Postoperative neurosurgical infection rates after shared-resource intraoperative magnetic resonance imaging: a single-center experience with 195 cases

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Abstract: OBJECTIVES: To determine the rate of surgical-site infections (SSI) in neurosurgical procedures involving a shared-resource intraoperative magnetic resonance imaging (ioMRI) scanner at a single institution derived from a prospective clinical quality management database. METHODS: All consecutive neurosurgical procedures that were performed with a high-field, 2-room ioMRI between April 2013 and June 2016 were included (N = 195; 109 craniotomies and 86 endoscopic transsphenoidal procedures). The incidence of SSIs within 3 months after surgery was assessed for both operative groups (craniotomies vs. transsphenoidal approach). RESULTS: Of the 109 craniotomies, 6 patients developed an SSI (5.5%, 95% confidence interval [CI] 1.2-9.8%), including 1 superficial SSI, 2 cases of bone flap osteitis, 1 intracranial abscess, and 2 cases of meningitis/ventriculitis. Wound revision surgery due to infection was necessary in 4 patients (4%). Of the 86 transsphenoidal skull base surgeries, 6 patients (7.0%, 95% CI 1.5-12.4%) developed an infection, including 2 non-central nervous system intranasal SSIs (3%) and 4 cases of meningitis (5%). Logistic regression analysis revealed that the likelihood of infection significantly decreased with the number of operations in the new operational setting (odds ratio 0.982, 95% CI 0.969-0.995, P = 0.008). CONCLUSIONS: The use of a shared-resource ioMRI in neurosurgery did not demonstrate increased rates of infection compared with the current available literature. The likelihood of infection decreased with the accumulating number of operations, underlining the importance of surgical staff training after the introduction of a shared-resource ioMRI.

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Postoperative neurosurgical infection rates after shared-resource intraoperative magnetic resonance imaging – a single center experience with 195 cases

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Conflicts of interest: The Department of Neurosurgery and the Department of Neuroradiology at the University Hospital Zurich are reference centers for ioMRI scanners of Siemens AG

Abstract

Objective: To determine the rate of surgical site infections (SSI) in neurosurgical procedures involving a shared-resource intraoperative magnetic resonance imaging (ioMRI) scanner at a single institution derived from a prospective clinical quality management database

Methods: All consecutive neurosurgical procedures that were performed with a high-field, two-room ioMRI between April 2013 and June 2016 were included (N=195; 109 craniotomies and 86 endoscopic transsphenoidal procedures). The incidence of surgical site infections (SSI) within three months after surgery was assessed for both operative groups (craniotomies versus transsphenoidal approach).

Results: Of the 109 craniotomies, six patients developed an SSI (5.5%, 95%-Confidence interval [CI]: 1.2%, 9.8%), including one superficial SSI, two cases of bone flap osteitis, one intracranial abscess and two cases of meningitis/ventriculitis. Wound revision surgery due to infection was necessary in four patients (4%). Of the 86 transsphenoidal skull base surgeries, six patients (7.0%, 95%-CI: 1.5%, 12.4%) developed an infection, including two non-CNS intranasal SSIs (3%) and four cases of meningitis (5%). Logistic regression analysis revealed that the likelihood of infection significantly decreased with the number of operations in the new operational setting (odds ratio: 0.982, 95%-CI: 0.969-0.995, p=0.008).

Conclusions: The use of a shared-resource ioMRI in neurosurgery did not demonstrate elevated infection rates as compared to the current available literature. The likelihood of infection decreased with the accumulating number of operations, underlining the importance of surgical staff training after the introduction of a shared-resource ioMRI.

Introduction

Over the past decade, intraoperative magnetic resonance imaging (ioMRI) has increasingly been implemented for numerous neurosurgical procedures.[1-7] Although the use of high-field ioMRI has greatly influenced the management of neuro-oncological patients by increasing the extent of tumor resection and therefore survival time,[8] the acquisition and maintenance costs of high-field scanners are considerably high, imposing a challenge for many neurosurgical clinics.[9] As a cost-effective alternative to the single-room ioMRI, the two-room ioMRI suite comprises a high-field scanner that is spatially separated from the operating theater by a double-layered sliding door (Figure 1). This setting allows for continuous nonsurgical outpatient MRI examinations outside the intraoperative MRI time window, thereby sharing resources and greatly improving the scanner's cost-effectiveness.[10]

While procedures in one-room intraoperative MRI suites have infection rates as low as conventional operations,[11,12] there are concerns whether such a shared-resource design imposes a greater risk for infections or anesthesia related complications.[13] For example, patient transportation into the MRI room imposes a challenge to anesthesia and it is still unclear whether exposure to a non-sterile environment such as the ioMRI, the repetitive draping and undraping of the operation site as well as the longer procedure time of approximately one hour increase the risk of surgical site infections.[13] While several studies find low infection rates in shared-resource designs,[9,14-16] their validity is restricted as they only investigated a small number of patients and rarely included transsphenoidal procedures.

This study is part of an ongoing quality assessment of neurosurgical complication rates at our clinic.[17] Specifically, in this study we prospectively documented surgical site infections (SSIs) after 195 consecutive procedures involving a two-room ioMRI. The rates of infections and infection-related reoperations of two operative groups (craniotomies and transsphenoidal approaches) were then compared to rates from previous studies without ioMRIs and single-room scanners to assess whether the use of this two-room setting imposes a greater infection risk for patients. Furthermore, logistic regression analysis was used to determine whether the likelihood of infection changes with the accumulative number of operations performed in this new setting.

Material and methods

Patients

We prospectively documented all 195 consecutive neurosurgical interventions with our two-room ioMRI that occurred between April 2013 and June 2016. Ethical board approval was given (KEK-ZH 2012-0244). Operations were performed by eleven surgeons at the University Hospital Zurich, led by one of the two senior authors. The use of the ioMRI was decided upon medical indication and the surgeon's preference. The surgeries were grouped by approach (109 craniotomies on 102 patients and 86 transsphenoidal skull base surgeries on 79 patients). This grouping accounts for the surgical site's difference in level of contamination: All craniotomies were clean operations, all transsphenoidal surgeries were clean-contaminated entries.[18,19] In addition to the 195 cases, one spinal case was performed with the ioMRI. This case was not followed by an infection, but it was not included into the study because the entry and operative protocol considerably differs from the cranial surgeries. All operations were elective procedures and all patients preoperatively consented to clinical data analysis. Patient characteristics are listed in Table 1.

Two-room ioMRI unit

The two-room ioMRI unit at our facility contains a 3T MRI (MAGNETOM® Skyra, Siemens Healthcare, Erlangen, Germany), which is located adjacent to the operating room and separated from it through a sliding double-door (Figure 1A). The scanner room is accessible from outside the operating floor, allowing for outpatient scans outside the intraoperative MRI time window. On average, 15 outpatient MRI scans are performed on the scanner when an ioMRI case is planned for that day. The MRI room is radiofrequency shielded, whereas the operating room does not have further modifications apart from the sliding doors. Aside from MRI-compatible anesthesia equipment and the non-ferromagnetic head holder and coils (Noras MRI products, Germany), standard ferromagnetic operating equipment was used.

Anesthesia

All procedures were performed under general anesthesia, which was induced via intravenous application of Fentanyl (2-3 µg/kg) and Propofol (1.5-2 mg/kg) with facilitation of intratracheal intubation by Atracurium (0.5 mg/kg). Anesthesia was maintained with Remifentanil (0.1-2 µg/kg/min) and Propofol (5-10 mg/kg/h), while relaxation was continued with Atracurium (0.5 mg/kg/h) unless intraoperative neurophysiological monitoring (IONM) was performed. Equipment that remained on the patient during ioMRI was MR-compatible. In contrast to surgeries without ioMRI, no electrodes were applied to record the bispectral index (BIS).

Surgical procedure and ioMRI protocol

Preoperatively, all patents were given one dose of Cefuroxime as antibiotic prophylaxis (1500mg for adults, weight-adjusted for pediatric patients) and a second dose if the surgery exceeded 4 hours. Vancomycin or Clindamycin (second-line) was selected if allergies to Cefuroxime were known. Craniotomy patients were not shaved but the hair was occasionally shortened with an electric razor. After fixation in the MRI-compatible headrest, craniotomy patients were draped and the operative site disinfected with chlorhexidine solution. In transsphenoidal surgery, the facial skin was disinfected with povidone-iodine solution from both eyebrows to the upper lip. While the nasal vestibule skin was disinfected with the same agent, the depth of the nasal cavity was not disinfected. Special care was taken to prevent MR image distortions and tissue heating in surgeries with IONM.[20] Instruments like neuronavigation (Stealthstation® S7, Medtronic, United States), microscope (Pentero® 900, Zeiss, Germany), intraoperative sonography (iU 22, Philips, Netherlands) and endoscope (Storz, Germany) were routinely used as in surgeries without ioMRI.

The surgeon decided when to use the intraoperative MRI and reserved the scanner room one hour prior to its use. 15 minutes before the scan, the MRI-room was cleaned and locked against the outpatient area (Figure 1A). Before opening the door to the scanner, the surgical site was provisionally closed and covered with sterile incise drapes (OPSITE™, Smith & Nephew, United Kingdom). Neuronavigation and dispensable operating equipment was removed. The patient was then fully covered with three sterile layers. After going through checklists with standard operating procedures, the sliding doors were opened and the patient was transferred to the ioMRI in the adjacent room (Figure 1B). During scanning the doors to the OR were kept closed. After ioMRI, the patient was transferred back to the operating room and re-draped to continue surgery. The intraoperative scan and the additional measures associated with it prolonged surgery time by approximately one hour. Upon surgeon’s decision, subgaleal drains were postoperatively placed for 48 hours. If necessary, lumbar drains were placed for a varying length of time.

Assessment of postoperative complications and data collection

Patients’ postoperative course was assessed daily until discharge and three months after surgery. Wound complications were assessed by the attending neurosurgeon on the ward and revision surgery was performed if necessary. SSIs were categorized according to the Centers for Disease Control and Prevention (CDC, Atlanta, GA

USA) guidelines with modifications for neurosurgical procedures.[19, 21] Although the CDC guidelines define that an SSI must occur within 30 days after surgery (or one year if a device is implanted), we considered a follow-up period of 90 days as more appropriate to detect surgically related infections.

Postoperative infections after craniotomy were defined as follows: *Superficial incisional SSIs* were considered if the infection involved the skin or subcutaneous tissue and diagnosed in the presence of purulent discharge, isolated organisms from serous drainage or by clinical diagnosis of the attending physician. *Deep incisional/organ-space SSIs* were considered when an infection involved deeper tissues and include *bone flap osteitis* (diagnosed surgically/clinically or by cranial imaging), *meningitis-ventriculitis*, *intracranial abscesses or empyema* (diagnosed surgically/clinically, by microbial testing or by cranial imaging).

Since the CDC definitions of surgical site infections are not directly applicable to intranasal incisions, postoperative infections after transsphenoidal surgery were defined as follows: *Intranasal SSIs* included postoperative infections of the nasal and paranasal cavities with positive culture samples without infection of the CNS. *Deep incisional/organ-space SSIs* described all infections of the CNS and included infections of the dural closure or graft, meningitis-ventriculitis and intracranial abscesses or empyema. *Meningitis-ventriculitis* was also defined according to the CDC guidelines and diagnosed when patients had organisms cultured from the CSF or when they showed clinical signs of meningitis (fever >38°C, headache, stiff neck, meningeal signs, cranial nerve signs, irritability) and had lab results suggestive of meningitis (increased white cells, elevated protein, decreased glucose in CSF, detectable organisms on Gram's stain of CSF, positive blood cultures, positive antigen test or antibody titer).[21]

Swabs of the wound, blood cultures or CSF samples were sent for microbiological testing if a patient showed signs of an infection (erythema, wound dehiscence, purulent wound, fever or signs of meningitis). Furthermore, CSF samples were taken for microbiological testing if a CSF leak occurred.

All patients with an infection received broad-spectrum empiric antibiotic treatment after consulting a specialist for infectious diseases and amendments to the therapy plan were made if required by the results of the microbiological testing. Data on infectious complications were prospectively collected in our patient registry and completed with information from patient records of associated clinics, anesthesia protocols and intensive care unit records.

Statistical Analysis

Statistical analysis was performed with IBM® SPSS® Statistics, version 23 (IBM Corp., Armonk, NY, USA) and Microsoft® Excel® version 14.4.1 (Microsoft Corp, Redmond, WA, USA). Figures were created using Prism 7 software (GraphPad Software Inc., San Diego, CA, USA). Univariate logistic regression was used to determine, whether the number of infections was correlated to the cumulative number of operations performed in the new ioMRI setting. Significance was defined as $p<0.05$.

Results

Patient cohorts and operative statistics

Patient characteristics are listed in Table 1. The average age of the craniotomy group is considerably lower than in the transsphenoidal group (40 (21, 57) vs. 46 (33, 63.75) years median age and quartiles) due to the high proportion of pediatric patients in this cohort (22%). The majority of the procedures were first-time operations (83% of the transsphenoidal procedures, 58% of the craniotomies). Craniotomies were performed for revascularization (10%) and resection of tumors (glioma in 72% of all craniotomies). The most frequent pathology requiring transsphenoidal surgery was pituitary adenoma (83%). The remaining pathologies included craniopharyngioma, mesenchymal tumors and meningioma. Median duration of the craniotomies reported in this study (including time for ioMRI and transfer) was 340 minutes with 94 (86%) procedures exceeding 4 hours. The median duration of transsphenoidal skull base surgeries reported in this study (including time for ioMRI and transfer) was 200 minutes with 25 (29%) operations exceeding the operating time of 4 hours.

Surgical site infections

Complications that occurred in both operative groups are listed in Tables 2 and 3. SSIs were observed in six craniotomies (5.5% 95%-Confidence interval [CI]: 1.2%, 9.8%), of which five (5%) classified as deep incisional/organ-space SSIs (Table 2). These include two cases of bone flap osteitis (2%), two cases of meningitis-ventriculitis (2%) and one epidural abscess (1%). CSF fistula occurred in one case (1%). Infection-related wound revision surgery was necessary in four cases (4%). The revision surgery included bone flap removal and subsequent cranioplasty in three patients, whereas one patient had repeated superficial wound revisions, a VP-shunt placement and dural reconstruction. All patients with an SSI received antibiotic treatment. The most frequent cultures were *Staphylococcus aureus* (three cases, 50%) and *Citrobacter koseri* (two cases, 33%). Other identified pathogens included *Acinetobacter* and *Pseudomonas aeruginosa* (Table 4). Mean operative time of craniotomies that were followed by an SSI (including time for ioMRI and transfer) was 360 minutes and five of these procedures lasted longer than four hours (Table 4). No craniotomy patient with an SSI had recent neurosurgery within 30 days prior to the operation.

Six cases of SSI (7.0% 95%-CI: 1.5%, 12.4%) occurred in the transsphenoidal group (Table 3). Two patients (2%) had intranasal infections without direct connection to the CNS (one septum abscess and one bacterial rhinosinusitis) and four patients (5%) had meningitis coinciding a CSF leak. Overall, CSF leaks after transsphenoidal surgery was observed in nine cases (10%). Five patients (6%) with infections required revision surgery (four CSF leak closures and one intranasal abscess drainage). All patients with an infection received antibiotic treatment. Pathogens were identified in four patients, of which three (50%) had *Staphylococcus aureus* (Table 4). Other pathogens included *Citrobacter freudii, Pseudomonas aeruginosa, Staphylococcus epidermidis* and *Finegoldia magna*. Mean operative time of the transsphenoidal surgeries that were followed by an infection (including time for ioMRI and transfer) was 243 minutes, while only one of these lasted longer than four hours (Table 4). No patient of this group with an infection had recent neurosurgery within 30 days prior to the operation.

Considering all operations of both types, logistic regression showed that the likelihood of SSIs was significantly negatively associated with the accumulative number of operations performed in this new setting (odds ratio: 0.982; 95%-CI: 0.969-0.995, p=0.008).

Discussion

Incidence of SSIs in neurosurgical operations with shared-resource ioMRI is within normal range

In this study, we have evaluated the incidence of postoperative infections in neurosurgical procedures that involved a shared-resource ioMRI.

During the study period, we performed 109 craniotomies and 86 transsphenoidal skull-base surgeries with involvement of a shared-resource ioMRI and observed six cases of SSI (5.5%) among craniotomy patients and six cases of postoperative infection among patients that underwent transsphenoidal surgery (7.0%), although only four of the infections in the transsphenoidal group affected the CNS (5%). All patients with meningitis after transsphenoidal skull base surgery had a CSF leak, received a lumbar drain and required endoscopic repair of the CSF leak. Furthermore, four craniotomy patients (4%) needed to have at least one unplanned reoperation for infection-related wound revision and three of these patients (3%) needed an extensive revision surgery with bone flap removal (Tables 2 and 4).

Previous studies without specific inclusion of intraoperative MRI reported SSI rates after craniotomy that vary between 1% and 8% with CNS infection rates after transsphenoidal surgery varying between 1.6% and 10%.[19,22-35] A study on complications in glioma surgery with use of a one-room ioMRI operating suite recently reported a 1.4% incidence of SSIs. Furthermore, others have reported rates of infection-related reoperations after craniotomy that vary between <1% and 4%.[26, 27, 36]

Both operative groups in our study have an SSI rate that is within the upper half of the range mentioned above. Also, our infection-related reoperation rate after craniotomy is in the upper range of rates described in previous reports.

Pathogens similar to infections without ioMRI

The most frequent pathogen identified in this series of postoperative infections was *Staphylococcus aureus* (50% of the pathogens in both groups). *Staphylococcus aureus* is associated with the flora of the skin as well as the nasopharynx and has been previously identified as the most frequent bacterial pathogen in craniotomy and endoscopic skull base surgery.[12,24,28,29,31,36] Gram-negative bacilli associated with nosocomial infections (*Acinetobacter*, *Citerobacter*, *Pseudomonas aeruginosa*) were found in 42% of the infections. This is above the 35% found in a study on meningitis after craniotomy and lower than the percentage of gram-negative bacilli observed in a study focusing on meningitis after endoscopic endonasal surgery.[31,37]

Adaptation to new operative protocol and operative complexity contributed to infection rate

It is possible that a selection bias contributed to the marginally higher infection and reoperation rates in the craniotomy group. The scanner was predominantly used in complex cases that are longer in duration and thus more prone to perioperative infections. In fact, 86% of all craniotomies (and five out of the six procedures that were followed by an SSI) lasted longer than four hours, which has been identified as a risk factor for infections in craniotomy patients.[19]

Furthermore, it is noteworthy that almost all infections occurred in the first half of consecutive operations in this study (Figure 2). Among the 109 craniotomies, five infections occurred in the first 55 operations and one infection in the following 54 operations. Similarly among the transsphenoidal surgeries, all six infections occurred in the first 43 operations and no infection occurred in the successive 43 operations (Table 4). This observation is supported by the result of the logistic regression analysis, which shows that the likelihood of infection significantly decreases with the cumulative number of operations performed in the new setting. Since the two-room ioMRI suite began operating at the same time as the study period, we attribute a part of these early infections to the novelty of the operative setting. The surgeons and the OR staff needed to adapt to a new operative protocol and new hygiene standards of the non-sterile environment. The decreasing number of infections throughout the study period indicates that a learning curve effect has occurred and underlines the importance of extensive surgical staff training when such a new operative setting is introduced. Although we observed relatively high overall infection and reoperation rates, it is encouraging that the infection rates throughout the study period decreased and we anticipate them to approach and remain at around 1-2%.

Limitations

This is a preliminary report and we will continue to prospectively collect further data. A limitation of this study is that the analysis was not adjusted for patient-related factors, such as age and preoperative chemotherapy or steroid use, that have been associated with increased SSI risk in neurosurgery.[23, 29] Also, our results cannot be generalized to all centers since this is a single-center study. As such, the study is insufficiently powered to provide a conclusive answer for higher SSI risk in ioMRI settings. Adequately powered analysis would require a prospective multi-center collaboration.

Conclusion

Despite transportation into a non-sterile environment and prolonged operation time, the use of a two-room ioMRI in neurosurgical procedures did not demonstrate elevated infection rates compared to other studies. However, the incidence of postoperative infections in both study groups was initially higher than targeted. The likelihood of infection significantly decreased with the number of operations, underlining the importance of surgical staff training after the introduction of the novel operative setting.

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Figure and table legends

Figure 1. Two-room ioMRI operating suite (A) Floor plan of the operating suite. The suite is separated in two distinct areas, the OR-compartment (blue) and the radiology-compartment (green) that is accessible for outpatient examinations. The ioMRI-room (red) is accessible from both compartments.

(B) Transfer of the patient into the ioMRI. (Bi) A mobile MRI-table is pulled into the OR and docked to the OR-table. (Bii) The patient is transferred onto the MRI-table via a floating table top. (Biii) The patient is directed into the scanner on the mobile MRI-table.

Figure 2. Cumulative number of surgeries over time (grey) and number of SSIs at time of appearance (black). The considerably high infection incidence in the beginning and the subsequent decline demonstrate the learning curve effect that occurred in this new two room setting.

Table 1. Patient Characteristics

Table 2. Complications after craniotomy with two-room ioMRI

Table 3. Complications after transsphenoidal skull base surgery with two-room ioMRI

Table 4. Characteristics of the 12 cases with infections after neurosurgical procedure with two-room ioMRI