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Effect of Intraoperative Mixed-Reality use on Nonsurgical Team Members in the Neurosurgical Operating Room: An Explorative Study

T.M. Kos¹, S. Haaksman², L. Regli², T.P.C. van Doormaal², E. Colombo²

■ **OBJECTIVES:** Mixed-reality (MxR) implementation in the neurosurgical operating room (OR) is emerging, but the impact of this technology on the nonsurgical OR staff has not been investigated yet. The purpose of this study is to evaluate the nonsurgical OR team's perception of the impact of intraoperative MxR use.

■ **METHODS:** The evaluation occurred in a neurosurgical institution implementing MxR perioperatively on a daily basis for 15 months. The questionnaire measuring the impact of MxR consisted of 5 binary questions and 4 sub-questions measured on a 7-point Likert scale.

■ **RESULTS:** Fifteen nonsurgical staff members of a neurosurgical OR team were interviewed. Most (85%) of the cohort stated that MxR changed their perception of the surgery, improving understanding of the spatial orientation (median 6, interquartile range 5–7) and of the pathology dimensions (6, 5.5–7). One participant (7%) was of the opinion that MxR disrupted the OR workflow. The majority (60%) stated that use of the holograms improved efficiency in the OR. The participants were neutral about the potential role of MxR to improve communication among different OR team members (4, 2–5) and overall teamwork (4, 2–5).

■ **CONCLUSIONS:** The use of 3-Dimensional interactive holograms of neurosurgical cases in the nonsterile intraoperative phase was not perceived as distracting, and neither was OR flow disruption by members of the nonsurgical OR staff. MxR was considered an adjunct to improve OR efficiency. A thorough understanding of the

impact of MxR's implementation on the nonsurgical staff could lead to targeted improvement of the MxR use and, potentially, to increasing the quality of the teamwork.

INTRODUCTION

The neurosurgical operating room (OR) is a challenging workplace where a multidisciplinary team must collaborate effectively to obtain optimal surgical outcomes. The presence of stress factors in the OR may impair the ability of the surgical and nonsurgical operative team to collaborate productively, potentially putting patient safety at risk.^{1,2} In addition to patient- or surgery-related stress factors, disruptions from the regular workflow can be experienced as stressful. Examples of these flow disruptions (FDs) are phone calls, visiting external staff members, or defective medical equipment. In the arduous working environment of the neurosurgical OR, FDs may decrease intraoperative efficiency or even cause adverse events.^{3,4}

The application of mixed reality (MxR) in the neurosurgical environment is increasing, and its potential benefits have been described for the surgical staff.^{5,6} Often during development and testing of surgical devices, the surgeon's experience or opinion is the primary focus. However, because the introduction of new technologies into the OR may be considered disruptive for the OR workflow, testing the device in the related user groups is an essential step. In addition, most studies performed with the aim of investigating the impact of FDs in the surgical OR environment provided little focus on their consequences on the anesthesiology and nursing staff.⁷ However, as these groups

Key words

- Communication
- Efficiency
- Flow disruptions
- Mixed reality
- Teamwork

Abbreviations and Acronyms

- 3D:** 3-Dimensional
- FD:** Flow disruption
- IQR:** Interquartile range
- MxR:** Mixed reality
- OR:** Operating room

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have their own workflow and challenges, focusing on their perspective allows for designing devices that enhance efficiency while minimizing disruptions for the entire OR team. To our knowledge, the impact of the implementation of MxR on nonsurgical members of the neurosurgical OR team has not been investigated yet. A more detailed understanding of the potentially disruptive effect of the intraoperative use of 3-Dimensional (3D) holograms on the OR team members would allow an improvement of the use of this technology, eventually leading to improved teamwork and a safer surgical practice. Therefore this initial exploratory study aims to investigate the impact of MxR use in a neurosurgical OR as experienced by nonsurgical members of the OR team.

MATERIAL AND METHODS

An exploratory study was performed by interviewing nonsurgical members of the OR team in a neurosurgical department where MxR has been implemented on a daily basis for surgical planning for 15 months.

Given the nature of the study and the noninvolvement of medical or radiologic data of patients, no ethical board approval was required. The participation of the nonsurgical medical and nursing OR personnel was entirely voluntary, and anonymity was assured.

Routine Implementation of Mixed Reality

The use of 3D interactive holographic reconstructions of the patient-specific anatomy and pathology has been implemented in the surgical planning, training, and nonsterile intraoperative phase of over 200 diverse neurosurgical procedures (i.e., neuro-oncologic, cerebrovascular, spinal surgeries) in our institution (Figure 1). To observe whether MxR caused any delay in the operative workflow, the surgical preparation time using MxR was compared with the preparation time in a historical cohort of cases, matched by type of pathology and primary operating neurosurgeons. Daily use of MxR encompassed the preparation of the holograms by a dedicated neurosurgical team, their use for preoperative surgical planning, and their visualization in the nonsterile intraoperative phase. The 3D models for the holograms were made using a combination of automatic segmentations using a validated expanding meshes algorithm (Disior, Helsinki, Finland) and manual segmentation of specific anatomic structures, when needed (Figure 2)⁸⁻¹⁰. The algorithm and resulting holograms were accessed through a cloud environment (Lumi, Augmedit BV, Naarden, The Netherlands). The holograms have been visualized through MxR glasses (HoloLens 2, Microsoft, Redmond, Washington, USA). The primary user's holographic field of view has been streamed to a 2-dimensional or 3D monitor and made available for the rest of the OR team to observe the interaction with the hologram. Members of the nonsurgical OR team were also provided the opportunity to view the hologram through the MxR glasses, to have a direct understanding of the neurosurgeons' viewpoint.

Impact and Implementation of Mixed Reality

The impact of the MxR technology on the nonsurgical staff in the OR was measured through a questionnaire (Figure 3). The

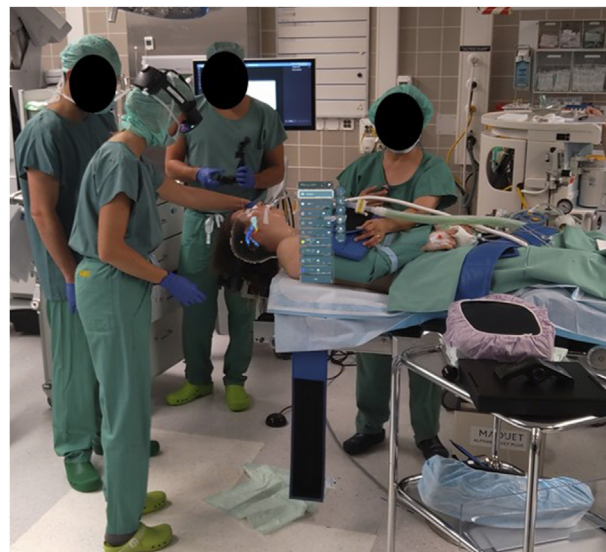


Figure 1. The use of 3-Dimensional interactive holographic reconstructions of the patient-specific anatomy and pathology has been implemented in the surgical planning, training, and nonsterile intraoperative phase of more than 200 diverse neurosurgical procedures (i.e., neuro-oncologic, cerebrovascular, spinal surgeries) in our institution.

questionnaire consisted of binary questions (yes/no) regarding the disruptiveness of MxR hologram use in the OR and the effect of MxR hologram use on perception and understanding of the surgery and perceived efficiency of the nonsurgical workflow in the OR. Each of the main questions was followed up by scoring the contributing factors on a 7-point Likert scale (1 = Strongly Disagree, 4 = Neutral, 7 = Strongly Agree). A positive appraisal of MxR technology was recorded if the participant answered "Yes" to questions 3 and 5 and "No" to question 4.

Preliminary data on the implementation of the technology in the OR, namely length of surgical preparation time and intraoperative hologram use, were also gathered. Surgical preparation time was defined as the time frame from entrance of the intubated patient in the OR to the end of draping.

Data Analysis

Data were analyzed using R Studio (version 4.3.1). Descriptive statistics (median and interquartile range [IQR] using an inclusive median) were computed for all quantitative outcome measures. Additional comments were categorized as "Workflow" and "Communication."

RESULTS

Participant Characteristics

Fifteen nonsurgical staff members of a neurosurgical OR team were interviewed (Table 1). Seven of these were members of the anesthesiology team. Five were scrub nurses, 1 was a positioning nurse, and 1 was a clinical neurophysicist performing intraoperative neuromonitoring. The interviewed

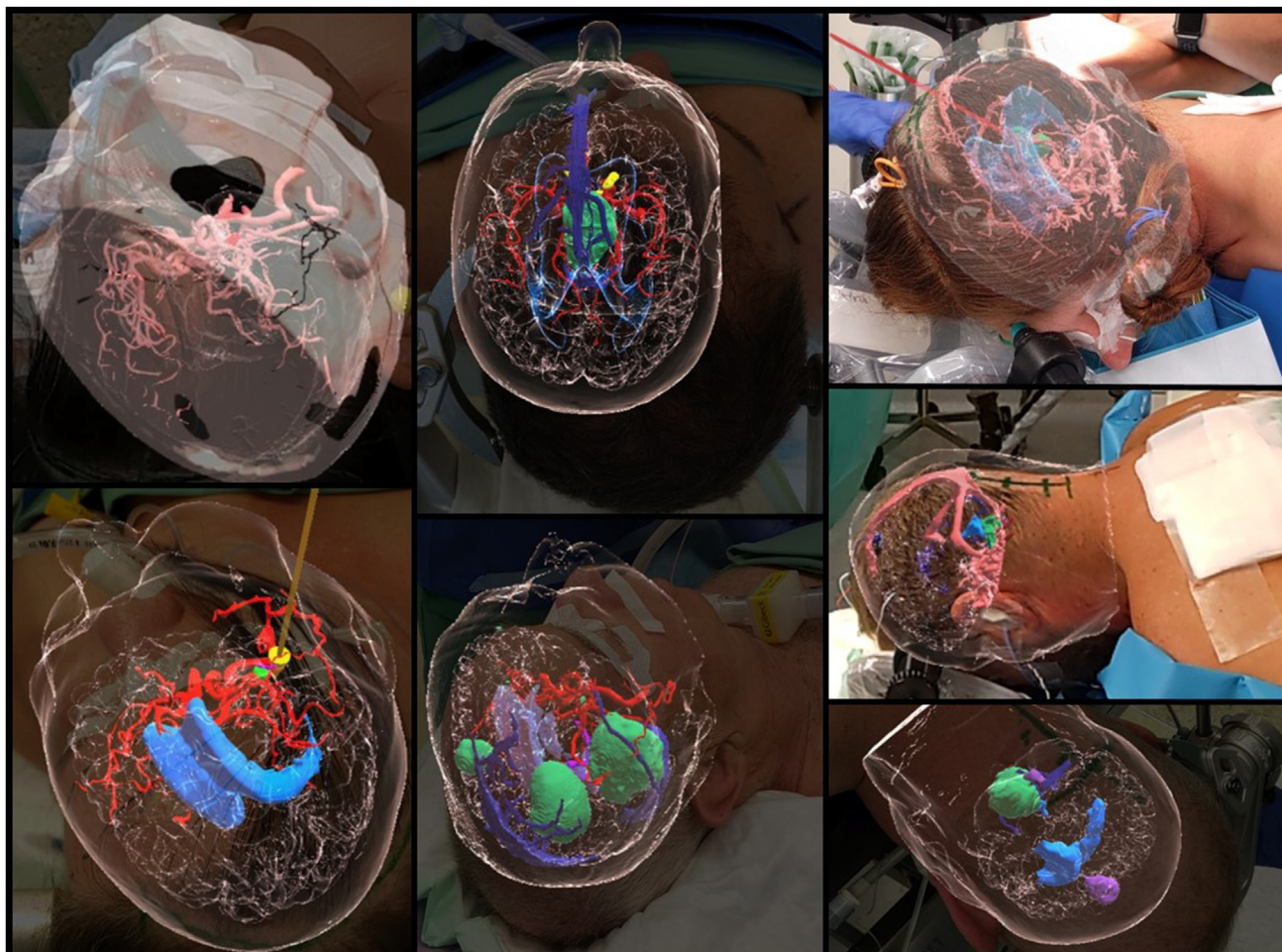


Figure 2. The 3-Dimensional models for the holograms were made using a combination of automatic segmentations using a validated expanding

meshes algorithm and manual segmentation of specific anatomic structures, when needed.

cohort had a mean experience of 5 ± 7 years in a neurosurgical OR.

Impact of MxR on the Nonsurgical Workflow

The results were visualized in box plots (Figure 4). Fourteen out of 15 (93%) participants understood the clinical purpose of the hologram use. Thirteen out of 15 (87%) of the participants had personally used the MxR system before the interview. The remaining 2 (13%) participants had indirect experience with the MxR by observing the hologram's use on a 2-dimensional or 3D screen in the OR. Eleven of the 13 (85%) participants who used the MxR system were of the opinion it changed their perception of the surgery, improving their understanding of the spatial orientation (median 6, IQR 5–7) and the dimensions of the pathology being operated (median 6, IQR 5.5–7). An improved understanding of the surgical difficulty emerged less evidently (median 5, IQR 4–6.5). One participant (7%) was of the opinion that hologram use

disrupted the OR workflow, stating it negatively influenced the speed of the surgical preparation time. Nine participants (60%) stated that use of the holograms improved efficiency in the OR. Nonetheless, the participants were neutral about the potential role of MxR to improve communication among different OR team members (median 4, IQR 2–5) and overall teamwork (median 4, IQR 2–5). There was no notable difference in perception of the impact of the MxR technology based on the participant's level of experience (Table 1).

Table 2 shows the categorization of additional comments from interviewed OR staff members. With regard to workflow, the main concerns were the timing of the hologram use and the exposure of the nonsurgical team to the holograms. Regarding the impact of MxR use on communication in the neurosurgical OR, visualization of the holograms during time-out on a 3D monitor was suggested to improve multidisciplinary communication.

Number	Question	Answers
1.1	Do you understand the purpose of the hologram?	<input type="radio"/> Yes <input type="radio"/> No
1.2	Did you try the MxR system?	<input type="radio"/> Yes <input type="radio"/> No
1.3	Does hologram use change your perception of the surgical procedure?	<input type="radio"/> Yes <input type="radio"/> No
1.3.1	<i>If 'Does hologram use change your perception of the surgical procedure?' is equal to 'Yes' answer this question: My spatial orientation improved through hologram use.</i>	Strongly Disagree (1) _____ Strongly Agree (7)
1.3.2	<i>If 'Does hologram use change your perception of the surgical procedure?' is equal to 'Yes' answer this question: My perception of the lesion dimensions improved with hologram use.</i>	Strongly Disagree (1) _____ Strongly Agree (7)
1.3.3	<i>If 'Does hologram use change your perception of the surgical procedure?' is equal to 'Yes' answer this question: My perception of the surgical difficulty improved with hologram use.</i>	Strongly Disagree (1) _____ Strongly Agree (7)
1.4	Do you experience hologram use as disruptive for the OR workflow?	<input type="radio"/> Yes <input type="radio"/> No
1.4.1	<i>If 'Do you experience hologram use as disruptive for the OR workflow?' is equal to 'Yes' answer this question: Hologram use increases stress in the OR.</i>	Strongly Disagree (1) _____ Strongly Agree (7)
1.4.2	<i>If 'Do you experience hologram use as disruptive for the OR workflow?' is equal to 'Yes' answer this question: Hologram use in the OR decreases operative speed.</i>	Strongly Disagree (1) _____ Strongly Agree (7)
1.5	Do you think hologram use improves efficiency in the OR?	<input type="radio"/> Yes <input type="radio"/> No
1.5.1	<i>If 'Do you think hologram use improves efficiency in the OR?' is equal to 'Yes' answer this question: Hologram use improves communication in the OR.</i>	Strongly Disagree (1) _____ Strongly Agree (7)
1.5.2	<i>If 'Do you think hologram use improves efficiency in the OR?' is equal to 'Yes' answer this question: Hologram use improves teamwork in the OR.</i>	Strongly Disagree (1) _____ Strongly Agree (7)

Figure 3. The impact of the mixed-reality technology on the nonsurgical staff in the OR was measured through a questionnaire.

Intraoperative MxR Implementation

In our single-center experience, we observed no significant difference in the average surgical preparation time using MxR (i.e., time from entrance in the OR to end of patient positioning, compared with cases with standard planning). The mean surgical preparation time was 48 ± 16 minutes in the cohort of MxR cases versus 52 ± 17 minutes in the historical cohort (unpublished data). Furthermore, the estimated average time of intraoperative MxR use is currently 7 ± 3 minutes. An analysis of the total time of surgery for the whole cohort and for specific approaches is currently under evaluation.

DISCUSSION

This exploratory study aimed to investigate the impact of MxR use on the nonsurgical OR staff, after more than 1 year of routine use of technology for surgical planning, rehearsal, and training.

Previous investigation of the impact of intraoperative FDs has provided conflicting results, and, to our knowledge, there is no literature focusing on the impact of FDs in a neurosurgical OR.¹¹ Results from studies performed in other surgical environments showed that a precise quantification of intraoperative FDs could be of paramount importance to categorize, stratify, and describe their impact on the whole OR team.¹²⁻¹⁴ However, a precise analysis of FDs is complicated due to challenges in accurately measuring their duration, source, and degree of severity. For assessment of the impact of MxR, it is possible to measure the duration and source of the technology, although the presence of confounding FDs must be taken into consideration.

In our experience, the integration of MxR into the OR workflow affected the operating neurosurgeons and involved the entire OR team. The exploratory assessment of the impact of this technology after more than 1 year of routine implementation unveiled a predominantly positive perception among the nonsurgical OR team. According to the interviewed anesthesia, nursing, and neuro-monitoring staff, the use of MxR did not lead to workflow disruptions, nor did it impose heightened stress levels on the OR teamwork. Furthermore, this technology demonstrated potential utility in enhancing the comprehension of the nonsurgical staff with regard to the location and dimensions of the pathology. Indeed, we believe that a better understanding of the dimension, location, and anatomic surroundings could improve the understanding of the estimated time of surgery, as well as patient positioning and eventual special anesthesiologic measures and/or interventions. Interestingly, the added value of 3D visualization was less pronounced in terms of facilitating a more comprehensive appraisal of the procedure's complexity. Similarly, no benefits were observed concerning communication among OR team members and the overall OR teamwork. This might indicate that the current scope of this technology's role is still confined to the use for the surgical staff members, possibly due to its suboptimal integration into the overall OR workflow.

The current study presents several limitations. First, the study has been performed in a single tertiary neurosurgical referral center with a high caseload, easy access to the MxR technology, and a specialized team working on its implementation. As these conditions may differ for other centers, the resulting impact on the OR team may also differ. Nevertheless, this unique setting provided the opportunity to perform the first exploratory study on

Table 1. Questionnaire Results

Role	Experience*	1	2	3	3a	3b	3c	4	4a	4b	5	5a	5b
Positioning Nurse	1	Yes	Yes	Yes	5	5	7	No	NA	NA	No	NA	NA
Positioning Nurse	5	Yes	Yes	No	NA	NA	NA	No	NA	NA	Yes	5	5
Scrub Nurse	30	Yes	Yes	No	NA	NA	NA	No	NA	NA	No	NA	NA
Scrub Nurse	6	Yes	Yes	Yes	7	7	1	No	NA	NA	No	NA	NA
Scrub Nurse	2	Yes	No	NA	NA	NA	NA	No	NA	NA	Yes	5	4
Scrub Nurse	3.5	Yes	Yes	Yes	6	6	NA	Yes	1	4	Yes	1	6
Scrub Nurse	1.5	Yes	No	NA	NA	NA	NA	No	NA	NA	Yes	3	2
Anesthesia Resident	0.3	No	Yes	Yes	NA	6	NA	No	NA	NA	NA	NA	NA
Anesthesia Attending	2	Yes	Yes	Yes	5	5	5	No	NA	NA	Yes	2	2
Anesthesia Attending	3	Yes	Yes	Yes	5	7	NA	No	NA	NA	Yes	4	5
Anesthesia Attending	6.5	Yes	Yes	Yes	3	4	3	No	NA	NA	Yes	1	1
Anesthesia Nurse	0.75	Yes	Yes	Yes	5.5	5.5	5.5	No	NA	NA	NA	NA	NA
Anesthesia Attending	0.8	Yes	Yes	Yes	7	7	NA	No	NA	NA	Yes	4	4
Anesthesia Resident	0.3	Yes	Yes	Yes	6	6	5	No	NA	NA	Yes	7	7
Neuromonitorist	5	Yes	Yes	Yes	7	7	7	No	NA	NA	No	NA	NA

NA, not applicable.
*Experience in a neurosurgical OR is measured in years.

the impact of MxR in a neurosurgical OR from the point of view of the nonsurgical staff. Second, the study was performed on a relatively small study population. The participants were only interviewed once, and the results from this study are purely perceptual. Therefore an evaluation of any potential development

of the critical appraisal of MxR over time and a quantitative evaluation of the impact of MxR on the OR team and workflow were not possible. Additionally, only 1 participant without any MxR experience was interviewed. This was due to the fact that all other personnel had previously experienced the MxR device in the

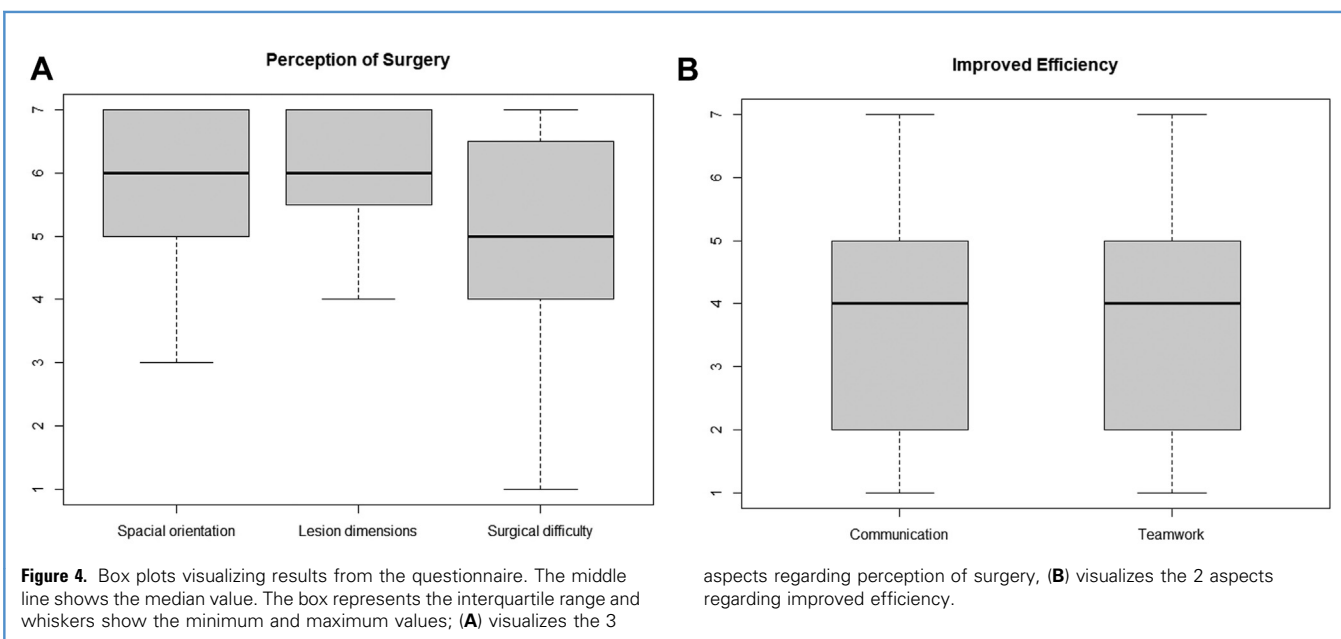


Table 2. Additional Comments from Participants

Workflow	The technology should be implemented further before it proves valuable for surgeons and patient safety.
Teamwork	Entire team should be introduced to the system
	Interesting but probably not necessary for the workflow
	The holograms do not provide a distraction if they are helpful for surgeons
	Timing of the hologram use could be improved
	Surgical confidence might improve
Communication	Now only neurosurgeons use it, could improve communication but that is dependent on the moment in which the hologram is shown
	Having a monitor in the OR would be helpful, might improve communication during time-out
	The future would be a monitor of the whole team with MxR glasses

OR. Another limitation to this study was the questionnaire used for assessment of the impact of MxR, which was designed specifically for this study by the authors and did not represent a standardized assessment methodology. Furthermore, intraoperative efficiency was not assessed in depth, and a more detailed analysis examining quantifiable measure of intraoperative efficiency indeed represents the goal for a future study. Nonetheless, to our knowledge this is the first study investigating the impact of MxR on the nonsurgical workflow in the neurosurgical OR; therefore no standardized questionnaire was available as a reference.

Future studies should include a larger number of participants, a control group without MxR experience, make use of a longitudinal study design also including quantitative measurements to investigate a possible change in perception over time, and possibly focus on the validation of a questionnaire that could be used as a gold standard by all centers using MxR in the perioperative neurosurgical environment.

CONCLUSION

This explorative study may represent a first relevant step to demonstrate that the use of 3D interactive holographic reconstructions of the surgical cases in the nonsterile intraoperative phase is not perceived as a distraction or OR workflow disruption

by members of the nonsurgical OR staff. MxR use was actually considered an adjunct to improve OR efficiency and the nonsurgical OR team's anatomic understanding of the neurosurgical pathology. A thorough understanding of the impact of routine MxR's implementation in a neurosurgical OR on the nonsurgical staff could lead to targeted improvement of the use of the technology and, eventually, to increase the quality of the team communication and multidisciplinary teamwork.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

T.M. Kos: Conceptualization, Methodology, Formal analysis, Writing – original draft, Visualization, Writing – review & editing. **S. Haaksman:** Validation, Writing – review & editing. **L. Regli:** Supervision, Writing – review & editing. **T.P.C. van Doormaal:** Supervision, Writing – review & editing. **E. Colombo:** Conceptualization, Methodology, Investigation, Writing – original draft, Visualization, Writing – review & editing, Funding acquisition.

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