Advancing laparoscopic surgery with the use of augmented reality headsets

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ABSTRACT

Introduction: Laparoscopic surgery faces ergonomic and visualization challenges. While robotic surgery addresses these challenges, it is often limited by cost. AR headset technology can offer a readily implementable complement to laparoscopic surgery at a lower cost. We aimed to evaluate the potential utility of implementing augmented reality (AR) glasses as an alternative to traditional laparoscopic display screens.
Methods: A within-subjects crossover study was conducted, including 34 participants consisting of urology residents, fellows, and staff. Participants completed either a circle cutting exercise in a laparoscopic box simulator (n=19) or a procedural step during a live porcine nephrectomy (n=15), using both the traditional laparoscopic display and AR glasses. Participants completed a questionnaire assessing the AR glasses in image quality, ergonomics, task performance, and overall experience.
Results: The majority of ratings favored AR glasses over traditional monitors for image quality, ergonomics, and performance. Most participants favored AR glasses over traditional monitors, with 85.8% favoring AR for image quality ($p<0.001$), 84.8% for ergonomics ($p<0.001$), 90.1% for performance ($p<0.001$), and 90.1% for overall experience ($p<0.001$).
Conclusions: AR glasses are a feasible alternative to traditional laparoscopic displays, providing the benefits of improved ergonomics and visualization during laparoscopic surgery, while benefiting from substantially lower costs in comparison to robotic systems. These advantages and high overall participant satisfaction suggest that AR technology could serve a role in

complementing and enhancing laparoscopic surgery. Validation in a real-world setting is imperative to corroborate these findings.

INTRODUCTION

Augmented reality (AR) is a rapidly evolving technology that can readily be integrated into a surgical setting by overlaying digital information/pre-operative imaging into the surgeon's field of view[1-3]. With the advent of wearable AR technology, such as headsets, AR has been able to be integrated into surgical contexts, where it has enhanced intraoperative navigation and depth perception through improved three-dimensional (3D) visualization[4-6]. However, despite the growing literature surrounding various potential clinical applications, its integration into clinical practice remains in its early stages[7, 8].

Laparoscopic surgery is a well-established minimally invasive surgical approach that is routinely utilized globally across surgical specialties[9]. Traditional visual displays, typically consisting of external monitor screens connected to the laparoscopic camera apparatus, are critical for safety and efficiency, but often suffer from limitations, including suboptimal positioning, poor image quality, and high costs[10]. Robotic surgery addresses many of these limitations by providing improved surgeon ergonomics, as well as 3D visualization capabilities[11]. However, the cost of robotic platforms can be substantial, limiting their adoption in many resource-limited healthcare settings[12].

AR glasses present an opportunity to complement laparoscopic surgery by providing some of the ergonomic benefits and 3D visualization capabilities of robotic platforms at a fraction of the cost. However, despite the potential benefits, the current body of literature on the use of AR glasses in laparoscopic surgery is lacking, perhaps due in part to surgeon unfamiliarity and perceived limitations of image quality and task performance. The XREAL Air 2 glasses are a lightweight, inexpensive, commercially available set of AR glasses with on-demand adjustable electrochromic dimming for optimal surgical visibility. The current study aimed to investigate the effectiveness of these AR glasses in a bench-top laparoscopic trainer and a live porcine animal model. The goal was to determine if AR headsets can provide a practical, efficient, and cost-effective alternative to traditional displays in the operating room.

METHODS

Study design and participants

This was a within-subjects crossover study that was conducted at a single center (McMaster University, Hamilton, Ontario). Data was collected during urology resident laparoscopic surgery courses at the McMaster Centre for Minimal Access Surgery (CMAS) on two separate occasions in September and October 2024. Participants included urologists at various career stages,

including residents, fellows, and staff attending the course. Enrolment was voluntary and there was no offered remuneration or incentive for participation. Participants were assigned to a station based on availability in a non-random allocation. This study was in compliance with the institutional research board (AUP-23-72).

The technologies compared in the study included a traditional Stryker 30-inch laparoscopic monitor display and XREAL Air 2 Ultra AR glasses. This device was selected over other commercially available AR headsets due to being more affordable, lightweight, and easily integrable into standard laparoscopic setups. These glasses weigh 82 g and currently cost $700 CAD per unit[13]. The AR glasses were connected to existing laparoscopic systems in the operating room via a standard HDMI cable to the Stryker Connected OR Hub[14] with the XREAL Beam adapter (Figure 1)[15]. The quick setup allowed the AR glasses to mirror the 2D laparoscopic feed with minimal setup time and no additional software or equipment. The setup maintained the functionality of existing laparoscopic monitors, allowing concurrent visualization on traditional monitors, if required.

The first station involved a laparoscopic box simulator circle cutting task, in which participants used laparoscopic scissors and a grasper to cut out a circle from a piece of cloth along a pre-drawn outline. This simulation was connected to both the laparoscopic monitor display and the AR glasses. Participants were instructed to perform the exercise twice, once utilizing the laparoscopic monitor, once utilizing the AR glasses; the order of the arms was alternated for each participant. Each participant was given 5 minutes to complete each exercise. The second station involved a live porcine nephrectomy model during which participating urologists performed various parts of the procedure. Participants were given opportunities to utilize both technologies, each for a step of the nephrectomy, enabling assessment of AR visualization in a dynamic surgical environment. The exact step of the nephrectomy was not consistent across participants, given the limited number of porcine models available.

Outcomes

A pre-determined survey was created by two surgeons (EM, YG). All study participants were given the survey following completion of the study exercises. The primary outcome was the overall experience of the AR goggle display compared to the traditional laparoscopic display. The questionnaire collected basic demographic information and included multiple items across three primary surgical domains: ergonomics, image quality, and task performance. Responses were recorded using a modified five-point Likert scale, ranging from "Strongly Favours Laparoscopic Monitor" to "Strongly Favours AR Glasses" and “no preference” as the 3-point mark. Additionally, there were open-ended sections to allow general feedback and personal insights on the potential advantages and/or limitations of AR glasses in laparoscopic surgery. The questionnaire can be found at: AR Survey Final.pdf - Google Drive.

Data analysis

Responses were categorized into three groups for each questionnaire item: “Prefer AR” (combining “Strongly Favors AR Glasses” and “Favors AR Glasses”), “No Preference,” and “Prefer Traditional” (combining “Favors Laparoscopic Monitor” and “Strongly Favors Laparoscopic Monitor”). For each domain of ergonomics, image quality, and task performance, composite scores were calculated by aggregating responses across all items within that domain. To evaluate overall preference for AR glasses versus traditional laparoscopic monitors, neutral ratings were excluded, and McNemar’s test was performed within each domain to compare the proportion of participants preferring AR to those preferring traditional monitors. Chi-squared tests were conducted to assess differences in preference distributions between participants with and without baseline corrective vision, and between those who participated in the box simulator model versus the live porcine model. Qualitative responses from open-ended questions were analyzed to identify recurring feedback patterns in order to summarize the benefits and challenges associated with the AR-assisted laparoscopic workflow.

RESULTS

Cohort overview

A total of 34 participants were enrolled in the study, including 26 residents (76.5%), 4 fellows (11.8%), and 4 attending surgeons (11.8%). The mean age was 32.2±9.6 years. Of the participants, 25 (73.5%) had no prior experience with AR systems, while 8 (23.5%) reported minimal previous experience and 1 (2.9%) reported moderate previous experience. There were 14 (41.2%) participants that wore corrective lenses, whereas the remaining 20 (58.8%) did not (Table 1). Of the participants, 19 (55.9%) participated in the box simulator model and 15 (44.1%) in the live porcine model.

Preferences for Display Type

AR glasses were consistently preferred over traditional laparoscopic monitors across all domains in both the box simulator and live porcine nephrectomy groups (Figure 2). Preference patterns were largely comparable, with similar rating across all domains.

When both groups were combined and neutral responses were excluded, AR glasses were consistently preferred across all domains, with 85.8% preferring the AR glasses over the traditional monitor for image quality ($p<0.001$), 84.8% for ergonomics ($p<0.001$), 90.1% for task performance, and 90.1% for overall experience ($p<0.001$) (Figure 3).

Preferences were compared between participants who required corrective lenses and those who did not. Participants who did not require corrective lenses preferred AR glasses in the domains of image quality ($p<0.001$), ergonomics ($p=0.03$), and performance ($p<0.001$). However, there was no significant difference in overall evaluation between the two groups (Figure 4).

Final perception

The overall impressions of AR glasses were positive, with 88.2% of participants indicating a favourable experience using AR glasses, 82.4% reporting benefits in display size, and 92.2% reporting improved ergonomics. A subset of participants (17.6%) felt that the AR glasses could interfere with certain aspects with surgery. Overall, 82.4% of participants endorsed that they would be interested in using AR in clinical practice (Table 2).

Qualitative feedback

In total, 7 (20.1%) offered additional qualitative feedback. Thematic analysis of the feedback revealed participants enjoyed the increased comfort and overall improvement of ergonomics provided by the AR glasses, with one participant summating that the AR glasses were "…more comfortable, dynamic, and focused". Areas of concerns identified by participants included potential logistical limitations during the open aspects of the procedure (e.g., port placement, specimen extraction, closure) as well as lens fogging intra-operatively. A suggestion for future improvement was to expand the visual field by using larger lenses in the AR glasses.

DISCUSSION

The findings of this study show an overall positive reception of AR glasses in a laparoscopic simulation setting by participating urologists and trainees. In total, 91.1% of participants preferred AR glasses over the traditional laparoscopic monitor, with preference for AR glasses consistent throughout all domains evaluated, namely, image quality, ergonomics, and task performance. Furthermore, the final impressions of the AR glasses were overall favourable, with 82.4% of participants indicating they would be interested in in using AR glasses in clinical practice. These results suggest that AR glasses have a potential complementary role for adoption as a technological adjunct in laparoscopic approaches.

A key advantage AR glasses provides over traditional laparoscopic monitors is the improvement in surgeon ergonomics. We found that 84.8% of participant ratings found AR glasses more ergonomic than the traditional laparoscopic monitor. The ergonomics were frequently commented on in the qualitative feedback portion of the survey as participants reported the AR glasses were comfortable, light and easy to handle. Unlike fixed monitors that require surgeons to maintain static neck positioning, AR glasses allow dynamic positioning and a more natural head positioning, improving posture and reducing neck strain. Ergonomics has been a longstanding issue with laparoscopy, given they are established to produce musculoskeletal strain for surgeons due to prolonged fixed positions with repetitive movements[16]. A workload study assessing the impact of surgical modality on surgeon wellness demonstrated that laparoscopic surgery is associated with high levels of physical demand, postoperative surgeon discomfort, and risk of developing neuromusculoskeletal disorders[17]. In a study similar, the use of AR headsets in video-assisted surgeries reported that headset use resulted in improved scores on a muscular workload questionnaire, indicating lower physical and strain when compared to traditional monitors[18]. The AR glasses evaluated in this study also had on-demand adjustable

electrochromic dimming, allowing users to adjust screen transparency so it can be readily transitioned to clear for with open portions of the procedure (e.g., port placement, specimen extraction). Collectively, this evidence suggests AR glasses provide meaningful ergonomic benefits that contribute to improved surgeon comfort in laparoscopic settings.

Image quality and task performance using AR glasses were important metrics to evaluate. Participants reported an 85.8% and 90.1% preference for AR glasses in image quality and task performance, respectively. A study assessing the feasibility of AR head mounted devices (HMDs) in orthopedic surgery corroborates our findings as they showed surgeons were generally satisfied with image quality and accuracy when using AR HMDs[19]. There are still mixed opinions on AR implementation in surgical settings as other reports identified concerns including suboptimal image quality and latency compared to standard monitors[19, 20]. Similarly, evidence surrounding task performance remains inconclusive as some reports suggest AR users increase the risk of surgical errors[7, 21, 22]. These varying findings likely reflect differences in AR headset models, quality and technical configurations and reflect the heterogeneity in the products available in the market.

Robotic-assisted surgery has recently increased in popularity[11]. However, the widespread adoption of robotic-assisted surgery is often limited due to the significant expenses involved, costing well over $1,000,000 USD for initial investments as well as ongoing maintenance costs[12]. AR headsets can provide a more affordable and accessible alternative to enhance laparoscopic procedures with some of the benefits of robotics without the significant financial burden of robotic equipment. The AR glasses used in this study were priced at $700 CAD per unit, putting them at a fraction of the cost of new laparoscopic monitors and robotic systems[13]. The AR glasses were also easy to integrate into existing laparoscopic setups, requiring minimal hardware and no additional software. The affordability and easy integration of AR glasses into laparoscopic operating rooms makes them an attractive alternative in resource-limited settings.

There are limitations to the use of AR goggles. A clear population of surgeons who may be hindered by AR goggles are those who require corrective vision. Our analysis revealed that participants who required corrective lenses were less likely to prefer AR glasses. These experiences likely vary by device, with different headsets offering various levels of accommodation for corrective vision. The AR glasses used in this study (i.e., XREAL Air 2 Ultra) have the option of a prescription lens attachment, but this was not implemented in this study. Despite the lower ratings, the majority of participants requiring corrective lenses still reported an overall positive impression of AR glasses (72%). Secondly, AR glasses may interfere with certain operative steps that require access to the surgical field, such as trocar placement and specimen extraction; although the AR glasses have lenses which are transparent when images are not being displayed, visualized may be suboptimal compared to usual practice. In addition, it is important to note that ideally all operating team members, including assistants and scrub nurses, utilize their own pair of AR glasses , however, this is not necessary and standard 2D displays operating rooms carry can be used simultaneously while the primary surgeon(s) use the AR

glasses. Thirdly, only one AR headset model was evaluated. Varying models will inevitably introduce differences in image quality, latency, and depth perception, weight and ergonomics. Additionally, outcomes were assessed through subjective questionnaire ratings rather than objective performance measures. While subjective impressions are key in determining the potential for adoption of a new tool, objective measures of accuracy, task completion time, and error rates are key in providing quality and safety data. Lastly, our evaluation time was short (i.e., 5 minutes) and inconsistent for the specific steps performed which introduces variability in user experience and thus, impacts perceptions.

CONCLUSIONS

Overall, our study shows that AR glasses were rated favourably compared to traditional laparoscopic display monitors amongst urologists across training stages. AR glasses were favourable in image quality, ergonomics, and task performance, and overall experience. AR glasses represent an attractive, affordable adjunct technology to enhance laparoscopic procedures compared to traditional monitors. Validation in a real-world setting is imperative to corroborate these findings.

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FIGURES AND TABLES

Figure 1. (A) XREAL Air 2 Ultra AR glasses. (B) Laparoscopic simulation setup with Stryker 30-inch laparoscopic monitor.

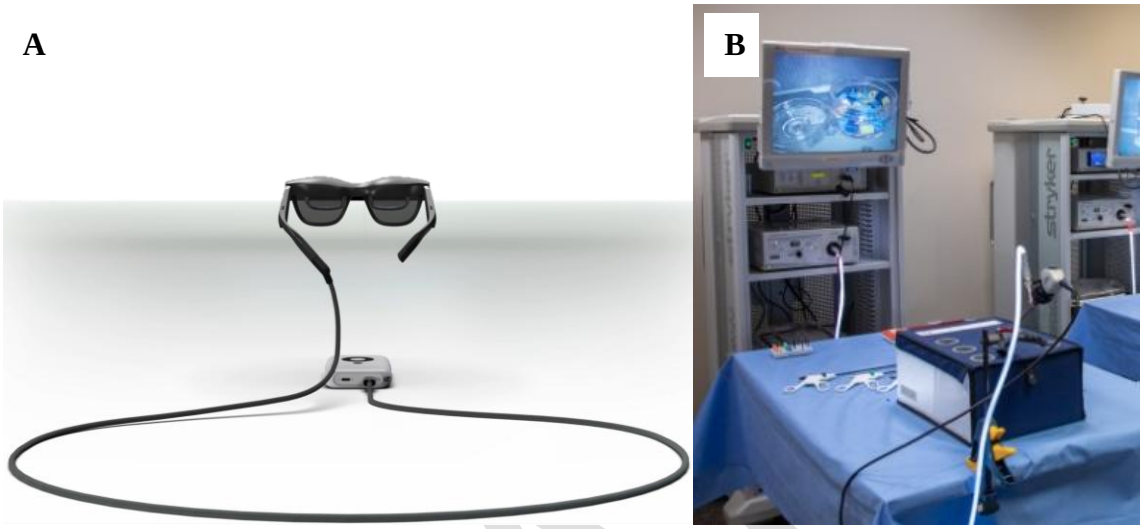

Figure 2. Preferences for augmented reality vs. traditional monitors between laparoscopic simulation and live porcine nephrectomy groups.

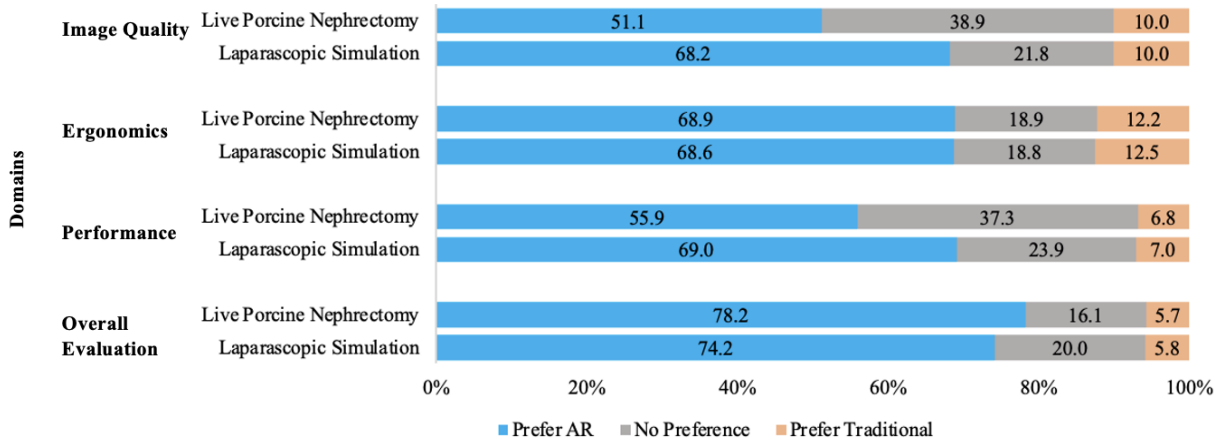

Figure 3. Proportion of non-neutral participant ratings that preferred augmented reality glasses over traditional laparoscopic monitors.

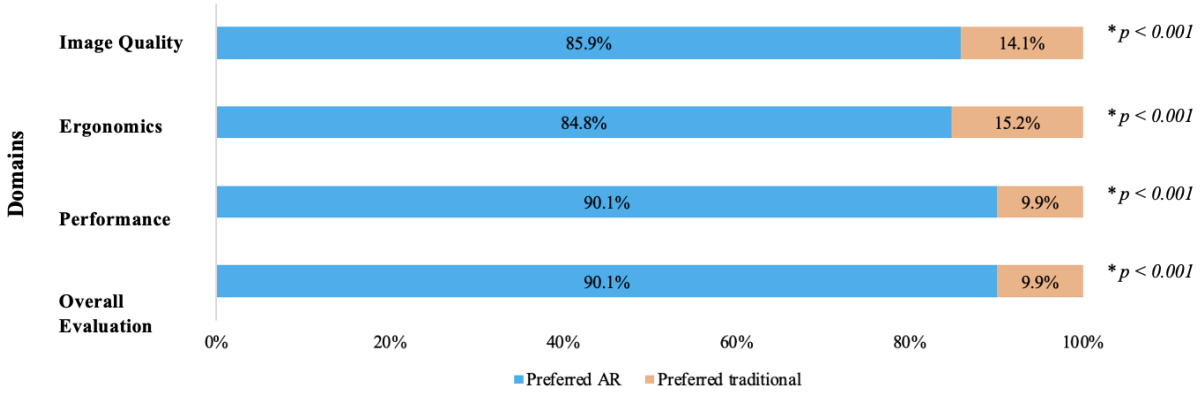

Figure 4. Preferences for augmented reality vs. traditional monitors based on corrective vision status.

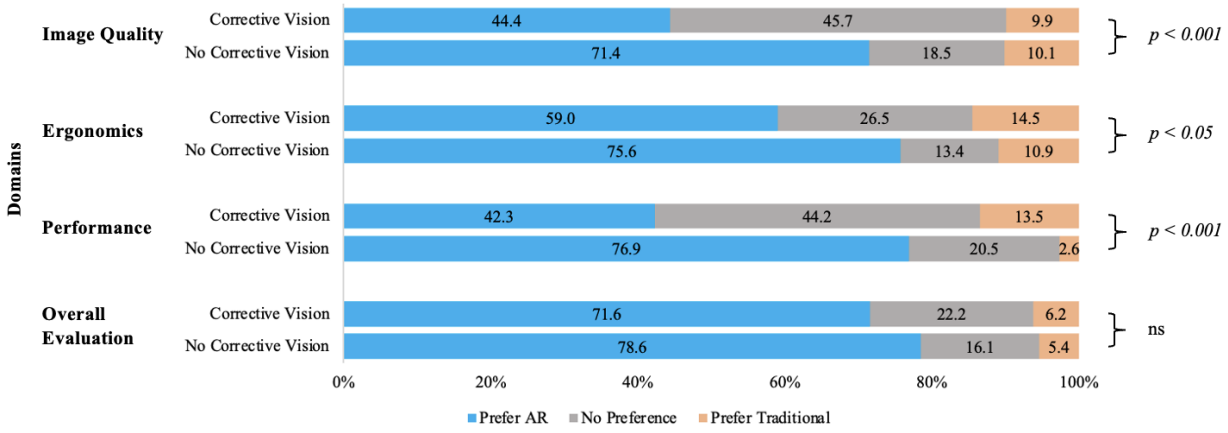

Table 1. Demographic data of participants testing augmented reality glasses in laparoscopic simulations		
Demographic		**Value**
Age, mean (SD)		
		32.2 (±9.6)
Position, n=34 (%)		
	Resident	26 (76.5)
	Fellow	4 (11.8)
	Staff	4 (11.8)
Previous AR experience, n=34 (%)		
	None	25 (73.5)
	Minimal	8 (23.5)
	Moderate	1 (2.9)
Application type, n=34 (%)		
	Box simulator	19 (55.9)
	Live porcine model	15 (44.1)
Baselines corrective vision, n=34 (%)		
	Yes	14 (41.2)
	No	20 (58.8)

SD: standard deviation.

Table 2. Final perception ratings about use of AR glasses in laparoscopic surgery		
Final perception	**n=34**	**Percentage (%)**
Liked AR	30	88.2
Sees benefit in usage	20	58.8
Benefits in display size	28	82.4
Improved ergonomics	31	92.2
AR glasses interfered with surgery	6	17.6
Interested in using in clinical practice	28	82.4

AR: augmented reality.