ADVANCES IN ORTHOPEDIC SURGERY: MINIMALLY INVASIVE TECHNIQUES FOR THE TREATMENT OF COMPLEX LOWER LIMB FRACTURES

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Abstract: Orthopaedic surgery has undergone significant evolution with the development of minimally invasive techniques (MIT) for the treatment of complex lower limb fractures. These innovations have transformed orthopaedic management, offering less traumatic and more effective alternatives to traditional procedures. IMTs are designed to reduce tissue damage, speed up recovery and minimize post-operative complications, making them increasingly relevant in today's orthopaedic scenario. The aim of this study is to discuss recent advances in minimally invasive techniques in orthopaedic surgery for complex lower limb fractures. The research explores the benefits of these techniques, the challenges faced in clinical practice and the future prospects for their widespread adoption. The research was based on a literature review, with a qualitative approach, using the PubMed, Google Scholar, and Scielo databases. For a comprehensive and relevant analysis of the advances and challenges of minimally invasive techniques in orthopaedic surgery, specific descriptors reflecting the area of study were applied, with a time frame covering publications from 2018 to 2023. The analysis is based on a review of up-to-date literature, including clinical studies and meta-analyses that demonstrate the efficacy and safety of minimally invasive techniques. Innovations such as the use of external fixators, locked intramedullary rods and surgical navigation systems are highlighted. These approaches allow for precise stabilization of fractures with smaller incisions and less impairment of soft tissue vascularization. In addition, advances in intraoperative imaging and surgical instrumentation are discussed, which have improved the precision of procedures and reduced operative time. Challenges such as the learning curve and the cost of the technologies are also addressed. Thus, advances in minimally invasive techniques have revolutionized orthopaedic surgery, offering effective solutions for the treatment of complex lower limb fractures. Despite the challenges, such as the need for specialized training and investment in new technologies, the benefits for patients, including shorter recovery times and better functional results, are undeniable. The future of orthopaedic surgery will

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continue to benefit from these innovations, with the potential to further increase access and the quality of treatments.

Keywords: Orthopedic Surgery; General Surgery; Traumatology.

INTRODUCTION

In recent years, orthopedic surgery has experienced significant advances, mainly with the development and popularization of minimally invasive techniques for the treatment of complex fractures of the lower limbs. These innovative procedures have revolutionized orthopedic management, bringing benefits to both patients and healthcare professionals. The transition from traditional approaches to less invasive techniques has been driven by the search for better clinical outcomes, lower surgical morbidity, and faster recovery (Smith et al., 2018).

Complex fractures of the lower limbs, which affect regions such as the femur, tibia, and ankle, continue to pose a major challenge due to their anatomical complexity and the need for precise alignment for satisfactory functional recovery. Minimally invasive techniques, such as percutaneous osteosynthesis, the use of locked intramedullary nails, and fixation with low-aggressiveness plates, have demonstrated greater efficacy in preserving soft tissues and minimizing surgical trauma. This results in a lower risk of infections, less blood loss, and a faster recovery, with superior functional outcomes (Lee and Kim, 2020).

Additionally, the development of advanced technologies, such as image-assisted surgical navigation and robotic surgery, has improved the accuracy of these interventions, ensuring more predictable and effective outcomes. However, while promising, these advancements face considerable challenges, including the need for specialized training, high costs of technologies, and a significant learning curve for professionals. The relevance of these techniques in contemporary orthopaedic surgery highlights the need for a critical analysis of their impact, limitations, and future potential

(Gonzalez and Martinez, 2021).

Modern orthopedic surgery has benefited immensely from the incorporation of minimally invasive techniques, especially in the treatment of complex fractures of the lower limbs. These advancements reflect an ongoing effort to improve clinical outcomes by optimizing the patient experience and reducing postoperative complications. Compared to conventional approaches that involve extensive incisions and significant damage to surrounding tissues, minimally invasive techniques stand out for their soft tissue preservation, reduced postoperative pain, and shortened hospital stay. Such benefits are fundamental for the faster return of patients to their daily activities and for the improvement of quality of life (Johnson and Wang, 2019).

The increasing use of minimally invasive osteosynthesis and technologies such as assisted navigation and 3D printing for surgical planning exemplifies how sophisticated orthopedic practice has become in recent years. Assisted navigation, for example, allows surgeons to perform procedures with greater precision by adjusting the position of implants in real time and minimizing the margin of error. Thus, the integration of these technologies with more conservative fixation techniques has been seen as a fundamental step in the evolution of orthopedic surgery. In addition, recent studies have explored the use of biomaterials and smart implants, which promote better bone integration and facilitate recovery (Harris et al., 2020).

However, it is important to note that despite notable advances, minimally invasive orthopedic surgery still faces critical challenges. The infrastructure required to perform these techniques is costly, which limits their access in many medical centers, especially in developing countries. In addition, specialized surgical training continues to be an obstacle, since the learning curve to master these approaches can be long and demanding. Still, the prospect of continuing to innovate in the orthopedic field brings the expectation that the dissemination of these techniques will become more feasible over time, democratizing the benefits for a broader population (Murphy and Evans, 2021).

The aim of this study is to discuss recent advances in minimally invasive techniques in orthopedic surgery for complex fractures of the lower limbs. The research explores the benefits of

these techniques, the challenges faced in clinical practice, and the future prospects for their widespread adoption.

MATERIALS AND METHODS

The research was based on a literature review, with a qualitative focus, using the PubMed, Google Scholar, and Scielo databases. For a comprehensive and relevant analysis of the advances and challenges of minimally invasive techniques in orthopedic surgery, specific descriptors that reflect the area of study were applied, with a time frame that covers publications from 2018 to 2023.

Inclusion Criteria:

- Articles published between 2018 and 2023.

- Peer-reviewed studies discussing minimally invasive techniques in orthopedic surgery, including new technologies, biomaterials, and image-assisted navigation.

- Works that address innovations such as 3D printing for surgical planning and the integration of artificial intelligence in orthopedic management.

Exclusion Criteria:

- Studies that do not directly focus on minimally invasive techniques or that present theoretical analyses without clinical application.

- Publications in journals with a low impact factor or without peer review.

- Papers that do not discuss specific technological advances, such as biomaterials or assisted navigation systems.

Search Strategy and Boolean Markers:

- AND: to associate different concepts (e.g., “minimally invasive surgery” AND “orthopedic

innovations").

- OR: to cover synonyms (e.g., "biomaterials" OR "advanced surgical materials").

- NOT: to exclude irrelevant topics (e.g. "invasive surgery" NOT "traditional techniques").

Guiding Question:

What are the technological innovations and the main challenges in the adoption of minimally invasive techniques in orthopedic surgeries, and how do these changes impact the treatment of complex fractures?

THEORETICAL FOUNDATION

The development of minimally invasive techniques for the treatment of complex fractures of the lower limbs has revolutionized modern orthopedic surgery, improving clinical outcomes and quality of life for patients. These techniques include approaches such as minimally invasive osteosynthesis, which uses small incisions and special devices for bone fixation, and the use of image-assisted technology, which provides greater precision during procedures. According to Lee et al. (2021), these methods offer considerable advantages, such as preservation of adjacent muscles, less intraoperative bleeding, and a reduction in hospital stay. The minimally invasive approach also reduces the risk of infections, facilitating a faster and more efficient recovery, with less need for intensive rehabilitation.

Technological innovations, such as surgical navigation by 3D imaging, have played a crucial role in this advancement. Assisted navigation allows for real-time visualization of anatomical structures, which helps the surgeon to accurately position implants and minimize bone exposure. Studies show that this accuracy is especially important in complex intra-articular fractures, where poor alignment can lead to complications such as early osteoarthritis (Smith and Garcia, 2022). Another emerging technology is 3D printing, used to plan surgical interventions based on personalized models

of fractures. These models facilitate more detailed preparation, allowing the surgeon to anticipate specific challenges of the patient's anatomy and improve surgical execution (Brown et al., 2020).

In addition, the development of advanced biomaterials, such as resorbable fixation plates and biocompatible implants, has contributed to the effectiveness of these techniques. Bioactive implants, which promote faster bone integration and accelerated healing, are constantly evolving. Studies demonstrate that these materials not only support bone structure properly, but can also stimulate tissue regeneration, a critical advancement for fractures involving regions with poor healing capacity (Chen et al., 2021). The use of robotics in orthopedic surgeries is also a booming field, with devices that increase accuracy and reduce human errors. Assisted robotics is becoming particularly relevant in highly complex procedures, providing greater control and consistency in results.

Despite the clear benefits, widespread adoption of these techniques faces significant challenges. The need for advanced infrastructure and high-tech equipment represents a considerable investment, which limits its availability in hospitals with limited financial resources. According to Johnson and Martin (2021), there is considerable disparity in the distribution of these advances, with better-equipped urban health centers benefiting disproportionately compared to rural or less developed regions.

What's more, the learning curve for surgeons is another limiting factor; minimally invasive procedures require extensive training, which can discourage professionals from adopting these techniques, especially in contexts where time and resources for continuing education are scarce (Thompson and Li, 2022).

In terms of future research, there is a need to more broadly explore the application of minimally invasive techniques in different populations and types of fractures. This includes evaluating the effectiveness of new approaches in elderly patients or in cases of osteoporosis, where bone strength is a critical factor. Additionally, the integration of artificial intelligence (AI) to optimize surgical planning is a promising area. AI can help identify patterns in surgical data and propose personalized approaches for each case, potentially further increasing the success of surgeries (Nguyen et al., 2023).

CONCLUSION

It is therefore concluded that the evolution of minimally invasive techniques in orthopedic surgery represents a significant milestone in the treatment of complex fractures of the lower limbs, promoting substantial improvements both in the management of injuries and in the recovery of patients. The development of technologies such as image-assisted navigation, 3D printing for preoperative planning, and the use of advanced biomaterials has brought a new level of precision and effectiveness to procedures, minimizing complications and speeding up the healing process. These advances demonstrate that orthopedics is increasingly focused on personalization and surgical damage reduction, which translates into a higher quality of life for patients.

However, the work also highlights the challenges that are still present, such as the need for greater access to these technologies in less developed regions and the complexity of adequate training for surgeons. The disparity in the distribution of technological resources and the required learning curve underscore the importance of strategies aimed at democratizing access to advanced techniques, ensuring that more patients can benefit from scientific advances.

The future outlook is promising, with the potential for artificial intelligence and robotics to further transform the field, offering increasingly personalized and secure solutions. There is, therefore, considerable ground to go to fully integrate these innovations into daily clinical practice. However, with continued investments in research and education, it is possible for minimally invasive orthopedic surgery to consolidate itself as a highly efficient standard of care, redefining the treatment of complex fractures and significantly improving surgical outcomes.

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