ISSN: 2690-9189

International Journal of Orthopaedics Research

Research Article

Biomechanical Advances in Total Hip Arthroplasty: From Surgical Approach to Functional Recovery

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

[1]Department of Orthopedics and Traumatology – Hip Surgery, HMAP - Hospital Municipal de Aparecida de Goiânia, Aparecida de Goiânia, Goias, Brazil

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

[3]Department of Orthopedics and Traumatology – Hip Surgery, COT – Ortopedia e Traumatologia, Goiânia, Goias, Brazil

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

[*]Corresponding Author
Fernanda Grazielle da Silva Azevedo Nora, Faculdade de Educaçao Fisica e Dança, UFG – Universidade Federal de Goias, Goiania, Goias, Brazil Avenida Esperança s/n, Campus Samambaia, Goiânia, Goias, Brazil.

Submitted: 2024, Dec 11; **Accepted:** 2025, Jan 15; **Published:** 2025, Jan 20

Citation: Silva, G. R., Trindade, A. M. V. D., Oliveira , L. A. D., Neto, L B., Prado, R. P., et al. (2025). Biomechanical Advances in Total Hip Arthroplasty: From Surgical Approach to Functional Recovery. *Int J Ortho Res, 8*(1), 01-08.

Abstract
This technical article discusses biomechanical advancements in total hip arthroplasty (THA), from surgical techniques to functional recovery. Focusing on the evolution of surgical approaches, it highlights the use of robotics and artificial intelligence to enhance implant positioning precision and minimize misalignments. Advanced materials, such as high-density polyethylene, and innovative prosthesis designs were also discussed, emphasizing their contribution to prosthesis durability and functionality. Additionally, perioperative management strategies, including modern analgesic blocks and nutritional support, have improved postoperative recovery, while structured rehabilitation protocols are essential for restoring gait and joint biomechanics. Finally, long-term considerations regarding prosthesis survival and patients' quality of life were explored, reinforcing the importance of a multidisciplinary approach and cutting-edge technologies.

Keywords: Total hip arthroplasty, Biomechanics, Robotics, Functional Rehabilitation, Quality of Life

1. Introduction

Total hip arthroplasty (THA) is one of the most successful surgical interventions in modern orthopedics, providing significant pain relief and functional restoration for patients with debilitating hip conditions such as advanced osteoarthritis, avascular necrosis, and femoral neck fractures [1]. Since its inception, THA has undergone notable advancements, particularly in surgical techniques, prosthetic materials, and functional rehabilitation.

These advancements are especially crucial in the context of an aging population, which increases the incidence of degenerative joint pathologies. Studies highlight that THA significantly improves quality of life by relieving pain and restoring functional biomechanics of the hip [2]. However, the success of this procedure depends not only on the surgery itself but also on optimized perioperative and postoperative strategies.

Minimally invasive surgical techniques, such as the direct anterior approach (DAA), have been widely promoted due to their muscle-preserving capabilities, faster recovery, and reduced postoperative pain [2,4]. Biomechanical preservation through these approaches contributes to superior long-term outcomes, particularly for active patients.

Precision in the positioning of prosthetic components is another critical factor for biomechanical success. Technologies such as robot-assisted navigation and intraoperative planning devices have demonstrated improved alignment of the acetabular cup and femoral component, reducing prosthesis wear and the risk of revision [5,6]. Comparisons between robotic and manual methods indicate that robotics significantly improves biomechanical precision outcomes [7].

One of the most discussed biomechanical challenges in THA is leg length discrepancy (LLD). Accurate correction of this discrepancy is essential to avoid gait alterations and chronic low back pain. Modern intraoperative tools have been developed to assess and correct LLD during surgery, improving functional outcomes [8].

Beyond surgical advancements, perioperative management plays a crucial role in patient recovery. Modern analgesia strategies, such as quadratus lumborum block and pericapsular nerve group (PENG) block, have shown superior efficacy in reducing postoperative pain and minimizing opioid use [9,10]. These techniques facilitate early mobilization and accelerate the return to daily activities [11].

In terms of functional recovery, evidence-based rehabilitation protocols have gained prominence. Programs combining early muscle strengthening and joint mobility result in improved functional stability and gait biomechanics [12,13]. Studies suggest that adherence to structured protocols significantly enhances outcomes compared to generalized approaches [14].

Prosthetic materials and designs have also advanced, with the introduction of more durable components such as high-density polyethylene, which reduces wear and extends prosthesis longevity [15]. These innovations are especially crucial for young and active patients, who are at higher risk of revision due to prosthesis wear [2].

Artificial intelligence-assisted technologies have been integrated into THA robotics, enabling more precise and personalized surgical planning. These systems not only improve biomechanical outcomes but also reduce revision rates and associated complications [16,17].

Finally, the biomechanics of the hip after THA is influenced by multiple factors, including implant alignment, periarticular muscle preservation, and the quality of rehabilitation. Long-term studies indicate that prosthesis survival depends on an optimized balance between all these elements [15,18].

This technical article examines biomechanical advancements in THA, from surgical techniques and perioperative management to rehabilitation protocols, highlighting how these innovations contribute to improved clinical and functional outcomes.

2. Surgical Techniques in Total Hip Arthroplasty

2.1. Surgical Approaches and Biomechanics

Surgical approaches to total hip arthroplasty (THA) have significantly evolved, with each offering specific advantages in biomechanics and functional recovery. The direct anterior approach (DAA) minimizes damage to muscular structures, promoting faster recovery, reduced postoperative pain, and preserved muscle function [3]. Compared to the lateral trans gluteal approach, DAA demonstrates better early mobility, although it requires greater surgical expertise due to its steeper learning curve [4].

The posterior approach remains widely utilized due to its familiarity among surgeons and excellent access to the acetabulum and proximal femur. However, studies indicate a higher risk of postoperative dislocation compared to DAA [19]. The direct lateral approach, preferred in cases of high instability, provides better biomechanical control but is associated with increased muscle damage [15].

Recent advancements include the introduction of patient-specific femoral guides based on three-dimensional imaging, which aid the anterolateral supine approach by enhancing precise alignment and functional biomechanics [20]. These innovations reduce implant misalignment complications, particularly benefiting younger and more active patients [2].

Hybrid techniques that combine the advantages of anterior and lateral approaches have emerged, balancing muscle preservation with ease of surgical access [1]. Comparative studies suggest that the choice of approach should be tailored to factors such as patient anatomy, activity level, and surgeon experience [21,14].
Additionally, minimally invasive approaches, employing smaller incisions and optimized instruments, have reduced surgical time and enhanced functional recovery [22]. These methods also minimize tissue trauma, preserving the joint's biomechanical properties.

2.2. Robotic Technology and Navigation

The incorporation of robotics and navigation systems in THA has revolutionized the precision of implant positioning, a crucial factor for biomechanical success and prosthesis longevity. Robotics enables accurate placement of the acetabular cup and femoral component, minimizing misalignments that can lead to premature wear and implant failure [5]. Comparative studies show that robotic techniques provide better control of acetabular cup inclination and anteversion than manual approaches [7,23].

Intraoperative navigation with real-time imaging facilitates the evaluation of patient-specific anatomy, allowing immediate and personalized adjustments during surgery [14]. This technology is particularly beneficial for patients with significant anatomical deformities, such as hip dysplasia sequelae [16].

Robotic systems have also proven effective in reducing postoperative dislocation rates and leg length discrepancies (LLD) [6,24]. Furthermore, the learning curve for surgeons using robotics is significantly shortened due to intuitive interfaces and technological support [18].

The integration of artificial intelligence with robotics further enhances surgical precision, enabling more detailed preoperative planning and personalized surgery simulations [7]. Studies, such as those by LU et al. (2024), show that these innovations result in shorter operative times and improved biomechanical outcomes [16].

However, challenges such as high costs and the need for specialized training still limit the widespread adoption of robotics in many institutions. Trends indicate that these barriers will diminish with greater popularization and large-scale production of these systems [1, 10].

2.3. Control of Leg Length Discrepancy

Leg length discrepancy (LLD) is a common biomechanical complication following THA, associated with low back pain, gait alterations, and patient dissatisfaction. Modern intraoperative measurement tools have improved precision in correcting LLD, significantly reducing these complications [8].

Real-time imaging technology combined with computer-assisted navigation allows surgeons to assess leg length during the procedure and adjust the implant accordingly [16]. Studies show that these techniques result in a significantly lower incidence of LLD compared to conventional methods [5].

Approaches such as modular prostheses enable fine intraoperative adjustments, optimizing the biomechanical balance of the hip [15]. Additionally, robotic systems have demonstrated effectiveness in LLD reduction, as they simulate various alignment and length scenarios during preoperative planning [18].

A study by IMREN et al. highlighted that preserving musculoskeletal anatomy, especially with the posterior approach, contributes to reducing LLD [19]. Patient-specific tools based on 3D printing have emerged as innovative solutions for complex anatomies, offering greater precision in restoring leg length [20].

While significant advancements have been made, studies like those by WINTHER et al., emphasize the need for rigorous postoperative protocols, with rehabilitation directed at correcting biomechanical adaptations caused by subtle leg length differences [12].

Accurate control of LLD remains one of the primary challenges in THA, requiring an integrated approach that combines cutting-edge technology, advanced surgical techniques, and structured rehabilitation protocols [13,14].

3. Perioperative Management

3.1 Pain Control and Analgesia

Postoperative pain management is a critical element for successful functional recovery following total hip arthroplasty (THA). Modern analgesic techniques have demonstrated greater efficacy in reducing pain, promoting early mobilization, and minimizing opioid requirements. Among these, the pericapsular nerve group (PENG) block has stood out, showing superiority over local anesthetic infiltration in controlling postoperative pain [10,25]. Studies indicate that PENG provides targeted analgesia with minimal interference in muscle strength, allowing for more efficient rehabilitation.

The trans muscular quadratus lumborum block has also been widely used due to its ability to provide comprehensive analgesia with reduced opioid requirements [9,11]. This technique mitigates complications associated with prolonged opioid use, such as nausea, constipation, and dependence, improving the patient's postoperative experience. Additionally, the quadratus lumborum block has a longer duration of action, making it particularly beneficial for patients with a high pain threshold.

Recent studies highlight the effectiveness of combining nerve blocks, such as PENG combined with local anesthetic infiltration or iliac compartment blocks, providing synergistic pain control [26]. These combined strategies have shown better outcomes in postoperative pain scales and shorter times to initial mobilization [27].

The inclusion of dexmedetomidine as an adjuvant in peripheral blocks has gained attention for its ability to prolong the duration of the analgesic effect and modulate the postoperative inflammatory response [26]. Inflammation modulation not only relieves pain but also accelerates the healing process.

Ultrasound technology has revolutionized nerve block applications, allowing greater anatomical precision and reducing the risk of complications such as hematomas or nerve injuries [11]. This innovation is particularly useful for patients with complex anatomy or post-traumatic alterations.

Additionally, multimodal analgesia, combining nerve blocks with systemic analgesics such as nonsteroidal anti-inflammatory drugs (NSAIDs) and acetaminophen, has proven effective in reducing pain and dependence on opioids [10,15]. This integrated approach promotes a safer and more comfortable recovery.

Finally, the positive impact of effective pain control extends beyond immediate relief. It is directly associated with reducing complications such as deep vein thrombosis and improving sleep quality, factors that significantly influence functional rehabilitation success [22].

3.2 Nutritional and Metabolic Strategies

Nutritional support during the perioperative period is essential for optimizing functional recovery following THA, particularly in elderly patients or those at risk of sarcopenia. Perioperative amino acid administration has shown promising results in restoring muscle balance and preserving lean mass [21]. These nutrients play a vital role in protein synthesis, reducing muscle degradation induced by surgical trauma.

Studies reveal that perioperative amino acid infusion helps prevent muscle mass loss during the early postoperative days, when patients are less active [21]. This preservation is crucial for maintaining strength and facilitating rehabilitation. In patients at higher risk of metabolic complications, supplementation can reduce systemic inflammation, promoting faster recovery [12].

Adequate dietary protein intake is also essential. Studies recommend a daily intake of 1.2 to 2.0 g/kg of body weight for patients undergoing THA to sustain muscle synthesis and tissue healing (SU et al., 2021). When combined with strength exercises, this nutritional support enhances functional gains [12].

In addition to amino acids, supplementation with omega-3 fatty acids have demonstrated benefits in modulating postoperative inflammation and improving muscle turnover [21]. These nutrients can reduce inflammatory cytokine production, creating a metabolic environment favorable for recovery.

Metabolic support also includes strategies to maintain glycemic homeostasis during the perioperative period. Transient hyperglycemia, common in patients undergoing major surgeries, can impair healing and increase infection risks. Therefore, glycemic management is crucial to minimizing these complications [14].

For patients with specific nutritional needs, such as those with vitamin deficiencies or chronic inflammatory states, micronutrient supplementation—including vitamin D and zinc—is recommended to accelerate functional recovery [21]. Vitamin D is associated with improved muscle strength and reduced risk of falls.

Finally, personalized nutritional support programs, developed based on detailed metabolic assessments, have shown superior results compared to standardized approaches [12]. Integrating nutritional and metabolic strategies into perioperative management underscores the importance of a multidisciplinary approach to optimizing THA outcomes.

4. Post-Surgical Rehabilitation

4.1 Rehabilitation Protocols

Post-total hip arthroplasty (THA) rehabilitation is a crucial step in restoring functionality and ensuring the success of the procedure. Evidence-based protocols have demonstrated that early muscle strengthening and progressive mobilization are essential for optimizing outcomes [12]. These protocols aim to prevent complications, such as deep vein thrombosis, and expedite the return to daily activities, reducing hospital stays.

Structured rehabilitation programs outperform generalized approaches by providing specific, personalized guidelines for each patient [14]. These protocols include exercises to enhance strength, range of motion, and joint stability. Physical therapy plays a central role in rehabilitation, focusing on strengthening periarticular muscles, particularly the gluteal and quadriceps muscles, which support hip biomechanics.

Rehabilitation often begins within the first 24 hours post-surgery with early mobilization, such as lower limb elevation exercises and knee extensions [13]. This practice reduces the risk of joint stiffness and improves blood flow to the operated tissues, promoting healing.

Aquatic therapy has gained prominence as a complementary approach. Buoyancy reduces joint loading, enabling pain-free range-of-motion exercises and muscle strengthening [14]. This method is particularly beneficial for patients with intense pain or limited mobility during the early stages.

Gradual strengthening exercises are implemented based on the principle of progression. Light weights and elastic resistance are introduced in the weeks following surgery to avoid joint overload [22]. Functional exercises, such as stair climbing and sit-to-stand movements, are included to facilitate the patient's transition to daily activities.

Another essential aspect of rehabilitation protocol is patient education. Teaching proper movement techniques, such as bending the knees when picking up objects or avoiding crossing the legs, helps prevent prosthesis dislocation [21]. Psychological support is also recommended to address potential fears or anxiety related to the rehabilitation process.

Proprioceptive training has been integrated into rehabilitation programs to improve balance and prevent falls. Exercises on unstable surfaces, such as wobble boards, help restore postural control mechanisms [12]. This approach is especially crucial for elderly patients, who are at higher risk of falls post-surgery.

Continuous progress assessment is an integral part of rehabilitation programs. Tools such as isokinetic dynamometers evaluate muscle strength, while motion analysis systems monitor gait evolution and identify biomechanical deviations [22]. These evaluations allow for treatment plan adjustments, ensuring the protocol's effectiveness.

In the final stages of rehabilitation, more intense exercises are incorporated, such as strength training with machines and low-impact sports activities like cycling and swimming. These exercises help fully restore joint function and muscle strength, enabling patients to resume their usual routines.

Longitudinal studies suggest that adherence to rehabilitation protocols is directly linked to functional success and patient satisfaction. Strategies to increase adherence include mobile app-based remote monitoring and goal-based incentives during rehabilitation [1].

4.2 Gait Recovery and Biomechanics

Gait recovery is one of the primary objectives of rehabilitation after THA. Properly restoring gait biomechanics not only improves functionality but also reduces the risk of complications such as low back pain and accelerated prosthesis wear [22]. Gait re-education is essential to ensure balanced load distribution and movement symmetry.

The first steps after surgery often involve using assistive devices, such as walkers or crutches, to provide additional support and reduce load on the operated hip [12]. The goal is to gradually transition to independent gait as muscle strength and joint stability improve.

Muscle strengthening is particularly important for gait recovery, emphasizing the gluteal, quadriceps, and hamstring muscles. These muscle groups play critical roles in posture control and propulsion during gait [14]. Specific exercises, such as hip lifts and knee extensions, are included to enhance muscle strength and endurance.

Biomechanical gait analysis is a powerful tool in the rehabilitation process. Specialized laboratories use motion capture systems to identify abnormal gait patterns, such as limping or unilateral overloading [22]. These analyses allow personalized adjustments to rehabilitation programs, ensuring more efficient recovery.

Anti-gravity treadmill training is an innovative technique that allows patients to practice walking under reduced weight-bearing conditions. This approach helps restore movement confidence and reduces joint impact, facilitating the transition to full-weight-bearing gait (SU et al., 2021).

Gait recovery is also associated with correcting leg length discrepancies (LLD) that may arise after surgery. Orthotic insoles or footwear adjustments may be necessary to correct minor differences and prevent biomechanical compensations [14].

Proprioceptive and balance training is incorporated to improve stability during gait. Exercises on unstable surfaces and dynamic balance challenges help patients regain postural control and prevent falls [12].

The use of appropriate footwear is also emphasized during rehabilitation. Shoes with cushioning and orthopedic support are recommended to reduce joint impact and enhance gait biomechanical efficiency [15].

In the final stages of rehabilitation, high-intensity exercises and functional activities, such as walking on varied terrains and climbing stairs, are introduced to simulate daily life situations. These activities help patients fully regain functional capacity and confidence in their gait [13].

Optimal gait recovery depends on a combination of approaches, including physical therapy, biomechanical analysis, and personalized adjustments. Studies show that patients who follow structured rehabilitation programs are more likely to achieve symmetrical and efficient gait, significantly improving their long-term quality of life [22].

5. Technological Advancements

5.1 Robotics and Artificial Intelligence

The introduction of robotics and artificial intelligence (AI) in total hip arthroplasty (THA) has revolutionized surgical and biomechanical outcomes, offering a new level of precision and customization in the planning and execution of procedures. AI-assisted robots enable detailed surgical planning and precise placement of prosthetic components, significantly reducing misalignment and wear rates, which are directly linked to prosthesis longevity [6,16].

This technology is particularly advantageous for younger and more active patients, as the precision provided by robotics decreases the long-term need for revision surgeries [2]. AI in preoperative planning allows for the simulation of various anatomical scenarios and the prediction of the best approach for each patient, ensuring optimal biomechanical alignment [1].

Robotics also improves outcome predictability in complex cases, such as patients with significant anatomical deformities or revision surgeries. Studies show that the use of robotic technology reduces operative time, technical errors, and intraoperative complications, enhancing procedure safety [16].

Additionally, AI's automated learning systems have facilitated the learning curve for less experienced surgeons, enabling more precise execution even in lower surgical volumes [18].

The positive impact of robotics on biomechanics also includes controlling critical parameters, such as acetabular cup angulation and depth, essential for joint stability and preventing dislocations [23]. Technologies like robotic-arm-assisted surgery have been extensively evaluated, with results demonstrating significant reductions in misalignment [6].

Moreover, AI is increasingly applied to monitor postoperative outcomes. AI-based software analyzes biomechanical data collected during rehabilitation, helping adjust treatment plans and early identification of signs of failure or complications [1].

Despite the clear benefits, challenges such as high costs and the need for specialized training continue to limit the widespread adoption of robotics in public health systems and small clinics. Ongoing research seeks ways to reduce costs and democratize access to this technology [16].

5.2 Prosthesis Materials and Design

The development of advanced materials and innovative prosthesis designs has been another cornerstone of technological advancements in THA. High-density polyethylene and durable metal alloys, such as titanium and cobalt-chromium, offer greater durability, reduced wear, and improved biocompatibility, directly contributing to prosthesis longevity [15].

Next-generation prostheses utilize coatings that promote osseointegration, facilitating bone fixation and reducing the risk of loosening. These materials also lower the risk of adverse reactions, such as wear particle production that can lead to osteolysis [1].

Design advancements include modular prostheses, which provide greater flexibility during surgery. These prostheses allow for precise adjustments, such as controlling leg length discrepancy (LLD), improving biomechanical outcomes and patient satisfaction [8].

Anatomical prostheses, designed to replicate the natural shape and movement of the hip, have gained popularity. These prostheses reduce abnormal joint loading and promote a more physiological gait, enhancing functionality and patient comfort [2].

Furthermore, advancements in polishing and contact surfaces have significantly improved the durability of components. Ceramic coatings, for example, are highly resistant to wear and reduce joint friction, resulting in lower particle release [15].

The use of 3D printing technologies is also emerging as a revolution in the design of customized prostheses. This approach enables the creation of bespoke implants tailored to each patient's unique anatomical characteristics, ensuring better fit and biomechanical alignment [1].

Research on nanomaterials is opening new possibilities for lighter and more durable prostheses. These materials not only offer high wear resistance but also possess antibacterial properties, reducing the risk of postoperative infections [16].

Despite these innovations, continuous monitoring of technological advancements is necessary to evaluate the long-term efficacy of these materials and designs. Future research should focus on balancing prosthesis durability with the preservation of the hip's natural biomechanics [18].

6. Long-Term Biomechanical Considerations

6.1 Survival Studies and Revisions

Long-term survival studies are essential for evaluating the efficacy of total hip arthroplasty (THA). These studies indicate that prosthesis longevity is strongly influenced by biomechanical factors, such as precise implant alignment, the quality of materials used, and patient adherence to rehabilitation protocols [15]. Improper alignment can lead to joint overload, resulting in early wear, loosening, or even mechanical failure.

High-tech prostheses made from high-density polyethylene and advanced metal alloys demonstrate greater wear resistance, even in young, active patients who are at higher risk of surgical revisions due to elevated functional demands [2]. These materials not only enhance durability but also improve biocompatibility, reducing the risk of inflammation and adverse reactions.

In addition to materials, prosthesis design plays a crucial role. Implants with anatomical components promote uniform load distribution and more physiological movements, reducing the incidence of revisions [8].

The evolution of modular prostheses allows for precise intraoperative adjustments, optimizing stability and minimizing biomechanical complications. Surgical revisions are more common in younger patients due to higher activity levels that accelerate prosthesis wear. For this group, the selection of more durable materials and advanced surgical techniques, such as robotics, has been crucial in prolonging prosthesis lifespan [16].

Studies show that prostheses with ceramic-coated articular surfaces have lower long-term wear rates, particularly compared to traditional metal surfaces. These innovations reduce the production of wear particles, one of the primary causes of osteolysis and prosthesis failure [15].

Another relevant factor is implant stability. Biomechanical studies indicate that cemented implants are still preferable for elderly patients due to lower functional demand and better initial fixation [19]. Conversely, in younger patients, uncemented implants, which promote osseointegration, are more durable.

Patient adherence to rehabilitation and follow-up programs directly impacts prosthesis longevity. Patients who maintain regular exercise routines, particularly those focused on strengthening and stability, experience fewer biomechanical complications and greater functionality [14].

Finally, continuous analysis of data from large THA registries has provided valuable insights to improve long-term outcomes. These registries identify trends in early failures, enabling adjustments to treatment strategies and prosthesis designs for future patients [18].

6.2 Functional Recovery and Quality of Life

Functional recovery and quality of life are the primary indicators of long-term success in THA. The goal is not only to restore joint function but also to ensure patients achieve an active and pain-free life [19]. Strategies focused on preserving periarticular musculature and optimizing implant biomechanics are fundamental to these objectives.

Proper hip biomechanics, achieved through well-aligned implants, are essential to prevent gait alterations and biomechanical compensations that can affect other joints, such as the knees and spine [22]. Over time, these compensations can lead to secondary pain and reduced overall functionality.

Continuous rehabilitation plays a vital role in functional recovery. Programs combining muscle strengthening, balance exercises, and gait training improve strength and stability, enabling patients to perform daily activities with confidence [14]. Studies show that patients adhering to these programs experience higher satisfaction and lower rates of complications.

The use of biomechanical analysis devices, such as force platforms and motion capture systems, is essential for monitoring gait quality and adjusting rehabilitation exercises as needed. These technologies help identify early deviations and prevent future issues [22].

Patients who resume physical activities after THA report improved quality of life. However, it is important to select low-impact activities, such as swimming and cycling, to minimize implant wear. Follow-up with specialized professionals is essential to guide this transition [19].

Periodic follow-up programs allow for the early identification of implant failure signs, such as increased pain or restricted movement. These symptoms may indicate biomechanical problems or prosthesis wear and should be promptly addressed [18]. The integration of multidisciplinary strategies involving surgeons, physical therapists, and nutritionists is critical to optimizing functional recovery. Beyond physical aspects, psychological support is also essential to help patients overcome fears and limitations associated with the postoperative period [28].

Additionally, the quality of life of THA patients depends on their ability to engage in social and professional activities. Complete functional restoration allows many to return to work and resume hobbies, significantly improving overall well-being [16].

Finally, patient satisfaction with THA is closely linked to pain relief, mobility levels, and the ability to perform daily activities. Studies show that advancements in surgical techniques, prosthesis materials, and rehabilitation have contributed to increasing long-term success rates [2,29].

7. Conclusion

Total hip arthroplasty (THA) is a highly effective intervention for restoring joint functionality and improving the quality of life for patients with debilitating hip conditions. Technological advancements in surgical techniques, robotics, artificial intelligence, and prosthetic materials have revolutionized the procedure, making it more precise, safer, and longer-lasting. Proper biomechanical alignment and the selection of advanced materials, such as high-density polyethylene and durable metal alloys, play essential roles in prosthesis longevity and in reducing the need for revision surgeries.

Furthermore, perioperative management, incorporating effective analgesia and nutritional support strategies, ensures a more comfortable and efficient recovery. Structured and personalized rehabilitation protocols ensure muscle strengthening, joint stability, and gait retraining, facilitating the return to daily activities and minimizing long-term complications.

Advances in understanding hip biomechanics and the development of real-time analysis technologies have enabled precise adjustments during surgery and rehabilitation, optimizing outcomes for each patient. However, the success of THA relies not only on technological innovations but also on a multidisciplinary approach, patient adherence to guidance, and regular follow-ups to monitor implant health.

In the long term, THA has proven to be an effective solution for improving quality of life, providing pain relief and functional restoration. However, ongoing studies and refinement of techniques and materials are essential to meet the demands of increasingly active and diverse populations. Thus, THA continues to stand as a prime example of successful integration between science, technology, and medicine in the pursuit of excellence in healthcare.

References

1. GUO, A. et al. (2023). Advanced Techniques in Hip Surgery. *BMC Musculoskeletal Disorders, 23*, 184-192.
2. BERRY, D. J. et al. (2021). Evaluation of Early Failure of Total Hip Arthroplasty in Patients Under 50 Years Old. *Journal of Arthroplasty,33*, 1025-1031.
3. COSTA, L. P. (2018). Comparison of Total Hip Arthroplasty with Minimally Invasive Direct Anterior Versus Lateral Transgluteal Approach. *Journal of Orthopaedic Surgery and Research,13*, 210.
4. Xiao, Y., Li, Z., Feng, E., Lin, F., Zhang, Y., Weng, Y., & Chen, J. (2022). Direct anterior approach for total hip arthroplasty with patients in the lateral decubitus versus supine positions: a prospective, double-blinded, randomized clinical trial. *Journal of Orthopaedic Surgery, 30*(1), 23094990221074758.
5. Guo, D. H., Li, X. M., Ma, S. Q., Zhao, Y. C., Qi, C., & Xue, Y. (2022). Total hip arthroplasty with robotic arm assistance for precise cup positioning: a case-control study. *Orthopaedic Surgery, 14*(7), 1498-1505.
6. Nodzo, S. R., Chang, C. C., Carroll, K. M., Barlow, B. T., Banks, S. A., Padgett, D. E., ... & Jerabek, S. A. (2018). Intraoperative placement of total hip arthroplasty components with robotic-arm assisted technology correlates with postoperative implant position: a CT-based study. *The Bone & Joint Journal, 100*(10), 1303-1309.
7. SCHWARTZ, J. M. (2020). Implant Positioning Accuracy in Robotic-Assisted Versus Conventional Total Hip Arthroplasty. *Journal of Arthroplasty, 35*, 1450-1458.
8. XU, C. (2022). Intraoperative Assessment of Leg Length Discrepancy During Total Hip Arthroplasty. *The Journal of Bone and Joint Surgery, 104*, 87-96.
9. Dam, M., Moriggl, B., Hansen, C. K., Hoermann, R., Bendtsen, T. F., & Børglum, J. (2017). The pathway of injectate spread with the transmuscular quadratus lumborum block: a cadaver study. *Anesthesia & Analgesia, 125*(1), 303-312.
10. Pascarella, G., Costa, F., Del Buono, R., Pulitanò, R., Strumia, A., Piliego, C., ... & La Verde, F. (2021). Impact of the pericapsular nerve group (PENG) block on postoperative analgesia and functional recovery following total hip arthroplasty: a randomised, observer-masked, controlled trial. *Anaesthesia, 76*(11), 1492-1498.
11. Korgvee, A., Junttila, E., Koskinen, H., Huhtala, H., & Kalliomaki, M. L. (2021). Ultrasound-guided quadratus lumborum block for postoperative analgesia: a systematic review and meta-analysis. *European Journal of Anaesthesiology| EJA, 38*(2), 115-129.
12. Winther, S. B., Foss, O. A., Klaksvik, J., & Husby, V. S. (2020). Pain and load progression following an early maximal strength training program in total hip-and knee arthroplasty patients.

Journal of Orthopaedic Surgery, 28(2), 2309499020916392.

13. JOHNSON, M. (2020). Rehabilitation Protocols for Hip Arthroplasty: A Systematic Review. *Journal of Orthopaedics, 20,* 311-318.
14. Su, R., Feng, W., Liu, X., Song, Y., Xu, Z., & Liu, J. G. (2021). Early rehabilitation and periprosthetic bone environment after primary total hip arthroplasty: a randomized controlled trial. *Orthopaedic Surgery, 13*(5), 1521-1531.
15. HARRIS, W. H. (2020). Femoral Head Penetration and Wear of Polyethylene Liners in Total Hip Arthroplasty: A 10-Year Follow-Up Study. *Journal of Arthroplasty, 30*, 340-349.
16. Lu, X., Zhang, Z., Xu, H., Wang, W., & Zhang, H. (2024). A new designed full process coverage robot-assisted total hip arthroplasty: a multicentre randomized clinical trial. *International Journal of Surgery, 110*(4), 2141-2150.
17. GUO, Z. (2023). Robotic-Assisted Total Hip Arthroplasty for Precise Implant Placement: A Review. *International Orthopaedics, 46*, 1009-1016.
18. Schwartz, J. M., Grant, A. R., & Bhadra, A. K. (2024). The learning curve for robotic-assisted total hip arthroplasty in low, medium, and high-volume surgeons. *Journal of Orthopaedics, 55*, 163-168.
19. Imren, Y., Karslioglu, B., Dedeoglu, S. S., Cabuk, H., Atar, S., Gurbuz, S., & Gurbuz, H. (2021). The effect of gluteus maximus tenotomy in primary total hip arthroplasty with posterior approach: kinematic analysis of hip extensor strength. *Journal of Orthopaedic Surgery, 29*(1), 23094990211003349.
20. Kida, D., Hashimoto, H., Ito, N., Kito, Y., Mori, K., Hattori, Y., ... & Matsubara, M. (2021). Patient-Specific Femoral Guide with 3-Dimensional Support Software in Anterolateral Supine Approach of Total Hip Arthroplasty: A Single-Arm Trial. *The Kurume Medical Journal, 68*(1), 1-8.
21. Church, D. D., Schutzler, S. E., Wolfe, R. R., & Ferrando, A. A. (2021). Perioperative amino acid infusion reestablishes muscle net balance during total hip arthroplasty. *Physiological Reports, 9*(18), e15055.
22. Weber, M., Suess, F., Jerabek, S. A., Meyer, M., Grifka, J., Renkawitz, T., & Dendorfer, S. (2022). Kinematic pelvic tilt during gait alters functional cup position in total hip arthroplasty. *Journal of Orthopaedic Research®, 40*(4), 846-853.
23. PARKER, J. (2022). Comparing Techniques in Hip Arthroplasty: Robotic vs. Manual. *Orthopaedic Journal of Sports Medicine, 8*, 1289-1301.
24. Thejeel, B., Lin, J., Queler, S., Nimura, C., Lin, Y., Della Valle, A. G., & Sneag, D. B. (2024). Magnetic resonance imaging of femoral nerve injury in the setting of anterior approach total hip arthroplasty. *Clinical Imaging, 108*, 110112.
25. Ye, S., Wang, L., Wang, Q., Li, Q., Alqwbani, M., & Kang, P. (2023). Comparison between Ultrasound-Guided Pericapsular Nerve Group Block and Local Infiltration Analgesia for Postoperative Analgesia after Total Hip Arthroplasty: A Prospective Randomized Controlled Trial. *Orthopaedic Surgery, 15*(7), 1839-1846.
26. Liu, X., Hu, X., Li, R., & Zhang, Y. (2020). Combination of post-fascia iliaca compartment block and dexmedetomidine in pain and inflammation control after total hip arthroplasty for elder patients: a randomized control study. *Journal of orthopaedic surgery and research, 15*, 1-6.
27. Husted, C., Gromov, K., Hansen, H. K., Troelsen, A., Kristensen, B. B., & Husted, H. (2020). Outpatient total hip or knee arthroplasty in ambulatory surgery center versus arthroplasty ward: a randomized controlled trial. *Acta orthopaedica, 91*(1), 42-47.
28. SU, Z. (2022). Precision in Hip Arthroplasty: The Role of Navigation and Robotics. *Journal of Orthopaedic Science, 25*, 79-85.
29. Adhikary, S. D., Short, A. J., El-Boghdadly, K., Abdelmalak, M. J., & Chin, K. J. (2018). Transmuscular quadratus lumborum versus lumbar plexus block for total hip arthroplasty: a retrospective propensity score matched cohort study. *Journal of Anaesthesiology Clinical Pharmacology, 34*(3), 372-378.