

Each data point represents an individual patient undergoing treatment. The median fence represents the median number of seconds per interaction with digital devices, while the lower and upper boundaries are the 25th and 75th percentiles. The whiskers, extending from the box, indicate the 10th and 90th percentiles. Procedures with lower median values indicate a higher dependence on digital technology, as interactions with digital devices occur more frequently during these treatments.

Table 1: Comparison of Treatment Time and Computer Usage in Implant Procedures

	Column1	Column2	Column3
	Procedure Number	**Treatment Time (min)**	**Computer Usage**
Implant w/o Assisted Reality Glasses	1	32.15	60
	2	28.58	88
	3	23.95	102
	4	24.76	125
	5	23.64	175
	Average	26.62	110

Implant w/ Assisted Reality Glasses	1	27.53	290
	2	21.26	315
	3	19.67	340
	4	15.75	373
	5	19.43	482
	Average	20.73	360

The table presents data for implant procedures performed with and without aR. The column labeled “Treatment Time (min)” displays treatment time in minutes for each procedure, while the column labelled “Computer Usage” shows computer usage, measured as treatment time (in seconds) per computer interaction. Averages for each category are provided in the row below the individual data points, offering a comparative view of the impact of aR on both treatment duration and digital interaction frequency.

Figure 4: Proposed Mixed Reality HMD and Application in Oral Surgery

The figure illustrates a conceptual design (developed using OpenArt) for Mixed Reality Loupes (a) and a potential application of mixed reality technology in third molar extractions (b).

CONCLUSION

The data collected from oral surgery procedures, excluding Implant with Assisted Reality Glasses, aimed to determine whether computer usage varies based on the type of dental treatment. Results from the ANOVA test revealed a statistically significant difference in computer usage across the various treatments, suggesting that mixed reality technology may be more beneficial for certain procedures. Given the high reliance on digital devices in the dental field, implementing mixed reality in loupes or glasses could offer significant advantages.

4.1 Discussion on Current Lack and Potential Future of Mixed Reality in Dentistry

4.1.1 Barriers to Reality Implementation in Dentistry

Currently, mixed reality (MR)—and, to a lesser extent, augmented reality (AR) and virtual reality (VR)—are rarely used in oral surgery or general dentistry. This limited implementation is due to several factors. Primarily, there is a lack of MR head-mounted displays (HMDs) with integrated magnification, which is crucial for most dental work. In other medical fields like neurosurgery and cardiovascular surgery, MR is used without magnification since these fields do not require the close, precise visualization needed in dentistry. Additionally, existing dental practice management and imaging software are often incompatible with MR systems, which hindering adoption.

4.1.2 Enhancing X-Guide Navigated Implant Surgeries with Mixed Reality

X-Guide navigated implants show the most promise for mixed reality enhancement. As demonstrated in Figure 3, Implant without Assisted Reality Glasses had the highest computer usage among all procedures studied due to the reliance on X-Guide for 3D navigation in the implant surgeries. Surgeons typically need to look away from the patient’s mouth to consult the X-Guide monitor, which may disrupt workflow and precision. Assisted reality glasses, used in the study, allowed surgeons to see a mirrored view of the X-Guide navigation display directly in the glasses while focusing on the patient’s mouth, reducing the need for external monitors.

4.1.3 Benefits of Assisted Reality in Reducing Time and Computer Usage for Implants

Assisted reality glasses proved highly effective in reducing both treatment time and external computer usage during implant procedures. The use of aR glasses resulted in a 22.1% decrease in treatment time and an 66.7% reduction in external computer interactions. However, more advanced mixed reality or true augmented reality devices could enable even greater efficiency by allowing surgeons to interact with digital systems directly within the HMD. For example, MR devices could allow surgeons to adjust settings on the X-

Guide or zoom in on X-rays without interrupting treatment, potentially enhancing treatment accuracy.

4.1.4 Limitations of the Study

One limitation of this study is the potential for bias in data collection by the Hawthorne effect, a phenomenon in which individuals alter their behavior due to being observed. In this study, monitoring the two oral surgeons could have unintentionally influenced a change in their behavior, such as altering the speed at which they treated patients, increasing or decreasing the amount of computer interaction, or deviating from their routine methods in patient care. These changes could have introduced variability and altered the data collected (Berkhout, C. *et al.,* 2022). To lower the impact of the Hawthorne effect, the researcher minimized social interaction with the surgeons during periods of observation and data collection. This approach was taken to reduce distraction and allow the oral surgeons to maintain their regular approach to patient treatment.

Another limitation is the small sample size, as only two oral surgeons were involved in the study. This could introduce a risk of variability and reduce the significance of the results. Future studies could address this issue by involving more oral surgeons to obtain more representative results.

Additionally, differences in experience between the two oral surgeons may have affected the results. The surgeons in this study had an experience level difference of approximately ten years post-residency, which may have influenced treatment times and the degree of reliance on computer interaction. Studies, such as one published in the *Journal of Oral Implantology*, have demonstrated that surgical experience significantly impacts accuracy during implant placement. Using three treatment groups, novice, intermediate, and experienced surgeons, the study showed statistically significant differences in the likelihood of less-experienced surgeons making more errors during implant surgeries compared to more experienced surgeons. It could be inferred that more errors may lead to longer treatment times; however, the study on experience level did not examine treatment time (Hinckfuss, S. *et al.,* 2012). To address this issue in future studies, researchers could select participants with similar experience levels to minimize variability arising from this factor.

4.1.5 The Need for Advanced Mixed Reality Technology and Further Research

The potential of MR in dentistry extends beyond convenience, as it could allow for greater control, enhanced precision, and reduced risk of iatrogenic injury. However, further advancements in MR technology tailored for dentistry are needed to realize these benefits. Future studies should examine whether MR can directly impact treatment accuracy, reduce complication rates, and lower the risk of unintended tissue damage during complex dental procedures.

4.1.6 Directions for Future Research

Future studies could investigate the potential benefits of MR across broader dental applications. A study examining computer usage in general dentistry procedures, as well as specialized fields like endodontics and orthodontics, would provide insights into whether MR could enhance efficiency in these areas. Additionally, a comparative study of complication rates in implant surgeries with and without aR could offer valuable data on MR's impact on patient outcome, establishing a clearer picture of MR's role in improving safety and precision in dentistry.

Author Contributions: Conceptualization, H.R.; methodology, H.R. and B.M.; validation, L.M. and D.L.; formal analysis, H.R.; investigation, H.R.; resources, L.M. and D.L.; data curation, H.R.; writing—original draft preparation, H.R.; writing—review and editing, H.R. and B.M.; visualization, H.R.; supervision, H.R. and L.M.; project administration, H.R. All authors have read and agreed to the published version of the manuscript.

Patient consent statement: Informed consent was obtained from the two oral surgeons as well as patient consent for those involved in the data collection.

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