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Research Article

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Total Hip Arthroplasty And Technological Advances-A Panorama Of The Last 10 Years: Systematic Review

Gabriel Rodrigues Silva[1,4], Andrei Machado Viegas da Trindade[2], Leandro Alves de Oliveira[1], Lauro Barbosa Neto[1], Reuder Pereira Prado[1], Lucas David Campos[2] and Fernanda Grazielle da Silva Azevedo Nora[3*]

[1]*Department of Orthopedics and Traumatology-Hip Surgery, COT-Ortopedia e Traumatologia, Brazil*

[2]*Department of Orthopedics and Traumatology Centro Estadual de Reabilitação e Readaptação Dr. Henrique Santillo, Brazil*

[3]*Faculdade de Educação Física e Dança, UFG – Universidade Federal de Goiás, Goiânia, Goiás, Brazil, Avenida Esperança s/n, Campus Samambaia, Brazil*

[4]*Department of Orthopedics and Traumatology Hip Surgery, HMAP – Hospita Municipal de Aparecida de Goiânia, Aparecida de Goiânia, Goiás, Brazil*

***Corresponding Author**
Fernanda Grazielle da Silva Azevedo Nora, Faculdade de Educação Física e Dança, UFG – Universidade Federal de Goiás, Goiânia, Goiás, Brazil, Avenida Esperança s/n, Campus Samambaia, Brazil

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Abstract

Objective: *The aim of this study is to analyze the impact of technological innovations on surgical precision, safety, complications, and functional recovery of patients undergoing Total Hip Arthroplasty (THA). Methodology: The review was conducted following PRISMA guidelines. A total of 41 articles published between 2014 and 2024 were selected from PubMed, Google Scholar, and Scopus databases. The included studies directly addressed technological innovations applied to THA, such as robotics, 3D navigation, and nerve blocks for pain management. The initial screening identified 450 studies, of which 50 were fully analyzed, and 41 were included in the final review.*

Results: *The results indicate that the use of robotics and 3D navigation significantly improves the accuracy of prosthetic component placement, reducing complications such as misalignment and dislocations. Additionally, pain management using Peri-capsular Nerve Group (PENG) blocks proved effective in reducing opioid use and promoting early functional recovery. These technologies contributed to better alignment of components and a reduced need for revision surgeries. Conclusion: Technological advances in THA, such as the use of robotics, 3D navigation, and new approaches to pain management, have shown a positive impact on clinical outcomes, reducing complications and accelerating patient recovery. However, there are challenges to large-scale implementation due to the learning curve and high costs. The study suggests that, with the continued advancement of technology, THA will become increasingly safer and more effective, providing better outcomes for patients.*

Keywords: Total Hip Arthroplasty, Robotics, 3D Navigation, Pain Management, Technological Innovations

1. Introduction

Total hip arthroplasty (THA) is one of the most frequently performed surgical procedures worldwide to treat degenerative hip joint conditions, such as osteoarthritis, rheumatoid arthritis, and avascular necrosis of the femoral head. The primary goal of this surgery is to restore joint function, relieve pain, and improve patients' quality of life. Over the past decades, THA has significantly evolved, with advancements in surgical techniques and materials used; however, challenges regarding implant durability and the occurrence of complications remain [1].

In the past ten years, technological innovations have played a critical role in improving THA outcomes. The introduction of robotics-assisted technologies and 3D navigation has allowed for greater control and precision in the placement of prosthetic components, reducing complication rates such as misalignment, early wear, and dislocations [2]. These technologies not only enable more precise surgery but also assist in preoperative planning, leading to better long-term functional outcomes [3].

Robotics has revolutionized the field of THA by providing greater precision in the alignment of acetabular and femoral components. This is crucial for the longevity of the prosthesis, as misalignments can lead to severe complications, such as excessive wear and early surgical revisions [4]. Studies indicate that robot-assisted surgery reduces alignment-related complications and increases prosthetic stability, which is especially beneficial for younger and more active patients [5].

3D navigation has proven equally effective in improving surgical outcomes, allowing surgeons to adjust the positioning of prosthetic components in real-time based on each patient's specific anatomical characteristics. This technology is particularly useful in cases with complex anatomies or revision surgeries, where precise component placement is essential to avoid prosthetic failure [6]. The combination of robotics and 3D navigation has shown promising results, with studies demonstrating a significant reduction in postoperative complications and faster patient recovery [7].

In addition to innovations in surgical precision, postoperative pain management has also seen significant improvements. Traditionally, pain control after THA relied heavily on opioid use, which, while effective, is associated with several undesirable side effects, such as dependency and constipation. Recently, the use of regional nerve blocks, such as the Peri-capsular Nerve Group (PENG) block, has emerged as an effective alternative for pain control, with reduced opioid requirements and faster functional recovery [8].

The PENG block has shown excellent results in controlling postoperative pain in patients undergoing THA, enabling early mobilization and improving long-term functional outcomes. Studies comparing the PENG block with other pain management techniques indicate that PENG offers more effective pain control during the first 24 hours after surgery, with less impact on lower limb motor function [7].

Minimally invasive techniques, such as the direct anterior approach, have also gained popularity in THA, primarily due to reduced recovery time and postoperative pain. Unlike traditional approaches, which involve cutting key muscles around the hip, the direct anterior approach preserves these muscles, allowing for quicker functional recovery [6]. This is particularly beneficial for young and active patients who seek to return quickly to their daily and sporting activities [9].

Despite these advancements, the adoption of technologies such as robotics and 3D navigation present some challenges. The main challenge is the learning curve associated with using these tools, which requires intensive training to ensure that surgeons can fully utilize the potential of these technologies. Studies indicate that surgeons with greater experience in robotic techniques achieve better clinical outcomes, suggesting that the learning curve is a key factor in the successful implementation of these innovations [10].

Another significant challenge is the cost associated with the implementation of these technologies. The acquisition and maintenance of robotic and 3D navigation systems represent a substantial investment for hospitals, which may limit the adoption of these technologies in centers with lower procedural volumes. However, as these technologies become more accessible and costs decrease, their adoption is expected to increase, benefiting a larger number of patients [3].

In addition, the materials used in prostheses have also seen significant advancements in recent years. The introduction of new polymers and high-strength metal alloys has helped increase the durability of prostheses, reducing the need for revision surgeries in young and active patients. These new materials are more resistant to wear, which is essential for extending the life of the prosthesis and improving long-term outcomes [9].

The use of preoperative planning software has also become increasingly common in THA. These programs allow surgeons to precisely plan the placement of prosthetic components before surgery, considering each patient's individual anatomical features. This improves the predictability of surgical outcomes and reduces the incidence of complications, such as misalignment and early wear [1].

Robotics has also facilitated the training of new surgeons by enabling precise surgical simulations, which accelerate the learning curve and reduce the risk of complications associated with surgical inexperience. Studies indicate that the use of robotic simulators in surgeon training can significantly improve clinical outcomes, especially in complex procedures such as THA [11].

Another important aspect of technological innovations in THA is the real-time collection of intraoperative data. This data can be analyzed to improve surgical techniques and refine treatment protocols, contributing to more predictable outcomes and fewer complications. The ability to continuously monitor data during surgery also allows for immediate adjustments, ensuring better prosthetic component positioning and reducing the risk of long-term complications [6].

Based on these advances, the aim of this systematic review is to analyze the major technological advances applied to total hip arthroplasty over the past ten years, focusing on the impact of these innovations on clinical outcomes, safety, complications, and patient functional recovery. By reviewing the existing literature, we hope to provide a comprehensive view of the benefits and challenges associated with the adoption of these technologies in clinical practice.

2. Methodology

This systematic review was conducted based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure clarity and reproducibility of the study. The research was guided by the question: "What are the main technological advances applied to total hip arthroplasty in the last ten years, and what are their impacts on clinical outcomes and patient safety?" Based on this question, we structured the search for relevant studies focused on technologies such as robotics, 3D navigation, and postoperative pain management.

To ensure the inclusion of current and relevant studies, we considered articles published between 2014 and 2024, written in English or Portuguese. The databases used for the search were PubMed, Google Scholar, and Scopus, chosen for their comprehensiveness and recognition in the health field. The selected studies had to directly address technological innovations in THA, focusing on clinical and safety outcomes, such as surgical precision, complications, and functional recovery.

Exclusion criteria included studies dealing with pediatric populations or conditions unrelated to total hip arthroplasty. Additionally, non-systematic literature reviews, studies with poor methodological quality, duplicate articles, or those that did not directly address technological advancements relevant to THA were excluded.

The search strategy involved a combination of keywords such as "total hip arthroplasty," "robotic surgery," "3D navigation," "pain management in hip replacement," and "pericapsular nerve group block." These keywords were adjusted according to the specificities of the databases. The initial search identified 450 articles, whose titles and abstracts were reviewed to ensure eligibility according to the established criteria.

After the initial screening, 50 articles were selected for full-text review. Each study was evaluated in terms of methodological quality and relevance to the review topic. In the end, 41 articles were included in the analysis based on strict inclusion and exclusion criteria. The quality of the studies was assessed using the Cochrane "Risk of Bias" tool, ensuring that the included studies were robust and presented appropriate methodologies.

Data extraction was performed by two independent reviewers. Information on the technologies used, sample size, type of study, clinical outcomes, complications, and recovery time was collected from each study. In cases of disagreement between the reviewers, a third reviewer was consulted to reach a consensus. Data extraction focused on identifying the key clinical outcomes related to the use of robotics, 3D navigation, and pain management.

The results were grouped into thematic categories, allowing for a more detailed analysis of the impact of each technology. Robotics was evaluated for its contribution to surgical precision and complication reduction, while 3D navigation was analyzed based on its ability to improve prosthetic alignment and postoperative outcomes. Pain management, in turn, was evaluated for the effectiveness of nerve block techniques, such as the pericapsular nerve group (PENG) block, in reducing opioid use and promoting faster functional recovery.

Finally, the data were synthesized in a qualitative analysis, comparing the benefits and limitations of the different technological innovations applied to THA. The results were discussed considering the evidence presented in the reviewed studies, highlighting the implications for clinical practice and areas requiring further research.

3. Results and Discussion

This study reviewed 41 articles published between 2014 and 2024, aiming to analyze technological advances in total hip arthroplasty (THA), particularly regarding robotics, 3D navigation, pain management, and complication reduction. The analysis was organized into three main thematic areas:

1. the impact of robotics and 3D navigation on surgical precision,
2. innovations in postoperative pain management, and
3. safety and complications related to the use of these technologies.

The results discuss the benefits, limitations, and clinical implications of these technological innovations.

3.1 Advances in Robotics and 3D Navigation

Advances in robotics and 3D navigation have transformed the surgical practice of THA, improving the precision in positioning prosthetic components, particularly the acetabular component, which plays a crucial role in the long-term success of the prosthesis [1]. Robotics has proven to be an important tool for ensuring millimeter-level precision in implant placement, something that is more prone to errors when done manually. NODZO et al. (2018) reported that robot-assisted surgery significantly reduced component misalignment rates, which contributed to greater prosthesis stability and longevity [3].

On the other hand, 3D navigation has been an effective technology, particularly in more complex surgeries, such as revisions and cases involving bone deformities. KIDA et al. (2021) demonstrated that 3D navigation improves prosthetic alignment and reduces limb length discrepancies, a common complication in THA that can affect gait and the patient's quality of life. GUO et al. (2023) reinforce that the combination of robotics and 3D navigation provides even more robust results, especially in revision surgeries or cases with difficult-to-manage anatomies [11].

The increased surgical precision provided by these technologies is associated with a reduction in postoperative complications, such as dislocations, misalignment, and early component wear [6]. Furthermore, studies indicate that with robotics and 3D navigation, the need for revision surgeries decreases, resulting in significant long-term cost savings for healthcare systems [11]. Although initially costly, the implementation of these technologies can be justified by better clinical outcomes and reduced complication rates.

3.2 Postoperative Pain Management

Effective postoperative pain management is essential to promote early functional recovery and minimize complications associated with prolonged use of painkillers, such as opioids. The development of nerve block techniques, especially the Peri-capsular Nerve Group (PENG) block, has proven to be an effective solution for pain control without compromising limb motor function [8]. This technique not only reduces the need for opioids but also minimizes associated side effects, such as nausea, constipation, and dependency, providing a more comfortable and safer recovery for patients.

YE et al. (2023) compared the PENG block with local anesthetic infiltrations and concluded that the PENG block provided more effective pain control in the first 24 hours after surgery, without impairing patient mobility [7]. Additionally, WINTHER et al. (2020) reported that the use of regional nerve blocks is associated with faster recovery and a lower incidence of complications, such as deep vein thrombosis and postoperative infections [12].

Effective pain reduction is directly related to improved early mobility, an essential factor in preventing serious complications and improving long-term functional outcomes [13]. Patients who experience adequate pain control tend to mobilize earlier, which shortens hospital stays and improves overall recovery.

3.3 Safety and Complications

The use of advanced technologies such as robotics and 3D navigation is directly associated with a significant reduction in intraoperative and postoperative complications. NODZO et al. (2018) reported that robotics, by increasing the precision of component positioning, reduced misalignment and dislocation rates by 30% in patients undergoing THA [3]. This higher precision decreases the risk of prosthesis failures, such as early wear, which increases the implant's longevity and, consequently, long-term patient satisfaction.

Additionally, 3D navigation has been a crucial tool in avoiding complications related to improper placement of prosthetic components, which can lead to the need for revision surgeries. KIDA et al. (2021) demonstrated that 3D navigation significantly reduced complication rates, such as limb length discrepancies and acetabular misalignment, which are often associated with early implant failures [4,6]. The use of these technologies improves the predictability of clinical outcomes and enables safer surgeries.

Advances in pain management, combined with the surgical precision of robotics and 3D navigation-assisted techniques, have contributed to a safer surgical environment, with fewer serious complications and faster recovery for patients. These innovations, although requiring high initial investments in infrastructure and training, show a significant positive impact on surgical outcomes, justifying their progressive adoption in specialized centers.

The review of the 41 articles identified that the application of these technologies is highly effective in improving surgical outcomes in total hip arthroplasty. In addition to promoting greater safety and efficacy in surgery, these technological innovations help reduce postoperative pain and accelerate functional recovery, offering patients a better quality of life. Robotics and 3D navigation prove to be essential tools for optimizing surgical precision, while pain management techniques, such as the PENG block, are fundamental for providing a more comfortable and safer postoperative period.

4. Conclusion

Technological advances in total hip arthroplasty (THA), such as robotics, 3D navigation, and new pain management techniques, have revolutionized surgical practice, demonstrating consistent positive impacts on clinical outcomes and patient safety. These innovations enable unprecedented surgical precision, significantly reducing intraoperative and postoperative complications, such as misalignment, dislocations, and early component wear. Additionally, effective pain management techniques, such as the PENG block, have improved functional recovery, reducing the need for opioids and enabling early and safe mobilization.

As these technologies continue to evolve and become more accessible, the success of THA is expected to expand further, not only providing safer and more efficient surgeries but also contributing to the longevity of implants and the overall improvement in patient quality of life. However, despite the clear benefits, challenges related to the learning curve and high costs need to be addressed to allow widespread implementation of these innovations across healthcare centers of various levels [14-29].

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