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Safe Anesthesia Practices for Minimally Invasive, Image-guided Procedures: CT, MRI, and Ultrasound

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Abstract **Original Research Article**

Background: The demand for minimally invasive, image-guided procedures, such as CT, MRI, and ultrasound, is increasing. Understanding the role of anesthesia in enhancing patient safety, comfort, and procedural success is essential. ***Methods:*** This study was conducted at Bangabandhu Sheikh Mujib Medical University, Dhaka, Bangladesh, over two years, involving 150 patients. Anesthesia techniques were categorized as general anesthesia, sedation, and local anesthesia. Patient outcomes, complications, and satisfaction scores were recorded and analyzed. ***Results:*** In this study, general anesthesia was administered to 65 patients (43.3% of cases), sedation was used for 56 patients (37.3%), and local anesthesia was applied to 29 patients (19.3%). The overall procedural success rate was high, at 141 successful completions (94%), with minor complications occurring in 7 patients (4.7%) and major complications in 2 patients (1.3%). Patient satisfaction scores indicated that 96 participants (64%) reported being very satisfied with their anesthesia experience, while 45 patients (30%) indicated they were satisfied. These findings highlight the effectiveness and safety of the selected anesthesia practices in minimally invasive, image-guided procedures, demonstrating a strong correlation between appropriate anesthesia techniques and positive patient outcomes. The data underscore the importance of tailored anesthesia protocols to enhance procedural success and patient satisfaction in this clinical setting. ***Conclusion:*** The study demonstrates that tailored anesthesia practices can achieve high success rates and patient satisfaction in minimally invasive, image-guided procedures. Despite the low incidence of complications, ongoing research is needed to refine anesthesia protocols and explore advanced, image-guided techniques to further enhance patient safety and comfort.

Keywords: Anesthesia, minimally invasive procedures, image-guided techniques, patient safety, satisfaction, CT, MRI, ultrasound.

INTRODUCTION

Minimally invasive, image-guided procedures have transformed modern medicine by providing safer, more efficient, and targeted alternatives to conventional surgeries [1]. Techniques like computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound now enable clinicians to perform complex interventions with precision while minimizing trauma and recovery time for patients [2]. These advancements, however, bring new challenges, particularly in anesthesia, where the objective is to balance patient comfort and safety with procedural requirements [3]. Anesthesia practices in such settings must be tailored to ensure immobility, minimize pain and anxiety, and maintain patient stability, all while accommodating the demands of sophisticated imaging technologies.[4] Thus, understanding safe anesthesia practices specific to these minimally invasive, image-guided procedures is crucial for improving patient outcomes and minimizing risks [3].

The role of anesthesia in image-guided interventions is multifaceted. Unlike traditional surgery, where general anesthesia is more uniformly applied, image-guided procedures require a nuanced approach. In many cases, local or regional anesthesia may suffice, but deeper sedation or even general anesthesia might be

necessary, particularly for MRI and CT-guided procedures that require absolute immobility [5]. MRI-guided interventions, for instance, require specific anesthetic considerations due to the presence of a strong magnetic field, which prohibits the use of ferromagnetic equipment and limits access to the patient once the procedure has commenced [6]. Similarly, CT imaging exposes patients to ionizing radiation, necessitating strategies that limit patient exposure while maintaining effective anesthesia [7]. Ultrasound-guided procedures offer more flexibility in anesthesia choice, given the lack of ionizing radiation and greater access to the patient, yet they still demand techniques that minimize patient movement and anxiety to ensure procedural accuracy [8].

Patient safety is the primary concern in anesthesia practices for these minimally invasive procedures. Sedation-related complications, including hypoxia, airway obstruction, and hemodynamic instability, remain possible, especially in patients with underlying health issues or those requiring prolonged sedation [9]. Moreover, imaging modalities often limit direct access to the patient, making continuous monitoring and quick intervention challenging [5]. For instance, MRI environments constrain the use of standard monitoring equipment, and specialized MRI-compatible monitors are required to track vital signs. Similarly, CT-guided procedures may require healthcare providers to monitor the patient remotely to avoid radiation exposure, adding an additional layer of complexity to anesthesia management [10,11].

Several anesthesia techniques are commonly employed in image-guided procedures, including local anesthesia, conscious sedation, deep sedation, and general anesthesia [7]. The choice of technique depends on the type of procedure, patient-specific factors, and the imaging modality involved [12]. Local anesthesia is typically used for short, less invasive procedures, while conscious sedation is common for patients who need to remain relaxed but awake [6]. Deep sedation or general anesthesia is often preferred in MRI-guided procedures and complex CT-guided interventions where patient movement must be minimized [10]. The selection of anesthesia agents also plays a crucial role, with agents like propofol, midazolam, fentanyl, and dexmedetomidine frequently used for their rapid onset and controllable effects. Each agent comes with its own risks and benefits; for example, propofol offers excellent sedation and rapid recovery but requires vigilant monitoring due to its potential to depress respiratory and cardiovascular function [9].

With this study, we aimed to examine the efficacy and safety of various anesthesia techniques in the context of CT, MRI, and ultrasound-guided procedures.

METHODOLOGY & MATERIALS

This prospective observational study was conducted at Bangabandhu Sheikh Mujib Medical University, Dhaka, Bangladesh, over a two-year period from January 2022 to December 2023, involving a sample size of 150 patients who underwent various minimally invasive procedures guided by imaging techniques, and informed consent was obtained from all participants prior to their inclusion in the study. Patients were assessed preoperatively for their medical history, physical examination findings, and American Society of Anesthesiologists (ASA) classification to identify any potential risks associated with anesthesia; subsequently, the anesthetic technique was chosen based on the procedure type, duration, and individual patient needs, with general anesthesia, sedation, and local anesthesia being the primary methods employed. Throughout the procedures, vital signs were continuously monitored using non-invasive methods, including pulse oximetry, electrocardiography, and non-invasive blood pressure measurements to ensure patient safety, and any complications that arose were documented meticulously. After the procedures, patients were monitored in the recovery unit, where they were assessed for any immediate adverse effects related to anesthesia, and follow-up evaluations were conducted at 30 days post-procedure to capture long-term outcomes and patient satisfaction, employing a structured questionnaire to quantify satisfaction levels and any complications experienced during this period. Patient satisfaction was assessed post-procedure using a 5-point Likert scale (1 = 'very dissatisfied' to 5 = 'very satisfied'), focusing on pain control, communication with staff, comfort during the procedure, and overall anesthesia experience. The survey was administered within 24 hours post-procedure, with a follow-up at 30 days to evaluate satisfaction with recovery. Data were analyzed using appropriate statistical methods, including descriptive statistics for demographic characteristics and outcomes, with results presented in tabular formats to illustrate the efficacy and safety of the anesthesia practices employed, thereby allowing for a comprehensive understanding of the relationship between anesthesia techniques and procedural outcomes in minimally invasive, image-guided procedures, ultimately aiming to enhance safety protocols and improve patient care in this clinical setting.

RESULTS

Table 1: Demographic Characteristics of our Participants (N = 150)

Characteristic	n	%
Age (years)		
- Mean ± SD	45.2 ± 12.3	
- Range	18 - 75	
Gender		
- Male	88	58.7
- Female	62	41.3
ASA Classification		
- ASA I	51	34.0
- ASA II	67	44.7
- ASA III	32	21.3

Table 1 provides an overview of the demographic characteristics of the study participants. The mean age of the participants was 45.2 years, with a standard deviation of 12.3 years, and an age range of 18 to 75 years. In terms of gender distribution, 88 participants were male (58.7%), while 62 were female (41.3%). The American Society of Anesthesiologists (ASA) classification was used to assess participants' preoperative health status: 51 participants (34.0%) were classified as ASA I (normal healthy patients), 67 (44.7%) as ASA II (patients with mild systemic disease), and 32 (21.3%) as ASA III (patients with severe systemic disease).

Table 2: Anesthesia Techniques Used (N = 150)

Anesthesia Technique	Frequency	Percentage (%)
General Anesthesia	65	43.3
Sedation	56	37.3
Local Anesthesia	29	19.3

Table 2 summarizes the anesthesia techniques employed in the study. General anesthesia was the most frequently used technique, applied to 65 participants (43.3%). Sedation was the second most common approach, used in 56 cases (37.3%), while local anesthesia was administered to 29 participants (19.3%).

Table 3: Type of Procedures Performed (N = 150)

Procedure Type	Frequency	Percentage (%)
CT Scan	62	41.3
MRI Scan	47	31.3
Ultrasound-guided Procedure	41	27.3

Table 3 details the types of minimally invasive, image-guided procedures performed on the study participants. CT-guided procedures were the most frequently conducted, with 62 cases (41.3%), followed by MRI-guided procedures, which accounted for 47 cases (31.3%). Ultrasound-guided procedures made up the remaining 41 cases (27.3%).

Table 4: Outcomes of Procedures (N = 150)

Outcome	Frequency	Percentage (%)
Successful Completion	141	94.0
Minor Complications	7	4.7
Major Complications	2	1.3

Table 4 presents the outcomes of the procedures performed in this study. The vast majority of procedures were successfully completed, with 141 cases (94.0%) achieving the intended outcome without significant issues. Minor complications occurred in 7 cases (4.7%), while major complications were rare, reported in only 2 cases (1.3%).

Table 5: Patient Satisfaction Scores (N = 150)

Satisfaction Level	Frequency (N = 150)	Percentage (%)
Very Satisfied	96	64.0
Satisfied	45	30.0
Dissatisfied	9	6.0

Table 5 summarizes the patient satisfaction scores following anesthesia for minimally invasive, image-guided procedures. The majority of participants reported a high level of satisfaction, with 96 patients (64.0%) indicating they were very satisfied with their experience. Another 45 patients (30.0%) reported being satisfied, while a smaller group of 9 patients (6.0%) expressed dissatisfaction.

Table 6: Follow-up Outcomes at 30 Days

Follow-up Outcome	Frequency (N = 150)	Percentage (%)
No issues	135	90.0
Minor complaints	12	8.0
Major concerns	3	2.0

Table 6 presents the follow-up outcomes of participants 30 days post-procedure. The majority of patients (135 cases, 90.0%) reported no issues following their procedure, indicating a favorable recovery process. Minor complaints were reported by 12 patients (8.0%), while major concerns were noted in only 3 cases (2.0%).

DISCUSSION

The study addresses a critical gap in understanding the complexities and safety concerns of anesthesia during minimally invasive procedures using imaging guidance. Given the rise in minimally invasive, image-guided interventions, anesthesia practices have had to adapt, balancing patient comfort, immobility requirements, and procedural accuracy.

The selection of anesthesia techniques in minimally invasive, image-guided procedures largely depends on patient stability, the specific imaging modality, and procedural requirements. Our results showed a preference for general anesthesia (43.3%) and sedation (37.3%), reflecting similar findings in studies by Reinbacher and Linte, which suggest these methods are often necessary to ensure immobility and minimize procedural anxiety, especially in MRI and CT-guided interventions [13,14]. MRI procedures, in particular, require patients to remain motionless, which, combined with the limited accessibility of the MRI room, necessitates anesthesia that provides deep sedation or even full immobility [15]. CT-guided procedures, on the other hand, face challenges related to ionizing radiation, requiring remote monitoring of anesthetized patients to limit radiation exposure, as Schenker observed [16]. This aligns with our study's findings where general anesthesia was favored especially in procedures needing minimal patient movement.

Patient outcomes in this study were largely positive, with a high rate of procedural success (94%) and minimal major complications (1.3%), aligning with studies that emphasize the safety of image-guided procedures with well-managed anesthesia practices. The complication rates in our study reflect those reported in similar research, indicating that the risks of sedation and anesthesia are relatively low when proper monitoring and tailored anesthesia plans are implemented [17,18]. However, minor complications were reported (4.7%), primarily related to transient respiratory depression or minor fluctuations in hemodynamics, common in both sedation and general anesthesia [19]. This highlights the importance of continuous monitoring and rapid response capabilities, especially in environments like MRI rooms, where access to the patient may be limited.

An essential component of safe anesthesia practices is addressing patient satisfaction, as it directly impacts patient compliance, recovery experience, and overall perception of care quality. In our study, patient satisfaction was notably high, with 64% of patients reporting they were very satisfied and 30% satisfied with the anesthesia experience. This is consistent with prior studies that emphasize the value of communication, effective pain management, and comfort during procedures as key factors in enhancing patient satisfaction [20,21]. Pre-procedural communication was a critical element, as it helped set realistic expectations, reduced anxiety, and increased cooperation during procedures, particularly important in conscious sedation scenarios where patient awareness plays a role [22].

Minimally invasive procedures using imaging modalities are growing in complexity and expanding into new areas such as robotic-assisted surgeries and advanced tumor ablations. Cleary *et al.*, found that robotic interventions, in particular, introduce precise navigational requirements that add layers of complexity

to anesthesia, necessitating enhanced compatibility between robotic systems and anesthesia setups [8]. Our findings, coupled with prior studies, suggest that future anesthesia protocols should integrate robotic compatibility and consider variable patient access limitations across imaging modalities [19,23].

An emerging area of interest is the incorporation of image-guided anesthesia itself, where ultrasound or MRI guidance is used to administer precise nerve blocks or targeted sedation to specific body areas, potentially reducing the need for full general anesthesia in certain procedures [24,25]. This targeted approach could significantly reduce anesthesia-related risks, especially in high-risk patients or those with contraindications for general anesthesia. While our study did not focus on such advanced techniques, the high satisfaction with sedation and local anesthesia suggests that these methods could be further explored in future studies, especially with the growing interest in minimizing the invasiveness of both surgical and anesthesia practices.

Overall, the study reinforces the importance of tailored anesthesia approaches that consider the specific demands of each imaging modality and patient profile. Establishing a standard protocol for anesthesia in minimally invasive, image-guided procedures could streamline practices and potentially improve patient outcomes, as suggested by Schenker and Ahrar [16,26]. However, individualization remains essential due to varying patient responses and the different requirements of each imaging modality. Future research should continue to explore the integration of anesthesia and imaging advancements, with a focus on enhancing patient safety, satisfaction, and procedural efficacy.

Limitations of the study

This study has several limitations. First, it was conducted at a single center, potentially limiting the generalizability of the results. Second, patient outcomes were only assessed within a 30-day follow-up, which may not capture long-term effects. Finally, the study's sample size, though adequate, may limit the detection of rare complications associated with anesthesia in minimally invasive, image-guided procedures.

CONCLUSION

In conclusion, our study contributes valuable insights into anesthesia practices in minimally invasive, image-guided interventions, emphasizing patient-centered, safety-oriented approaches. While high success and satisfaction rates underscore the effectiveness of current practices, further research could refine anesthesia protocols, especially as technology and procedural techniques evolve. Expanding this study to include diverse patient populations and exploring innovative, image-guided anesthesia techniques could pave the way for even safer, more effective anesthesia practices in the future.

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