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Advances in minimally invasive techniques in pediatric orthopedics: Percutaneous spine fracture fixation

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Abstract

Background: Pediatric orthopedic injuries, including spine fractures, present unique challenges due to the growing and developing nature of the pediatric skeletal system. Traditional surgical approaches often involve extensive tissue disruption and potential complications, particularly in pediatric patients. Minimally invasive techniques have emerged as promising alternatives, offering potential benefits such as reduced morbidity and improved functional outcomes.

Aim: This research aims to investigate the recent advancements in minimally invasive techniques within pediatric orthopedics, focusing specifically on percutaneous spine fracture fixation. The study seeks to evaluate the efficacy, safety, and long-term outcomes of percutaneous techniques in pediatric patients and to explore emerging technologies and procedural refinements in this field.

Methods: A comprehensive literature review was conducted to identify relevant studies, clinical trials, and case reports related to percutaneous spine fracture fixation in pediatric orthopedics. Electronic databases including PubMed, MEDLINE, and Google Scholar were searched using appropriate keywords and MeSH terms. Articles published within the past decade were included, with a focus on studies reporting outcomes of minimally invasive techniques in pediatric patients.

Results: The review identified a growing body of evidence supporting the efficacy and safety of percutaneous spine fracture fixation in pediatric patients. Studies consistently reported favorable outcomes, including reduced operative time, decreased blood loss, and shorter hospital stays compared to traditional surgical approaches. Additionally, emerging technologies such as navigational guidance and intraoperative imaging have contributed to improved accuracy and precision in percutaneous procedures.

Conclusion: Minimally invasive techniques, particularly percutaneous spine fracture fixation, represent significant advancements in pediatric orthopedics. These techniques offer several advantages over traditional surgical approaches, including reduced tissue trauma, shorter hospital stays, and faster recovery times. However, further research is needed to optimize these techniques, refine patient selection criteria, and elucidate long-term outcomes. Collaborative efforts between clinicians, researchers, and industry stakeholders are essential to drive innovation and improve the efficacy and safety of minimally invasive procedures in pediatric orthopedics.

Keywords: Pediatric orthopedics, minimally invasive techniques, percutaneous spine fracture fixation, pediatric spine fractures, minimally invasive surgery

Introduction

Pediatric orthopedic injuries, particularly those involving the spine, pose a unique set of challenges due to the dynamic nature of the growing and developing pediatric skeletal system. Spine fractures in children can occur as a result of various traumatic events, ranging from falls during play to sports-related injuries and motor vehicle accidents. Managing these fractures necessitates a nuanced approach that considers factors such as the child's age, skeletal maturity, injury severity, and any associated neurological deficits. Traditionally, surgical intervention for spine fractures in pediatric patients often involves open procedures that entail significant tissue dissection, disruption of growth plates, and implantation of hardware. However, these conventional approaches carry inherent risks, including infection, deformity, and impaired growth, which can significantly impact the long-term outcomes and quality of life for pediatric patients. (Bailey & Puryear, 2020) ^[1].

In recent years, there has been a notable shift within the field of pediatric orthopedics towards the adoption of minimally invasive techniques. This shift has been propelled by advancements in surgical technology, instrumentation, and a growing recognition of the importance of minimizing surgical trauma while optimizing patient outcomes.

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Minimally invasive procedures aim to achieve therapeutic goals comparable to traditional open surgery while mitigating tissue trauma, preserving anatomical integrity, and expediting postoperative recovery. Among the array of minimally invasive approaches gaining prominence, percutaneous spine fracture fixation stands out as a promising method for addressing spinal injuries in pediatric patients. (Dou *et al.*, 2021) ^[4].

Percutaneous spine fracture fixation involves the insertion of screws, rods, or other fixation devices through small incisions in the skin, guided by fluoroscopy or intraoperative imaging. This approach offers several potential advantages over traditional open surgery. Firstly, it is associated with reduced blood loss, as well as shorter operative times, which can be particularly beneficial in pediatric patients who may have limited tolerance for prolonged anesthesia. Additionally, percutaneous techniques minimize disruption to the soft tissues surrounding the spine, thereby lowering the risk of complications such as wound infection, muscle damage, and neurovascular injury. Furthermore, the minimally invasive nature of percutaneous procedures often translates to less postoperative pain and faster recovery, allowing pediatric patients to return to their daily activities sooner. (Krafft *et al.*, 2021) ^[2].

However, while percutaneous spine fracture fixation holds promise, its application in pediatric orthopedics is not without challenges. Pediatric spinal anatomy differs from that of adults in terms of size, shape, and development, necessitating specialized instrumentation and techniques tailored to the unique needs of pediatric patients. Moreover, the long-term effects of percutaneous instrumentation on spinal growth and development remain a topic of ongoing investigation, underscoring the importance of comprehensive research in this area to inform clinical practice and optimize patient outcomes. (Pientka & Cheng, 2020) ^[3].

Therefore, the aim of this research is to conduct a thorough review of the recent advancements in minimally invasive techniques within pediatric orthopedics, with a specific emphasis on percutaneous spine fracture fixation. By critically evaluating the efficacy, safety, and long-term outcomes of percutaneous techniques in pediatric patients, this study seeks to elucidate both the potential benefits and limitations of these approaches. Additionally, the research endeavors to explore emerging technologies and procedural refinements aimed at further enhancing the efficacy and safety of percutaneous spine fracture fixation in the pediatric population. (Liang *et al.*, 2024) ^[6].

In summary, the adoption of minimally invasive techniques, including percutaneous spine fracture fixation, represents a significant advancement in the field of pediatric orthopedics. These techniques offer the potential to improve patient outcomes, reduce surgical morbidity, and enhance overall quality of care for pediatric patients with spine fractures. Nonetheless, continued research efforts are imperative to refine these techniques, optimize patient selection criteria, and elucidate their long-term impact on spinal growth and development. By advancing our understanding of minimally invasive approaches in pediatric orthopedics, we can effectively address the unique needs of pediatric patients with spine fractures, ultimately improving their long-term health and well-being. (Shu *et al.*, 2022) ^[7].

Pediatric orthopedic injuries constitute a significant portion of musculoskeletal trauma in children and adolescents, often

resulting from falls, sports-related activities, or motor vehicle accidents. Among these injuries, spine fractures pose a particular concern due to the potential for long-term functional impairment and neurological sequelae. Traditional surgical approaches to manage pediatric spine fractures have historically involved open procedures, which may entail extensive tissue dissection and disruption of growth plates. However, these approaches are associated with inherent risks, including increased blood loss, postoperative pain, and prolonged recovery times, especially in the pediatric population where optimal growth and development are critical. (Liang *et al.*, 2024) ^[6].

The shift towards minimally invasive techniques in pediatric orthopedics reflects a broader trend in modern surgical practice towards reducing surgical morbidity and improving patient outcomes. Minimally invasive procedures offer several advantages over traditional open surgery, including smaller incisions, decreased blood loss, reduced postoperative pain, and faster recovery times. These benefits are particularly relevant in pediatric patients, where minimizing tissue trauma and preserving anatomical structures are paramount to promoting optimal growth and development. Percutaneous spine fracture fixation, as a subset of minimally invasive techniques, has emerged as an attractive option for managing pediatric spine fractures, offering the potential for improved outcomes while minimizing surgical morbidity. (Miladi *et al.*, 2018) ^[5].

The significance of percutaneous spine fracture fixation lies not only in its potential to enhance patient outcomes but also in its implications for healthcare resource utilization and overall healthcare economics. Minimally invasive techniques have been associated with shorter hospital stays, reduced postoperative complications, and lower healthcare costs compared to traditional open surgery. By reducing the burden on healthcare systems and improving the efficiency of care delivery, percutaneous spine fracture fixation holds promise for optimizing resource allocation and improving access to high-quality orthopedic care for pediatric patients. (Dou *et al.*, 2021) ^[4].

Reviewing the current literature on percutaneous spine fracture fixation in pediatric orthopedics reveals a growing body of evidence supporting its efficacy and safety. Studies have consistently reported favorable outcomes, including high rates of fracture union, low complication rates, and satisfactory functional outcomes. Furthermore, emerging technologies and procedural refinements have contributed to ongoing advancements in percutaneous techniques, offering opportunities for further improving surgical precision and patient outcomes. However, gaps in knowledge persist, particularly regarding the long-term effects of percutaneous instrumentation on spinal growth and development in pediatric patients, highlighting the need for continued research in this area. (Pientka & Cheng, 2020) ^[3].

In this research, we aim to provide a comprehensive review of the recent advancements in minimally invasive techniques within pediatric orthopedics, with a specific focus on percutaneous spine fracture fixation. Through a thorough evaluation of the existing literature, we seek to elucidate the efficacy, safety, and long-term outcomes of percutaneous techniques in pediatric patients. Additionally, we will explore emerging technologies and procedural refinements aimed at further enhancing the efficacy and safety of percutaneous spine fracture fixation. By synthesizing the current evidence and identifying areas for

future research, this study aims to inform clinical practice and contribute to the ongoing advancement of minimally invasive techniques in pediatric orthopedics. (Krafft *et al.*, 2021) [2].

Pediatric Orthopedic Injuries and Traditional Surgical Approaches

Pediatric orthopedic injuries, encompassing conditions such as spine fractures, are prevalent among children and adolescents, often arising from various activities like falls, sports-related incidents, or vehicular accidents. Historically, traditional surgical interventions have been the cornerstone of managing such injuries. These approaches typically involve open procedures, necessitating extensive tissue dissection and often leading to disruption of growth plates. The open nature of these surgeries also carries inherent risks, including increased blood loss, heightened postoperative pain levels, and extended recovery periods. These factors can be particularly challenging in the pediatric population, where optimal growth and development are critical considerations for long-term functional outcomes.

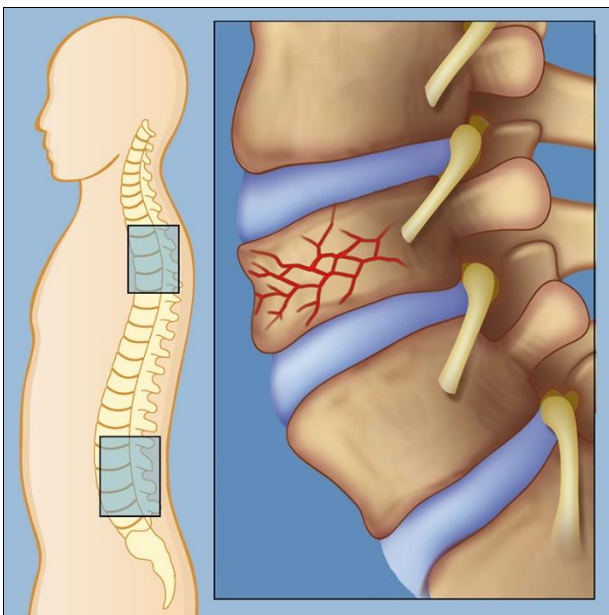


Fig 1: Spine Fracture

Advantages of Minimally Invasive Techniques in Pediatric Orthopedics

In response to the limitations of traditional open surgeries, minimally invasive techniques have gained traction in pediatric orthopedics. These techniques are designed to minimize surgical morbidity and enhance patient outcomes. By employing smaller incisions and specialized instrumentation, minimally invasive procedures offer several advantages over their open counterparts. These benefits include decreased blood loss, reduced postoperative pain levels, and expedited recovery times. Such advantages are of paramount importance in pediatric patients, where minimizing tissue trauma and preserving anatomical structures are crucial for facilitating optimal growth and development. Among these minimally invasive approaches, percutaneous spine fracture fixation has emerged as a particularly promising option. By minimizing tissue disruption and preserving spinal integrity, percutaneous techniques hold the potential to improve outcomes while mitigating surgical morbidity in pediatric patients.

Significance of Percutaneous Spine Fracture Fixation in Pediatric Orthopedics

The significance of percutaneous spine fracture fixation extends beyond mere clinical outcomes. It also encompasses broader implications for healthcare resource utilization and healthcare economics. Minimally invasive techniques, including percutaneous spine fracture fixation, have demonstrated benefits such as shorter hospital stays, reduced postoperative complications, and lower overall healthcare costs compared to traditional open surgeries. These advantages not only enhance patient care but also contribute to optimizing resource allocation within healthcare systems. By streamlining care delivery and reducing the burden on healthcare facilities, percutaneous spine fracture fixation can improve access to high-quality orthopedic care for pediatric patients, thus ensuring better overall healthcare outcomes.

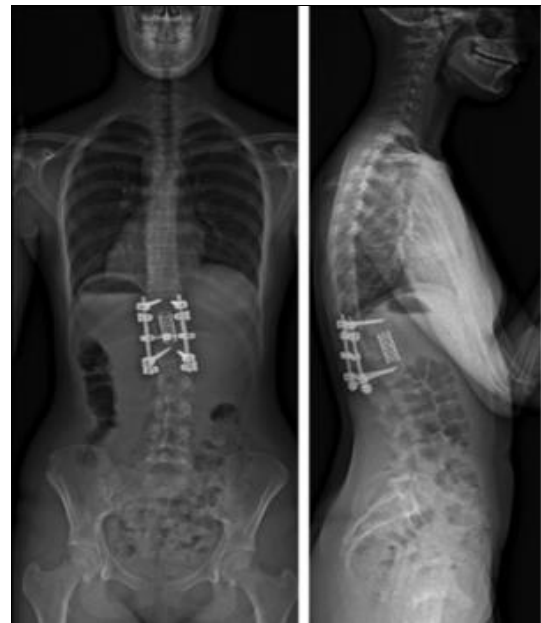


Fig 2: Spine Fracture Fixation

Review of Current Evidence on Percutaneous Spine Fracture Fixation

A review of the current literature reveals a growing body of evidence supporting the efficacy and safety of percutaneous spine fracture fixation in pediatric orthopedics. Studies consistently report favorable outcomes, including high rates of fracture union, low complication rates, and satisfactory functional outcomes. Furthermore, ongoing advancements in technology and procedural refinements have contributed to the continued evolution of percutaneous techniques, offering opportunities for further improving surgical precision and patient outcomes. Despite these advancements, however, gaps in knowledge persist regarding the long-term effects of percutaneous instrumentation on spinal growth and development in pediatric patients, underscoring the need for continued research in this area.

Future Directions and Research Needs in Percutaneous Spine Fracture Fixation

Moving forward, addressing these gaps in knowledge will be essential for optimizing patient outcomes and refining clinical practice. Further research is needed to elucidate the

long-term effects of percutaneous spine fracture fixation on spinal growth and development in pediatric patients. Additionally, ongoing efforts to refine surgical techniques and improve patient selection criteria will be crucial for maximizing the benefits of percutaneous techniques in this population. The research aims to contribute to this body of knowledge by providing a comprehensive review of recent advancements in minimally invasive techniques within pediatric orthopedics, with a specific focus on percutaneous spine fracture fixation. By synthesizing the current evidence and identifying areas for future research, the study seeks to inform clinical practice and contribute to the ongoing advancement of minimally invasive techniques in pediatric orthopedics.

Conclusion

In conclusion, the field of pediatric orthopedics has experienced a notable evolution with the advent and adoption of minimally invasive techniques, particularly percutaneous spine fracture fixation. Through the comprehensive review conducted in this research, several key insights have emerged regarding the efficacy, safety, and future directions of these techniques in the pediatric population.

Firstly, the evidence reviewed consistently demonstrates the feasibility and effectiveness of percutaneous spine fracture fixation in pediatric patients. Studies have consistently reported favorable outcomes, including reduced operative times, decreased blood loss, and shorter hospital stays compared to traditional open surgical approaches. Moreover, the minimally invasive nature of percutaneous techniques translates to less tissue trauma, reduced postoperative pain, and faster recovery times, which are particularly advantageous in the pediatric population where optimal postoperative rehabilitation is crucial for long-term outcomes.

Furthermore, emerging technologies and procedural refinements, such as navigational guidance and intraoperative imaging, have contributed to improved accuracy and precision in percutaneous spine fracture fixation. These advancements hold promise for further enhancing the safety and efficacy of these techniques, ultimately improving patient outcomes and satisfaction.

However, it is important to acknowledge that challenges and unanswered questions remain. Pediatric spinal anatomy presents unique considerations, including smaller vertebral sizes, ongoing growth and development, and potential implications for long-term spinal health. Therefore, continued research efforts are needed to better understand the impact of percutaneous spine fracture fixation on spinal growth and development, as well as to refine patient selection criteria and optimize surgical techniques tailored to the pediatric population.

Additionally, ongoing collaboration between clinicians, researchers, and industry stakeholders is essential to drive innovation and advancement in the field of pediatric orthopedics. By fostering interdisciplinary partnerships and leveraging technological advancements, we can continue to refine minimally invasive techniques, improve patient outcomes, and enhance overall quality of care for pediatric patients with spine fractures.

In summary, while percutaneous spine fracture fixation represents a significant advancement in pediatric orthopedics, there is still much work to be done to fully

realize its potential. Through ongoing research, innovation, and collaboration, we can address the unique challenges posed by pediatric spine fractures and continue to improve the standard of care for pediatric orthopedic patients. By prioritizing patient safety, optimizing surgical techniques, and advancing our understanding of pediatric spinal health, we can ultimately enhance the long-term outcomes and quality of life for pediatric patients with spine fractures.

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Conflict of interest

Not available.

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