JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Comparative Effectiveness of Sedation and Analgesic Protocols in Image-Guided Interventional Radiology Procedures: A Systematic Review

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Abstract :

Background

Image-guided interventional radiology (IR) has become an important part of modern healthcare because it allows many diseases to be treated through small skin punctures instead of open surgery. These procedures are usually less painful than surgery, but many patients still experience anxiety, discomfort, or pain during treatment. Sedation and analgesia help patients remain comfortable and allow the radiologist to perform the procedure safely. Several drugs are commonly used for this purpose, including Midazolam, Propofol, Dexmedetomidine, and Fentanyl. Each drug has its own advantages and limitations.

Objective

This review aims to compare the effectiveness and safety of commonly used sedative and analgesic drugs during image-guided interventional radiology procedures. The review focuses on pain control, recovery time, patient satisfaction, procedure duration, and complications.

Methods

A systematic review was planned following the PRISMA 2020 guidelines. Electronic databases including PubMed, Scopus, Web of Science, Embase, and the Cochrane Library were searched for relevant studies published in English. Studies comparing Midazolam, Propofol, Dexmedetomidine, and Fentanyl during image-guided interventional procedures were considered. Data on patient outcomes, procedural success, recovery, and adverse events were extracted and reviewed.

Results

The available evidence suggests that no single drug is ideal for every patient or procedure. Propofol generally provides rapid onset and faster recovery, making it suitable for short procedures. Dexmedetomidine offers good patient comfort with stable breathing and better cooperation during longer procedures. Midazolam remains a reliable option for reducing anxiety, especially when combined with an opioid. Fentanyl provides effective pain relief but requires careful monitoring because of the risk of respiratory depression. The choice of medication depends on the patient's condition, the type of procedure, and the level of sedation required.

Conclusion

Careful selection of sedation and analgesic protocols can improve patient comfort, shorten recovery time, and reduce complications during image-guided interventional radiology procedures. More well-designed clinical trials are needed to develop standardized sedation protocols for different interventional procedures.

Index Terms **- Interventional Radiology, Procedural Sedation, Midazolam, Propofol, Dexmedetomidine, Fentanyl, Pain Management, Image-Guided Procedures, Patient Safety, Systematic Review**

I. INTRODUCTION

Interventional radiology has changed the way many medical conditions are diagnosed and treated. Instead of performing large surgical operations, many diseases can now be managed using small catheters or needles that are guided by imaging techniques such as fluoroscopy, ultrasound, computed tomography (CT), and magnetic resonance imaging (MRI). These procedures are less invasive, cause less tissue damage, reduce blood loss, shorten hospital stay, and allow patients to recover more quickly than conventional surgery. Because of these advantages, image-guided interventions are now widely used in many areas of medicine, including oncology, vascular disease, hepatology, nephrology, pain management, and emergency care.

Although interventional radiology procedures are considered minimally invasive, they are not always painless. Many patients experience anxiety before the procedure and discomfort during needle insertion, catheter manipulation, or tissue ablation. Some

procedures are completed within a few minutes, while others may last for more than one hour. During these procedures, patients are usually required to remain still to ensure accurate placement of instruments and to reduce the risk of complications. Even small movements can affect image quality or increase the chance of procedural failure. For this reason, sedation and pain management are important parts of patient care in the interventional radiology suite.

The main purpose of procedural sedation is to reduce anxiety, provide comfort, and improve patient cooperation without causing complete loss of consciousness. An ideal sedative should work quickly, provide adequate comfort, maintain stable blood pressure and breathing, and allow the patient to recover soon after the procedure. At the same time, the medication should have minimal side effects and should not interfere with the success of the procedure. Since no single drug can achieve all these goals in every patient, different sedative and analgesic medications are selected according to the type of procedure and the patient's clinical condition.

Midazolam is one of the most commonly used sedative drugs in interventional radiology. It belongs to the benzodiazepine group and is widely used because it reduces anxiety, produces relaxation, and causes short-term memory loss. Many patients who receive Midazolam remember very little about the procedure, which can improve their overall experience. However, Midazolam may delay recovery in some patients, especially when higher doses are required.

Propofol is another commonly used sedative because it has a rapid onset of action and patients usually recover quickly after the procedure. These characteristics make it suitable for day-care procedures where early discharge is important. However, Propofol can cause low blood pressure and respiratory depression if it is not carefully monitored. Therefore, trained personnel and continuous monitoring are required whenever Propofol is used.

Dexmedetomidine has become increasingly popular during the last decade because it provides sedation while allowing patients to continue breathing normally. Patients receiving Dexmedetomidine often remain calm and cooperative, making it useful for procedures that require communication between the patient and the operator. Some studies have also reported lower pain scores and higher patient satisfaction with Dexmedetomidine. However, this drug may cause slow heart rate and low blood pressure in some patients, particularly when administered rapidly.

Unlike the previous three drugs, Fentanyl is primarily used as an analgesic rather than a sedative. It is a powerful opioid that provides rapid pain relief and is frequently combined with Midazolam or Propofol to improve patient comfort. Although Fentanyl is highly effective for controlling procedural pain, excessive doses may increase the risk of respiratory depression and oxygen desaturation. Careful dose adjustment and patient monitoring are therefore essential.

Over the past several years, many clinical studies have compared these medications in different interventional radiology procedures such as angiography, embolization, image-guided biopsy, drainage procedures, tumour ablation, and vascular interventions. While some studies suggest that Propofol offers faster recovery, others report that Dexmedetomidine provides better patient comfort and more stable cardiovascular parameters. Midazolam remains a popular choice because of its familiarity, low cost, and effectiveness, whereas Fentanyl continues to play an important role in procedural pain management. However, the findings are not always consistent because different studies include different patient populations, procedures, drug doses, and outcome measures.

A systematic review is useful because it brings together the available evidence and allows healthcare professionals to better understand the advantages and limitations of each medication. Comparing these drugs can help clinicians choose the most appropriate sedation protocol based on the patient's age, medical condition, procedure type, and expected recovery time. Improved sedation practices can enhance patient safety, increase procedural success, reduce complications, and improve the overall experience for both patients and healthcare providers.

The aim of this systematic review is to compare Midazolam, Propofol, Dexmedetomidine, and Fentanyl used during image-guided interventional radiology procedures. The review focuses on important clinical outcomes, including pain control, recovery time, patient satisfaction, procedure duration, and procedure-related complications. It also discusses current challenges and future directions that may help improve sedation practices in interventional radiology.

II. Aim and Objectives

Aim

The aim of this systematic review was to compare the effectiveness and safety of commonly used sedation and analgesic drugs Midazolam, Propofol, Dexmedetomidine, and Fentanyl during image-guided interventional radiology procedures. The review also aimed to identify the most suitable sedation protocol for improving patient comfort, procedural success, and overall clinical outcomes.

Objectives

1. To compare the effectiveness of Midazolam, Propofol, Dexmedetomidine, and Fentanyl in providing sedation and pain relief during image-guided interventional radiology procedures.
2. To identify the advantages and limitations of each sedation protocol based on the available clinical evidence.
3. To identify gaps in the existing literature and suggest future research directions for improving sedation practices in image-guided interventions.

III. Materials and Methods

Study Design

This systematic review was carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines. The review was planned to collect and summarize the available evidence on the use of Midazolam, Propofol, Dexmedetomidine, and Fentanyl for sedation and pain management during image-guided interventional radiology procedures. The main purpose was to compare the effectiveness and safety of these drugs based on patient outcomes reported in published studies.

Research Question

The review was based on the following research question:
Among patients undergoing image-guided interventional radiology procedures, which sedation or analgesic drug provides better pain control, faster recovery, greater patient satisfaction, shorter procedure duration, and fewer complications?
The research question was developed using the PICO framework.

PICO Component	Description
Population (P)	Adult patients undergoing image-guided interventional radiology procedures
Intervention (I)	Midazolam, Propofol, Dexmedetomidine, or Fentanyl used for procedural sedation or analgesia
Comparison (C)	Comparison between one or more sedative or analgesic drugs
Outcomes (O)	Pain control, recovery time, patient satisfaction, procedure duration, and complications

Search Strategy

A systematic search of the published literature was performed using the following electronic databases:

- PubMed
- Scopus
- Web of Science
- Embase
- Cochrane Library

Only studies published in English were considered. The search included articles published from January 2010 to December 2025.
Additional studies were identified by checking the reference lists of relevant review articles and clinical trials.
The search strategy combined Medical Subject Headings (MeSH) and free-text keywords.

Example search strategy

("Interventional Radiology" OR "Image-Guided Procedure" OR "Image-Guided Intervention")
AND
("Midazolam" OR "Propofol" OR "Dexmedetomidine" OR "Fentanyl")
AND
("Sedation" OR "Analgesia" OR "Procedural Sedation")
AND
("Pain" OR "Recovery" OR "Patient Satisfaction" OR "Complications")
The search strategy was slightly modified for each database according to its indexing system.

Eligibility Criteria

Inclusion Criteria

Studies were included if they met the following conditions:

- Adult patients (18 years or older).
- Image-guided interventional radiology procedures.
- Use of Midazolam, Propofol, Dexmedetomidine, or Fentanyl.
- Randomized controlled trials, prospective studies, retrospective cohort studies, or comparative observational studies.
- Reported at least one of the following outcomes:
    - Pain control
    - Recovery time
    - Patient satisfaction
    - Procedure duration
    - Drug-related complications
- Published in peer-reviewed journals.
- Full-text articles available in English.

Exclusion Criteria

The following studies were excluded:

- Case reports or case series with fewer than 10 patients.
- Editorials, letters, conference abstracts, and review articles.
- Animal or laboratory studies.
- Pediatric studies.
- Studies without clear sedation protocols.
- Studies with insufficient outcome data.

Study Selection

All records identified during the database search were imported into reference management software, and duplicate articles were removed.
Two independent reviewers screened the titles and abstracts of all retrieved studies. Full-text articles were obtained for studies that appeared relevant.
The reviewers independently assessed the full-text articles according to the inclusion and exclusion criteria. Any disagreement between the reviewers was resolved through discussion. When agreement could not be reached, a third reviewer made the final decision.

Data Extraction

Data from the included studies were collected using a standardized data extraction form.
The following information was recorded:

- First author
- Year of publication
- Country
- Study design
- Number of participants
- Patient age
- Type of interventional radiology procedure
- Sedation or analgesic drug used
- Drug dosage
- Procedure duration
- Pain score
- Recovery time
- Patient satisfaction
- Adverse events
- Main conclusions

Two reviewers independently extracted the data to reduce errors and improve accuracy.

Outcome Measures
The review focused on five major clinical outcomes.

Primary Outcomes

- Pain control
- Recovery time

- Patient satisfaction

Secondary Outcomes

- Procedure duration
- Sedation quality
- Hemodynamic stability
- Respiratory complications
- Oxygen desaturation
- Hypotension
- Bradycardia
- Need for additional sedation
- Procedure success rate

Quality Assessment

The methodological quality of the included studies was evaluated independently by two reviewers. Different assessment tools were used depending on the study design.

Study Design	Quality Assessment Tool
Randomized controlled trials	Cochrane Risk of Bias Tool (RoB 2)
Observational studies	Newcastle–Ottawa Scale (NOS)

The following domains were evaluated:

- Randomization process
- Allocation concealment
- Blinding
- Missing outcome data
- Outcome measurement
- Selective reporting
- Overall study quality

Each study was classified as:

- Low risk of bias
- Some concerns
- High risk of bias

Data Synthesis

The findings from the included studies were summarized in descriptive tables.
Studies with similar interventions and outcome measures were grouped together for comparison.
The results were organized according to:

- Midazolam
- Propofol
- Dexmedetomidine
- Fentanyl

Clinical outcomes such as pain control, recovery time, patient satisfaction, procedure duration, and complications were compared across studies.
Whenever numerical data were sufficiently similar, the results were intended to be combined through meta-analysis. If statistical pooling was not appropriate because of differences in study design, patient population, or outcome measurement, a narrative synthesis was performed.

Statistical Analysis

For studies included in the meta-analysis, statistical analysis was planned using Review Manager (RevMan) version 5.4.
Continuous outcomes such as pain scores and recovery time were summarized using the mean difference (MD) or standardized mean difference (SMD) with 95% confidence intervals (CI).
For categorical outcomes such as complications and adverse events, risk ratios (RR) with 95% confidence intervals were calculated.
Statistical heterogeneity among studies was assessed using the I^2 statistic.
The level of heterogeneity was interpreted as:

- 0–25%: Low heterogeneity
- 26–50%: Moderate heterogeneity
- 51–75%: Substantial heterogeneity
- More than 75%: Considerable heterogeneity

A random-effects model was planned when heterogeneity was high, while a fixed-effect model was used when heterogeneity was low.
A p-value of less than 0.05 was considered statistically significant.

Advantages and Disadvantages of Common Sedation and Analgesic Drugs
The choice of sedative or analgesic drug in interventional radiology depends on the patient's condition, the type of procedure, and the expected duration of the intervention. Each drug has its own strengths and limitations. Understanding these differences helps healthcare professionals select the most appropriate medication for safe and effective patient care.

Drug	Advantages	Disadvantages
Midazolam	Effective anxiolytic, produces amnesia, easy to administer, widely available, relatively inexpensive	Slower recovery than Propofol, respiratory depression when combined with opioids, prolonged sedation in elderly patients
Propofol	Rapid onset, quick recovery, high patient satisfaction, suitable for short procedures	Can cause hypotension, respiratory depression, requires continuous monitoring and trained personnel
Dexmedetomidine	Good patient cooperation, minimal respiratory depression, stable sedation, useful for long procedures	Bradycardia, hypotension, slower onset than Propofol, relatively expensive
Fentanyl	Strong pain relief, rapid action, useful when combined with sedatives, effective during painful procedures	Respiratory depression, nausea, vomiting, chest wall rigidity with high doses, risk of opioid-related side effects

Table 1. Advantages and Disadvantages of Common Sedation and Analgesic Drugs

Overall, Propofol is preferred when rapid recovery is important, while Dexmedetomidine is useful for longer procedures where patient cooperation is required. Midazolam remains a reliable option for reducing anxiety, and Fentanyl continues to be one of the most effective drugs for procedural pain relief when used carefully.

Clinical Implications
The findings of this review have several practical applications for interventional radiology practice. Choosing the correct sedation protocol can improve patient comfort, increase procedural success, and reduce complications.
Propofol may be the preferred choice for short outpatient procedures because patients usually recover quickly and can be discharged earlier. Dexmedetomidine may be more suitable for longer procedures where patient cooperation is important because it provides stable sedation while maintaining spontaneous breathing. Midazolam remains useful for reducing anxiety and is often selected for routine procedures because it is familiar to most healthcare professionals. Fentanyl should continue to be used primarily for pain control, especially during procedures that involve tissue puncture or ablation, but careful monitoring is necessary because of its effects on respiration.
Individual patient factors such as age, body weight, medical history, cardiovascular disease, respiratory disease, and previous reactions to sedative drugs should always be considered before selecting a sedation protocol. Continuous monitoring of oxygen saturation, heart rate, blood pressure, and respiratory rate is essential throughout the procedure.

Future Perspectives
Sedation practices in interventional radiology continue to improve as new medicines, monitoring systems, and imaging technologies become available. Future research should focus on developing standardized sedation guidelines that can be used for different types of interventional procedures.
Artificial intelligence may help clinicians choose the most appropriate sedation protocol by analyzing patient characteristics and predicting the risk of complications. Machine learning models may also assist in adjusting drug doses according to the patient's response during the procedure.

Future clinical trials should compare different combinations of sedative and analgesic drugs using larger patient populations and standardized outcome measures. More studies are also needed in elderly patients, critically ill patients, and those with multiple medical conditions because these groups may respond differently to sedation.

The development of newer sedative agents with rapid recovery, fewer cardiovascular effects, and minimal respiratory depression may further improve patient safety. In addition, advanced patient monitoring systems and automated drug delivery devices may reduce medication errors and improve procedural outcomes.

Conclusion

Sedation and pain management are essential parts of image-guided interventional radiology procedures. Appropriate use of sedative and analgesic drugs helps reduce patient anxiety, improve comfort, increase cooperation, and support successful completion of the procedure.

This review compared four commonly used medications: Midazolam, Propofol, Dexmedetomidine, and Fentanyl. Each drug offers specific advantages and has certain limitations. Midazolam is effective for reducing anxiety and producing amnesia but may delay recovery in some patients. Propofol provides rapid onset and fast recovery, making it suitable for short procedures, although careful monitoring is required because of its effects on blood pressure and breathing. Dexmedetomidine offers stable sedation with minimal respiratory depression and good patient cooperation but may cause bradycardia and hypotension. Fentanyl remains one of the most effective drugs for procedural pain relief but should be used cautiously because of its potential to cause respiratory depression.

The current evidence suggests that no single medication is ideal for every patient or every procedure. The choice of sedation should be individualized based on the patient's clinical condition, the type of intervention, procedure duration, and the experience of the healthcare team.

Further high-quality randomized controlled trials with larger sample sizes and standardized outcome measures are needed to identify the most effective and safest sedation protocols for different interventional radiology procedures. Continued research and improvements in sedation practice will help enhance patient safety, clinical outcomes, and the overall quality of interventional radiology services.

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