Review Paper

Advances in Biomechanics and Optimization Strategies for Total Hip Arthroplasty: A Mini-review

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ABSTRACT

Total hip arthroplasty (THA) is a transformative surgical procedure that addresses debilitating hip conditions such as fractures and osteoarthritis, especially in the aging population. Optimal acetabular positioning plays a pivotal role in achieving successful outcomes by influencing joint stability, range of motion, and implant longevity. This review synthesizes recent advancements in surgical techniques, including robotic-assisted systems, patient-specific instrumentation (PSI), and personalized orthopedics, to address challenges such as malpositioning, dislocation, and implant wear. Key factors affecting acetabular alignment—such as the center of rotation, angular positioning, and pelvic tilt—are explored, along with the role of preoperative optimization in enhancing patient outcomes. Furthermore, emerging technologies like 3D printing, advanced imaging, and multimodal analgesia are discussed for their impact on precision and recovery. By integrating biomechanical insights and innovation, this review highlights the potential to minimize complications and improve the durability and effectiveness of THA.

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Introduction

Hip fractures represent a growing challenge frequently managed by orthopedic surgeons across the United States. This trend is largely driven by the steady growth of the elderly population, a demographic shift that places an increasing strain on healthcare systems. Projections indicate that the incidence of hip fractures will surpass 580000 cases by 2040. This anticipated rise underscores the critical need for advancements in preventative strategies, improved surgical techniques, and post-operative care tailored to the aging population. Moreover, this issue highlights the importance of addressing underlying risk factors, such as osteoporosis and fall prevention, to mitigate the societal and economic burden associated with hip fractures [1, 2]. Management of hip fractures typically involves surgical intervention, with the choice of procedure depending on factors such as fracture type and location, patient age, bone quality, and overall health status. Common surgical options include open reduction and internal fixation (ORIF), which realigns the bone fragments and stabilizes them with hardware. Other approaches include the use of intramedullary devices or a dynamic hip screw and plate to provide stabilization. In cases where joint preservation is not feasible, partial joint replacement (hemiarthroplasty) or full joint replacement with a total hip arthroplasty (THA) may be performed. Each of these techniques aims to restore mobility, alleviate pain, and minimize complications, ensuring the best possible outcome for the patient [3, 4].

Although surgical interventions for hip fractures are typically effective in restoring mobility and function, postoperative complications are still a common concern. Potential issues following surgery include fracture non-union or malunion, hardware migration, femoral head osteonecrosis, infection, and the development of post-traumatic osteoarthritis. These complications can adversely affect recovery and long-term outcomes. Common issues include nonunion or malunion of the fracture, where the bone either fails to heal properly or heals in an incorrect alignment.

Additionally, hardware migration, in which the surgical implants shift from their intended position, may necessitate adjustment surgery. Other serious complications include osteonecrosis of the femoral head, a condition caused by disrupted blood flow leading to bone tissue death, and post-traumatic osteoarthritis, where joint degeneration occurs as a consequence of the injury and surgical intervention. Infections, particularly deep surgical site infections, can further complicate recovery and require intensive treatment, including antibiotics or additional surgeries. Recognizing these potential risks highlights the importance of meticulous surgical technique, early mobilization, and close postoperative monitoring to minimize complications and optimize patient outcomes. Research into advanced surgical methods, improved fixation devices, and innovative rehabilitation protocols may further reduce these risks in the future [5-11]. Failed surgical fixation of hip fractures is sometimes unsuccessful, leading to the need for conversion to arthroplasty as a salvage procedure. This procedure is typically indicated when primary treatments are unsuccessful, such as in cases of failed acetabular fracture fixation, unsuccessful hemiarthroplasty, or the onset of osteoarthritis in individuals with a history of prior hip surgeries, including those previously treated for developmental dysplasia of the hip (DDH). The growing prevalence of hip fractures and osteoarthritis, largely driven by an aging population, is expected to contribute significantly to the increasing number of conversion THA procedures being performed in the United States. Despite this trend, conversion THA is currently grouped with primary THA under the same diagnosis-related group classification by the Center for Medicare and Medicaid Services.

In this mini-review, we aim to explore the critical role of optimization strategies in improving patient outcomes after hip arthroplasty. Given the increasing prevalence of hip fractures and degenerative joint diseases in an aging population, the importance of addressing modifiable risk factors before surgery cannot be overstated. Factors such as nutritional status, comorbidity management, smoking cessation, and physical conditioning have been shown to significantly impact surgical outcomes, including recovery time, complication rates, and long-term joint function. By synthesizing recent evidence, this review highlights the value of a multidisciplinary approach to preoperative care, emphasizing its potential to enhance patient outcomes, reduce healthcare costs, and improve overall quality of life (QoL) for those undergoing hip arthroplasty.

Acetabular

Acetabular positioning

Proper acetabular positioning is a critical determinant of success in THA, playing a foundational role in achieving optimal functional and clinical outcomes. As the socket component of the hip joint, the acetabulum houses the femoral head, ensuring smooth articulation and joint stability. In the context of THA, the natural acetabulum is replaced with a prosthetic cup, making precise alignment essential to restoring normal hip biomechanics. Accurate positioning directly influences joint stability, range of motion, implant longevity, and the risk of complications such as dislocation, impingement, or abnormal wear of the prosthetic components. Furthermore, achieving the correct orientation of the acetabular cup requires balancing anatomical variations, soft-tissue dynamics, and patient-specific factors, underscoring the technical demands of this procedure and its importance for the long-term success of THA [12]. The positioning of the acetabular component is a pivotal factor in determining the biomechanical performance and stability of the artificial hip joint in THA. Precise alignment and orientation are essential to achieving even load distribution across the prosthetic surfaces, which helps minimize wear and decreases the likelihood of implant loosening or failure over time.

Additionally, proper placement is fundamental for restoring critical anatomical parameters, such as limb length, hip offset, and soft-tissue tension. These factors collectively contribute to optimal hip function, joint stability, and an improved range of motion following surgery. Failure to achieve proper acetabular positioning may result in complications such as dislocation, impingement, or premature prosthetic wear, emphasizing the importance of meticulous surgical planning and technique to ensure successful patient outcomes [13].

On the other hand, suboptimal acetabular positioning can significantly compromise the longevity and functionality of the prosthetic joint, leading to a cascade of adverse outcomes. Malpositioned components can result in impingement between the femoral neck and the acetabular rim, causing pain, restricted range of motion, and accelerated wear of the prosthetic materials. Additionally, insufficient coverage of the femoral head by the acetabular component heightens the risk of dislocation, one of the most frequent and impactful complications after THA. Dislocation not only necessitates additional medical interventions but also profoundly affects patient satisfaction and overall QoL. These risks underscore the necessity of precision in acetabular positioning to optimize surgical outcomes and ensure long-term success in THA [14].

Given the pivotal role of acetabular positioning in THA outcomes, meticulous attention to detail and precision are essential during both the planning and execution stages of surgery. Surgeons must carefully consider a range of factors, such as patient-specific anatomy, biomechanical requirements, and the chosen surgical approach, to ensure optimal placement of the acetabular component. Achieving this precise alignment is crucial to the long-term success of the procedure and the patient's functional recovery. Recent advancements in surgical techniques, coupled with innovations in navigation systems and intraoperative imaging technologies, have significantly improved the accuracy and reproducibility of acetabular positioning. These developments enable surgeons to tailor the procedure to individual patient needs, thereby enhancing the overall effectiveness, durability, and success of THA [13].

Biomechanical considerations in acetabular positioning

The acetabulum is a large, hemispherical cavity situated on the lateral side of the hip bone. It plays a fundamental role in the hip joint by serving as the socket that articulates with the femoral head, facilitating smooth, stable hip movement. This critical joint connection allows for a wide range of motion and weight-bearing functions essential for daily activities, making the proper alignment and maintenance of the acetabulum vital for overall hip joint health [15]. The acetabulum is formed through the fusion of three pelvic bones: The ilium, ischium, and pubis. The ilium forms the superior portion of the acetabulum, offering a wide and stable surface that supports the femoral head. The ischium forms the posterior wall of the acetabulum, providing support and reinforcing the socket's posterior aspect. The pubis constitutes the anterior wall, completing the structure of the acetabulum and ensuring a secure articulation with the femoral head. This triadic fusion creates a well-defined, functional socket, essential for proper hip joint movement and stability [15].

As a vital component of the hip joint, the acetabulum plays a central role in both weight-bearing and locomotion. It forms a crucial connection between the pelvis and the lower limb, facilitating the transfer of body weight during standing, walking, and other movements. By providing a stable, smooth socket for the femoral head, the acetabulum ensures the hip joint functions efficiently, supports the body's weight, and maintains flexibility and mobility during various activities. This dynamic relationship is essential for the overall biomechanics of the lower body [16]. The hip joint, a ball-and-socket joint, allows for a wide range of motion by enabling the spherical femoral head to rotate smoothly within the cup-shaped acetabular socket. This design facilitates dynamic movements, such as running, climbing, and jumping, by permitting flexion, extension, abduction, adduction, and rotational movements. The unique structure of the ball-and-socket joint ensures stability while providing the necessary mobility for various physical activities, making it crucial for daily functioning and athletic performance [16]. The joint formed between the acetabulum and the femoral head is primarily cartilaginous, allowing for smooth motion within the hip. The anteroinferior acetabular notch further deepens the socket, thereby enhancing the joint's stability. This notched area, located at the front and lower part of the acetabulum, plays a key role in accommodating the ligamentum teres. This structure helps maintain the femoral head's position within the socket. The acetabular notch also helps optimize the overall fit of the femoral head within the acetabulum, enhancing joint stability and mobility during various movements [16]. Surrounding the acetabulum is the acetabular labrum, a ring of cartilage that serves to enhance the joint's stability and depth. This fibrocartilaginous structure wraps around the acetabulum, deepening the socket and providing a better fit for the femoral head. The acetabular labrum plays a crucial role in maintaining the stability of the hip joint by acting as a seal, helping to prevent dislocation and reducing the risk of joint instability. Additionally, it contributes to the distribution of pressure across the joint during weight-bearing activities, ensuring smooth and efficient movement [16].

Biomechanical factors play a crucial role in the success of THA, especially regarding the accurate alignment of the acetabular component. Proper positioning of this component is vital to reestablish normal hip biomechanics, which in turn affects joint stability, function, and long-term results. Proper alignment ensures a functional range of motion, reducing the risk of complications such as dislocation, muscle weakness, and gait abnormalities. Additionally, proper acetabular positioning helps prevent such problems as limb-length discrepancies, impingement, noise generation, and premature implant wear and loosening. These biomechanical factors collectively contribute to the success of the procedure, enhancing patient satisfaction and minimizing the need for revision surgeries [12, 17]. Several variables influence the optimal positioning of the acetabular cup, including depth, height, and angular alignment—specifically anteversion and inclination. These parameters are critical for achieving the ideal joint mechanics and stability. Adjustments in the depth of the center of rotation (COR) have significant implications, particularly when comparing medialized versus anatomical positioning. A medialized position may improve joint reaction force by redistributing stress across the joint, potentially enhancing stability. However, anatomical positioning provides key benefits such as improving the range of motion, reducing the risk of impingement, ensuring an effective cortical rim press fit, and aiding in the preservation of medial bone stock. Balancing these factors is essential to optimize both functional outcomes and long-term implant survival [12]. The height of the COR is a key factor that influences muscle activity, limb lengths, and the available bone stock for supporting the acetabular cup. Variations in COR height can affect how forces are transmitted through the hip joint, impacting both function and stability. The ideal angular position of the acetabular cup remains a subject of ongoing debate, with various definitions of anteversion and inclination based on operative, radiologic, or anatomic perspectives.

Additionally, pelvic tilt plays a critical role in determining the functional orientation of the acetabulum. Yet, common positioning techniques may not accurately capture the true alignment of the pelvis during surgery. This discrepancy can result in significant pelvic adduction, flexion, and external rotation on the operating table, potentially leading to misalignment and affecting the long-term success of the procedure. Proper intraoperative assessment and adjustments are necessary to ensure the acetabular component is correctly positioned, thereby minimizing these risks [12]. Recent technological advancements, such as 3D printing for creating customized device components and surgical instrumentation, have significantly improved the outcomes of THA. However, the growing recognition of personalized orthopedics highlights that the success of THA is not solely dependent on advanced technology but also on achieving biomechanics tailored to each patient. Personalized orthopedics focuses on customizing treatment based on individual factors such as genetics, lifestyle, and environment, aiming to optimize the approach for each patient's unique needs. This evolving concept is gaining global traction, as it offers the potential for more effective, individualized care that enhances the short- and long-term success of THA procedures. By integrating these personalized approaches, healthcare providers can better address patients' diverse characteristics, ultimately improving functional outcomes and minimizing complications [17]. This customized approach holds significant promise for further optimizing THA outcomes, as it takes into account the unique needs of each patient, leading to more precise and effective treatment plans. By tailoring surgical techniques, implant selection, and rehabilitation strategies based on factors like genetics, lifestyle, and environment, healthcare providers can enhance both patient satisfaction and functional outcomes. The ability to customize treatment not only increases the likelihood of successful surgery but also helps reduce complications and accelerate recovery, offering a more holistic, patient-centered approach to THA.

Factors influencing optimal acetabular positioning

The ideal positioning of the acetabulum in THA depends on multiple parameters, such as depth, height, angular orientation (anteversion and inclination), and pelvic tilt. Accurate placement of the acetabular cup is essential, as it significantly affects several key outcomes of the procedure. These outcomes include reducing the risk of dislocation, maintaining abductor muscle strength, ensuring proper gait dynamics, and preserving limb length consistency. Accurate positioning also minimizes the risk of impingement, noise generation, and implant wear, while contributing to range of motion, implant loosening, and the overall durability of the cup. Given the complexity and significance of these factors, achieving optimal acetabular placement is essential for improving both short- and long-term THA outcomes [12]. The depth of the acetabular component relative to the COR plays a critical role in influencing both joint reaction force and range of motion. A properly positioned acetabular cup ensures optimal load distribution across the hip joint and facilitates functional movement.

Meanwhile, the height of the component affects muscle activation patterns, the consistency of limb lengths, and the structural support provided by the surrounding bone stock. Correct alignment in these dimensions helps maintain proper biomechanics, enhancing joint stability, preventing complications, and promoting long-term success in THA [12]. Angular positioning, including anteversion and inclination, is crucial for avoiding several complications following THA. Proper alignment of these angles helps mitigate risks such as dislocation, accelerated wear, osteolysis, impingement, and limb length discrepancies. Achieving the optimal anteversion and inclination ensures that the acetabular component functions within the ideal biomechanical range, improving stability, reducing stress on the implant, and enhancing overall hip function. These considerations are key to achieving favorable long-term outcomes for patients undergoing THA [12, 13].

Additionally, pelvic tilt is a critical factor in determining functional acetabular positioning, as variations in pelvic orientation can significantly influence the placement of the acetabular component during surgery. Pelvic tilt affects the relationship between the pelvis and the acetabulum, impacting the alignment of the cup and the overall biomechanics of the hip joint. Inaccurate assessment or adjustment of pelvic tilt during surgery may result in improper positioning, potentially leading to complications such as dislocation, impingement, or altered joint mechanics. Therefore, careful consideration of pelvic tilt is essential to ensure optimal acetabular alignment and improve postoperative outcomes [12, 13]. Achieving optimal acetabular positioning requires a thorough understanding of the multifaceted factors involved in THA to enhance both the efficacy and durability of the procedure. By carefully considering elements such as depth, height, angular positioning, and pelvic tilt, orthopedic surgeons can tailor the surgical approach to each patient's unique anatomy. Addressing these factors with precision helps optimize joint stability, range of motion, and implant longevity while minimizing the risk of complications such as dislocation, impingement, and wear. Ultimately, a meticulous approach to acetabular placement supports improved patient outcomes and long-term success, ensuring that THA remains a reliable option for hip joint restoration.

Historical perspective

The historical perspective on acetabular positioning in THA has undergone significant evolution. In the early stages of THA, conventional techniques focused on positioning the COR of the prosthetic medially relative to the native COR. This approach aimed to replicate the biomechanics of the natural hip joint by placing the acetabular component medially. Any resultant shifts in joint mechanics were typically addressed by adjusting the femoral offset to maintain proper function and stability. While this approach was effective in some cases, it did not fully account for the complex factors influencing range of motion, joint stability, and long-term implant survival, leading to the development of more refined techniques in later years [18]. However, this medially centered approach to acetabular positioning in THA presented several challenges. One of the primary issues was the soft tissue constraints, which limited the soft tissues' ability to adapt to the altered hip mechanics, potentially leading to complications such as muscle weakness and restricted movement. Additionally, impingement became a concern, as the altered positioning of the acetabular component could cause the femoral head to collide with the acetabular rim, restricting range of motion and leading to pain and functional limitations. Furthermore, this medially positioned COR sometimes contributed to instability, particularly with hip flexion and rotation, ultimately affecting the overall stability of the joint and increasing the risk of dislocation. These challenges prompted the search for more refined and individualized approaches to acetabular alignment to better accommodate the biomechanics of the hip joint [18]. A pivotal "kinematic revolution" has significantly transformed THA practice, marking a shift towards a more individualized approach to implant placement. This new paradigm emphasizes the importance of patient-specific biomechanics in determining the optimal positioning of the acetabular component and femoral prosthesis. Rather than adhering to a one-size-fits-all methodology, surgeons now take into account factors such as pelvic tilt, femoral offset, muscle strength, and anatomical variations to achieve a more personalized alignment. This approach aims to restore the natural mechanics of the hip joint, improving range of motion, joint stability, and patient satisfaction while minimizing the risk of complications like impingement and dislocation. The kinematic revolution has paved the way for more precise and successful THA procedures with better long-term outcomes [18]. Surgeons have transitioned from a standardized approach to acetabular cup placement in THA to a more nuanced strategy that emphasizes restoring the hip's native range of motion. This modern approach focuses on respecting the natural anteversion of the acetabulum and ensuring that the cup is positioned with precision, tailored to each patient's unique anatomy. By considering factors such as pelvic tilt, femoral offset, and muscle strength, surgeons aim to replicate the hip's original biomechanics, reducing the risk of impingement, dislocation, and wear. This shift to a more patient-specific technique not only improves joint stability and function but also enhances patient satisfaction and long-term implant success [18]. This paradigm shift underscores the growing recognition of the critical role that accurately reconstructing biomechanics plays in optimizing joint function and ensuring implant longevity in THA. By focusing on individual patient factors, such as pelvic anatomy, muscle dynamics, and natural hip alignment, surgeons can better replicate the original mechanics of the hip joint. This approach not only improves range of motion and stability but also helps minimize complications such as dislocation, impingement, and wear, ultimately contributing to better long-term outcomes and patient satisfaction [13]. This evolution in THA reflects growing patient demand for a greater range of motion, improved functional outcomes, and pain relief. As patients seek more active lifestyles, THA is increasingly being offered to younger, more physically active individuals, many of whom have higher expectations for their implants. This trend underscores the critical need for implant longevity to ensure long-term success, as these patients will likely place greater physical demands on the joint over time. The shift toward more personalized and precise surgical techniques plays a pivotal role in meeting these demands, ensuring both immediate and long-term improvements in joint function and QoL [12]. The transition towards patient-specific acetabular cup placement underscores the imperative of tailoring surgical interventions to individual biomechanical characteristics, intending to optimize both functional outcomes and implant durability. This shift is particularly significant given the evolving patient demographics—with younger, more active individuals seeking THA—and increasing patient expectations for improved range of motion, pain relief, and long-term performance. By considering these personalized factors, surgeons can better restore the hip's natural mechanics, ensuring not only a more stable and functional joint but also greater longevity of the implant, ultimately enhancing patient satisfaction and improving overall QoL.

Conventional techniques and their limitations

Traditional methods for acetabular placement in THA have shown significant drawbacks, especially regarding the medial shift or misalignment of the COR. These approaches, which traditionally aimed to position the acetabular component relative to the native COR medially, have often resulted in compromised biomechanics, including reduced joint stability, altered hip offset, and limited range of motion. Such limitations can contribute to increased wear, impingement, and dislocation risks, leading to suboptimal outcomes and reduced implant longevity. As a result, there has been a growing shift toward more individualized strategies that prioritize restoring the hip's natural biomechanics and anatomical alignment to optimize both function and implant durability [19]. Conventional methods for acetabular positioning can lead to problematic outcomes, such as anterior overhang, which may impinge on the iliopsoas, or posterior overhang if excessive anteversion is applied. Anterior overhang can result in muscle irritation and pain, while posterior overhang might compromise joint stability and increase the likelihood of dislocation. Additionally, poor alignment can lead to impingement between the femoral head and the acetabular rim, increasing the risk of implant wear, osteolysis, and premature failure. These issues highlight the importance of adopting more precise, patient-specific approaches to ensure better functional outcomes and implant longevity in THA [19]. To mitigate these issues, one suggestion is the use of extended offset polyethylene acetabular liners to help preserve COR. This modification aims to improve joint biomechanics and restore more natural motion. However, this approach may also increase torsional forces at both the liner-shell and bone-implant interfaces, potentially elevating the risk of implant loosening. While this strategy can provide benefits in terms of preserving the COR, it also necessitates careful consideration of the associated risks, particularly concerning the long-term stability of the implant [19]. Acknowledging the limitations of conventional techniques, there has been a significant shift towards more personalized approaches in acetabular positioning. There is growing emphasis on the benefits of achieving an anatomically optimal position that not only restores hip biomechanics but also enhances the functional range of motion. This approach takes into account individual patient anatomy and biomechanical considerations, aiming to improve outcomes by minimizing the risk of complications such as impingement, dislocation, and implant wear, while maximizing the overall functionality and longevity of the prosthetic joint [12, 17]. The introduction of robotic-assisted technology has significantly enhanced the precision of acetabular cup placement in THA. This advancement often leads to more accurate positioning, with a higher percentage of cups implanted within the Lewinnek and Callanan safe zones, recognized as optimal ranges for anteversion and inclination. By improving the precision of component placement, robotic systems help minimize complications such as dislocation, impingement, and wear, thereby improving functional outcomes and potentially extending the longevity of the implant [20]. Patient positioning is crucial for achieving optimal acetabular alignment during THA. While supine positioning simplifies assessment of pelvic orientation and limb length, lateral decubitus positioning is more commonly used, especially with the widespread adoption of the direct anterior approach (a minimally invasive technique). The lateral decubitus position facilitates better access to the acetabulum. It enhances the surgeon's ability to accurately position the acetabular component, though it may pose challenges in assessing pelvic tilt and rotation compared with the supine position. However, the direct anterior approach's benefits in terms of muscle sparing and early recovery have made it increasingly popular among surgeons [18]. These advancements and considerations highlight the continuous shift towards personalized and precise techniques in acetabular positioning. The goal is to optimize patient outcomes while minimizing the risk of complications in THA. By incorporating technologies such as robotic assistance, refining surgical approaches, and addressing individual anatomical and biomechanical factors, the field is moving towards a more tailored approach that enhances both functionality and implant longevity, ensuring better long-term results for patients.

Complications associated with suboptimal positioning

Complications resulting from improper acetabular component positioning in THA can lead to various detrimental outcomes, negatively affecting both the functional and long-term success of the procedure. These issues include a restricted range of motion, higher dislocation rates, and accelerated wear of various bearing materials, including polyethylene, metal-on-metal, and ceramic-on-ceramic. Moreover, poorly positioned components can lead to fatigue fractures in highly cross-linked polyethylene and to undesirable squeaking or even fracturing of ceramic bearings. Suboptimal positioning can also contribute to poorer patient-reported outcomes (PROs), iliopsoas tendinitis, discrepancies in leg length, and overall compromised biomechanics. Additionally, the risk of osteolysis, aseptic loosening, component migration, and a greater need for revisions is elevated, further underscoring the importance of accurate acetabular alignment to ensure long-lasting, optimal results in THA [21-23]. These complications limit the range of motion, increase the likelihood of dislocation, and accelerate wear- and fatigue-related failures across different bearing materials, ultimately affecting both patient satisfaction and the long-term durability of the implant [21-23].

Additionally, obese patients are more prone to malpositioning compared to those with lower body mass index (BMI), due to factors like a reduced surgical field within a fixed incision size, caused by increased adipose tissue. The considerable depth of fat can also alter the angle at which the acetabular component is positioned, particularly when navigating a deep wound [21]. Furthermore, in obese patients, achieving the ideal pelvic positioning becomes more difficult, which increases the likelihood of suboptimal acetabular component placement [21]. These factors highlight the necessity of personalized strategies and careful attention to individual patient characteristics to optimize acetabular positioning and reduce the risk of complications in THA.

Computer-assisted navigation systems are a technological advancement increasingly used across a range of surgical specialties, including orthopedic surgery, oral and maxillofacial surgery, and knee arthroplasty. These systems enhance precision, improve surgical planning, and allow for real-time intraoperative guidance, leading to more accurate procedures and better patient outcomes [24-26]. These systems utilize advanced imaging technology to provide real-time feedback, allowing surgeons to make more precise and accurate decisions during surgery. By tracking the position and orientation of surgical instruments and implants, computer-assisted navigation enhances the overall accuracy of procedures, leading to improved outcomes and reduced complications [27]. The rigid body marker is attached to the patient or surgical tools, enabling the system to track their precise location within the surgical field. Together, these components work seamlessly to provide enhanced guidance during procedures, improving accuracy and reducing the potential for errors [26]. The computer platform coordinates the integration of data from the surgical field, processes it through mathematical algorithms, and displays the resulting information on a monitor for the surgeon. This real-time visualization allows the surgeon to track the position of instruments and implants, making adjustments as needed to ensure optimal placement and alignment during the procedure. The platform's ability to provide precise, updated feedback enhances the accuracy of surgical actions, contributing to improved outcomes and reduced complication rates [26]. The tracking system uses optical cameras, electromagnetic coils, or ultrasonic probes to detect signals emitted by trackers attached to the patient's bones or surgical instruments. These trackers transmit positional data in real time, allowing the system to monitor the movements and alignment of both the patient and the surgical tools. The information is then relayed to the computer platform, where it is processed and displayed, providing the surgeon with precise spatial awareness of the instruments and anatomical structures, thereby enhancing the accuracy of the procedure [26]. Computer-assisted navigation systems have revolutionized surgical practice, particularly in orthopedics, by providing real-time feedback and enhancing the accuracy and precision of implant placement and instrument manipulation. These advanced technologies offer significant improvements over traditional methods, minimizing human error and increasing surgical precision.

Typically, computer-assisted navigation systems consist of three main components: A computer platform, a tracking system, and a rigid body marker. The computer platform integrates inputs from the surgical field, processes the data mathematically, and displays the resulting information on a monitor, guiding the surgeon throughout the procedure. The tracking system utilizes optical cameras, electromagnetic coils, or ultrasonic probes to capture signals from trackers attached to the patient's bones or surgical instruments. By pinning these trackers to specific anatomical landmarks or instruments, the system provides accurate, real-time spatial data, helping the surgeon navigate the surgical site. These systems are categorized into three main types: Active robotic systems, semi-active robotic systems, and passive systems. Each type offers distinct advantages and disadvantages, and the choice of system depends on the specific needs of the surgical procedure and the surgeon's preferences. Such technological advancements have been particularly beneficial in complex surgeries like THA or knee arthroplasty. Ultimately, these innovations have led to significant improvements in surgical outcomes, reducing complications and enhancing patient recovery and QoL [26]. Active robotic systems perform surgical tasks with a high degree of autonomy, executing movements and decisions based on preprogrammed instructions. In some cases, these systems can restrict the surgeon's actions within specific, predefined parameters, ensuring that certain critical aspects of the procedure remain within safe limits. This autonomy can reduce human error, enhance precision, and streamline complex procedures, especially when the surgery requires intricate and repetitive movements.

On the other hand, semi-active robotic systems provide the surgeon with detailed intraoperative feedback and guidance. Yet they also allow the surgeon significant freedom in decision-making and in controlling the surgical instruments. These systems assist by offering real-time data, such as anatomical mapping, alignment, and positioning information, but ultimately leave the surgeon with full control over the procedure. This blend of guidance and autonomy provides flexibility while improving surgical precision and reducing the likelihood of errors, offering an effective compromise between full independence and manual operation.

Both types of robotic systems enhance surgical outcomes by optimizing accuracy, reducing the risk of complications, and improving efficiency during complex operations. The choice between active and semi-active systems depends on the surgeon's preferences, the complexity of the procedure, and the level of assistance required [27]. Passive systems, such as computer-assisted navigation systems, provide real-time feedback and intraoperative data displayed on a monitor during the surgical procedure. These systems provide visual guidance, including anatomical mapping, alignment, and positioning information, but do not actively control or influence the surgeon's movements. Instead, the surgeon maintains complete autonomy in decision-making, with the system serving as an advanced tool to enhance precision and improve accuracy.

While passive systems do not impose any restrictions on the surgeon's actions, they enable more informed decision-making by presenting crucial data to optimize the placement of implants, instruments, and surgical approaches. By improving the surgeon's ability to assess the surgical environment, these systems can lead to more accurate procedures, reduce the risk of complications, and ultimately improve patient outcomes. The primary benefit of passive systems lies in their ability to offer detailed guidance without limiting the surgeon's control over the operation [27]. While computer-assisted navigation systems offer numerous advantages, including real-time feedback, enhanced precision, and reduced intraoperative errors, several drawbacks and challenges must be considered. One significant challenge is the potential for increased surgical time, as the system may require additional setup, calibration, and adjustments during the procedure. This challenge can lead to longer operating times, potentially affecting the overall workflow and increasing costs.

Furthermore, implementing these systems often requires specialized training for the surgical team, as familiarity with the technology and its capabilities is crucial for effective use. Surgeons and support staff must be well-versed in both the system's functionality and troubleshooting, which adds to the complexity of integrating it into routine surgical practice.

Another limitation is the potential for technical issues or malfunctions. Computer-assisted navigation systems are highly dependent on technology, and any failure or malfunction—such as tracking issues, calibration errors, or software glitches—can compromise the accuracy and success of the procedure. This condition introduces a level of vulnerability and reliance on the system's technical performance, which, in the event of a failure, could lead to complications and delays in surgery. Despite these challenges, the ongoing development and refinement of computer-assisted navigation systems, along with advancements in training and support, continue to enhance their effectiveness and mitigate these drawbacks over time [27].

Patient-specific Instrumentation (PSI)

PSI is a technique utilized in THA to improve the accuracy of implant placement. It uses 3D-printed, customized guides designed from preoperative imaging data—such as CT or MRI scans—to achieve optimal positioning of the acetabular component. By tailoring the guides to the patient's unique anatomy, PSI aims to ensure that the acetabulum is positioned accurately, minimizing the risk of complications such as dislocation, impingement, or wear, which can arise from improper alignment.

The use of PSI offers the advantage of reducing variability in surgical technique, allowing for more predictable and reproducible outcomes. It also helps preserve bone stock, as the guides precisely align the implant with the patient's natural anatomy, minimizing the need for excessive bone resection. Additionally, PSI can improve the efficiency of the procedure, as the surgical team can work with a predetermined guide tailored to the patient's needs, reducing the reliance on intraoperative adjustments.

However, despite its potential benefits, adopting PSI in THA is not without challenges. These challenges include the added cost of producing the patient-specific guides and the need for additional preoperative planning and imaging. Moreover, while PSI can improve accuracy, it still requires skilled execution by the surgical team to achieve optimal outcomes. Nevertheless, as technology advances, PSI is expected to play a crucial role in further refining THA procedures and improving patient outcomes [28, 29]. Notably, a study examining 100 consecutive patients demonstrated that the implementation of patient-specific guides in THA resulted in highly accurate acetabular component placement. In this study, 94.1% of cases fell within the planned position range of ±10°, highlighting the precision of this technique. The results underscore PSI's effectiveness in achieving optimal acetabular positioning, which is critical for improving functional outcomes and reducing the risk of complications such as dislocation, impingement, and implant wear. This finding supports the growing adoption of PSI in THA to enhance surgical accuracy and patient satisfaction [29].

PSI has been proven to enhance the accuracy of acetabular component placement, particularly in restoring implant orientation and mitigating leg length discrepancies. By utilizing 3D-printed, patient-specific guides, PSI enables surgeons to tailor the positioning of the acetabular component to each patient's unique anatomical features, ensuring more precise alignment. This personalized approach not only helps in achieving the desired orientation but also minimizes the risk of complications such as dislocation and impingement, while promoting improved post-operative functional outcomes. Furthermore, PSI has shown promise in addressing leg-length discrepancies, a common concern in THA, thereby contributing to enhanced patient satisfaction and mobility [30]. A study examining 34 THA cases using point-of-care-manufactured PSI found that 64.7% of patients ambulated on the day of surgery, with no reported complications. This finding highlights the potential benefits of PSI in facilitating faster recovery and improving immediate post-operative mobility. By providing highly accurate and personalized guidance for implant positioning, PSI not only enhances surgical precision but also contributes to favorable early outcomes, such as quicker mobilization and reduced complication rates [30]. Moreover, PSI can significantly optimize the surgical precision of component positioning, ultimately contributing to improved patient outcomes. By offering tailored guides based on each patient's anatomy, PSI enhances the accuracy of acetabular component placement, minimizing the risk of complications, such as implant malposition and associated biomechanical issues. This approach proves to be an invaluable and secure resource for surgeons, especially when navigating complex bone and joint deformities or challenging cases, ensuring that each procedure is customized to the patient's unique anatomical features and needs [30].

Nevertheless, the reliance on commercial PSI products may introduce several challenges. These include increased procedural costs due to specialized 3D printing and design processes, as well as extended waiting times for surgery. The time required to manufacture the customized guides can delay the procedure, which may be a concern in urgent or time-sensitive cases. Additionally, the costs associated with these advanced tools could increase the overall expense of the surgical intervention, potentially limiting their widespread use in certain healthcare settings [30]. Consequently, there is a growing shift towards point-of-care production of PSI, enabling the creation of customized guides directly at the surgical facility. This approach not only reduces the wait time associated with commercial PSI products but also lowers overall costs by eliminating the need for external manufacturing and shipping. Point-of-care production enhances the precision and safety of THA procedures, as surgeons can use guides specifically tailored to each patient's unique anatomy. Furthermore, it offers greater flexibility in responding to unforeseen challenges during surgery, ultimately optimizing patient outcomes [30]. This evolution underscores the ongoing effort to improve surgical accuracy and patient outcomes while also addressing logistical and economic challenges. By integrating point-of-care production of PSI, the field of THA is making significant strides toward more efficient, cost-effective, and personalized care. This approach not only enhances the precision of implant positioning but also ensures a more adaptable, streamlined surgical process, ultimately benefiting both patients and healthcare systems.

Robotic-assisted Surgery

Robotic-assisted surgery, also referred to as robot-assisted or robotic surgery, transforms traditional surgical procedures by incorporating robotic systems into the operating room. These cutting-edge systems provide surgeons with enhanced precision, flexibility, and control, improving their ability to perform complex surgeries. By enabling minimally invasive techniques, robotic surgery allows access to anatomically difficult regions with smaller incisions, reducing the trauma to surrounding tissues and promoting faster recovery times. This technology expands the potential for more accurate, efficient, and effective surgeries, particularly in delicate or intricate anatomical areas [31, 32]. In robot-assisted surgery, surgeons can control surgical instruments with exceptional precision and dexterity, offering a range of advantages. These benefits include a reduction in complications, minimized pain and blood loss, shorter hospital stays, faster recovery times, and less noticeable scarring. The enhanced control provided by robotic systems allows for more intricate and accurate procedures, contributing to improved surgical outcomes and a more efficient healing process. Consequently, patients experience a more favorable postoperative course and overall satisfaction with the treatment [31]. The surgeon controls the robotic arms via direct telemanipulation or computer-assisted commands, offering a detailed, high-definition, magnified, and three-dimensional view of the surgical site. This enhanced visualization enables more accurate instrument maneuvering, ensuring more precise tissue handling and better outcomes. The ability to see the surgical field in such detail helps surgeons to avoid critical structures, minimize tissue damage, and perform complex procedures with greater ease and safety [15]. Robotic surgery, often paired with minimally invasive techniques, provides several key benefits, including a reduced risk of infection, faster recovery times, and shorter hospital stays for patients. Surgeons appreciate the superior visualization and control offered by robotic systems, which allow for more precise and efficient execution of complex procedures. These systems enhance the surgeon's ability to perform delicate maneuvers with greater accuracy, making previously difficult or risky procedures more feasible and reducing the overall strain on patients [15]. While robotic surgery offers numerous advantages, it is not without its risks, which can resemble those found in traditional open surgeries, such as a slight risk of infection and other complications. Patients must have a thorough discussion with their healthcare providers to fully understand both the benefits and potential dangers of robotic surgery. This discussion enables a well-informed decision about whether this approach is the most appropriate option given their specific medical needs and circumstances [15].

Image-based Planning Techniques

Several advanced methods have transformed preoperative planning in THA, each offering unique benefits and considerations. A key innovation is 3D preoperative planning, which employs CT-based imaging and particular software to accurately estimate implant size, restore hip biomechanics, and determine the optimal alignment of components. This approach enhances surgical precision, streamlines implant inventory management, and facilitates the integration of computer-assisted systems such as robotic and navigation technologies, ultimately improving procedural efficiency and outcomes [33, 34]. Another emerging development is digital templating, which provides greater accuracy and consistency. Clinicians can apply various techniques, including acetate templating on digital radiographs, 2D digital templating on x-rays, and 3D digital templating using CT images, to gain valuable preoperative insights. Among these, 3D templating is particularly recognized for its precision in assessing the anatomy and planning the procedure. However, while it offers significant advantages in terms of accuracy, evidence regarding its direct impact on clinical outcomes remains limited, warranting further investigation to fully assess its benefits in clinical practice [35, 36].

Integrating artificial intelligence (AI) technology significantly enhances preoperative planning in THA, exemplified by advanced software such as AI HIP. This technology enables rapid, automated identification of acetabular and femoral morphology, facilitating optimal prosthetic sizing. AI-based planning systems not only streamline the planning process but also improve the accuracy and reliability of component sizing in THA, accounting for various factors such as acetabular dysplasia. Studies have indicated that AI-assisted planning can enhance the precision of prosthesis selection, leading to more personalized and effective surgical outcomes [36]. Understanding the spine-hip relationship is crucial for optimizing acetabular cup orientation and overall biomechanical alignment in THA. Key parameters such as sacral slope, pelvic tilt, and pelvic incidence play a significant role in spino-pelvic relations, which, in turn, affect the biomechanical setting of the hip joint. These factors influence how the pelvis and spine interact during motion, potentially affecting joint stability, range of motion, and the longevity of the implant. Careful consideration of these parameters during preoperative planning can help ensure optimal alignment and minimize the risk of complications, improving overall patient outcomes [36]. Moreover, the advantages of 3D templating are becoming increasingly evident, especially in complex cases. CT-based 3D templating provides superior accuracy compared to traditional methods, enabling precise preoperative planning and reducing surgical complications related to implant sizing and positioning. Although its direct effect on clinical outcomes may vary, 3D templating serves as an invaluable reference for identifying bone landmarks, thereby improving surgical precision and outcomes. This technology enhances the ability to tailor procedures to individual patient anatomies, contributing to more favorable long-term results and fewer complications [34, 35].

Intraoperative Fluoroscopy

Intraoperative fluoroscopy plays a crucial role in orthopedic procedures, particularly in THA, by providing real-time imaging to guide the precise placement and alignment of implants. This technique allows surgeons to verify component positioning during surgery, ensuring optimal alignment of the acetabular component, femoral stem, and overall joint orientation. Fluoroscopy helps reduce the risk of malpositioning, minimizes the need for multiple incisions, and enhances the accuracy of implant placement, which ultimately contributes to improved patient outcomes and reduced complication rates [37, 38]. This technique provides real-time, continuous x-ray imaging on a monitor, allowing surgeons to observe the patient's anatomy throughout the procedure. By offering immediate visual feedback, intraoperative fluoroscopy helps ensure that the implant is correctly positioned and aligned, minimizing the risk of complications such as dislocation or improper joint mechanics. The ability to adjust the placement of components in real time enhances surgical precision and contributes to better functional outcomes post-surgery. This dynamic imaging capability is particularly valuable in complex cases where precise alignment is critical for achieving optimal hip joint function [37, 38]. In THA, fluoroscopy plays a vital role in achieving the accurate positioning of the acetabular component, which is essential for restoring optimal joint function and stability. Accurate positioning helps prevent complications such as leg-length discrepancy, gait abnormalities, impingement, excessive wear, and implant loosening. By providing real-time imaging, fluoroscopy allows the surgeon to adjust the acetabular component during the procedure, ensuring proper alignment with the patient's anatomical landmarks. This advantage enhances the long-term success of the surgery and improves overall patient outcomes by minimizing the risk of mechanical failure and functional limitations [37, 38]. Studies have shown that the integration of intraoperative fluoroscopy significantly improves the accuracy of acetabular cup placement in THA.

This enhanced precision helps reduce the incidence of complications such as leg-length discrepancy, impingement, wear, and implant loosening. By offering real-time visual feedback, fluoroscopy allows surgeons to make immediate adjustments during the procedure, ensuring optimal alignment of the acetabular component. As a result, this technique contributes to improved surgical outcomes, faster recovery times, and greater long-term success in THA [37, 38]. However, the use of intraoperative fluoroscopy in THA raises concerns about exposure to ionizing radiation, which poses potential long-term health risks for both the patient and operating room personnel. While fluoroscopy offers significant benefits in ensuring precise implant placement and improving surgical outcomes, the cumulative effect of radiation exposure over time can contribute to an increased risk of radiation-induced injuries, such as tissue damage or cancer. Consequently, it is crucial to minimize radiation exposure by using protective measures, limiting fluoroscopy duration, and adopting alternative imaging techniques when possible [39, 40]. The extent of radiation exposure during intraoperative fluoroscopy is influenced by several factors, including the duration of the procedure, the frequency of fluoroscopic image acquisition, and the proximity of the x-ray source to the patient or surgical team. Longer procedures or frequent imaging may lead to increased exposure, which can be mitigated by minimizing the use of fluoroscopy and employing shielding devices. Additionally, the closer the x-ray source is to the patient or personnel, the higher the potential radiation dose, emphasizing the importance of maintaining appropriate distances and using lead aprons or other protective barriers to safeguard against unnecessary exposure [39, 40]. Several strategies can be employed to mitigate radiation exposure risks during intraoperative fluoroscopy. These include adopting low-dose fluoroscopy settings to reduce the radiation dose while maintaining image quality, optimizing the positioning of both the x-ray source and the patient to minimize radiation scatter, and utilizing protective shielding such as lead aprons, thyroid collars, and radiation barriers to safeguard the surgical team. Additionally, limiting fluoroscopy use to essential moments during the procedure, reducing the number of fluoroscopic images, and ensuring proper training in radiation safety protocols for operating room personnel can further enhance safety and minimize exposure [39, 40]. Additionally, navigation technology has significantly reduced radiation exposure for both the operating surgeon and other operating room personnel compared to conventional fluoroscopy-guided procedures. By providing real-time, detailed guidance on implant positioning without the need for continuous x-ray imaging, navigation systems minimize the frequency and duration of radiation exposure. This results in safer working conditions for the surgical team while still ensuring precision in implant placement, contributing to improved patient outcomes and reduced overall radiation risk [39, 40].

Customized Implants

Customized implants offer an effective solution in revision THA, especially in cases involving significant acetabular bone loss [41]. A retrospective study assessed the accuracy of custom-made acetabular implants by comparing preoperative planning with postoperative positioning in three patients who received custom acetabular prostheses [41]. Custom implants were precisely planned utilizing 3D CT analysis, focusing on key surgical landmarks. The accuracy of implant positioning was determined by comparing preoperative and postoperative CT scans, examining factors such as anteversion alignment, inclination angle, screw positioning, and the contact surface between the implant and bone [41]. The analysis demonstrated satisfactory accuracy in implant positioning across all three cases, except for the third case, where malposition occurred due to a posterior shift of the implant's COR exceeding 10 mm [41]. In all cases, the implant positioning differed by less than 10° in anteversion and inclination from the planned parameters [41]. Custom implants in hip replacements hold the promise of achieving superior outcomes by closely matching the patient's unique anatomy and accurately replicating the natural structure and function of the hip joint [15]. This personalized approach can deliver enhanced outcomes, especially for younger, more active patients who impose higher functional demands on the implant [15]. Custom implants are precisely engineered and fabricated to achieve equal leg length, enhance muscle function, and maintain the stability of the artificial ball-and-socket joint [15]. Additionally, custom-made femoral implants in THA for congenital hip disease improve the fit between the stem and femur, redistribute mechanical stress, and restore the natural biomechanics of the hip [42]. A thorough review explores multiple factors, such as preoperative planning, implant design, material selection, surgical techniques, and clinical outcomes, related to the use of custom-made femoral implants in patients with congenital hip disease [42]. Custom total hip replacement (THR), also known as bespoke or patient-specific hip replacement, is an advanced approach in THA that involves the use of a personalized hip implant designed to match the patient's distinct anatomical features [15]. This innovative technique requires preoperative CT scanning of the hip joint, which allows for the creation of a custom implant that accurately matches the patient's natural hip joint's size and orientation [15].

Clinical Outcomes and Evidence

Clinical studies comparing traditional and modern techniques highlight a clear shift toward technology-driven, virtual recruitment methods. These innovative strategies aim to improve research inclusivity by reaching a broader range of populations, while also potentially speeding up the recruitment process, offering significant benefits in terms of both inclusiveness and efficiency [43]. Moreover, there is an increasing focus on incorporating technology into clinical trials to modernize research methodologies. This approach includes a detailed comparison of traditional and digital approaches, highlighting the advantages of integrating technology into research, such as improved data collection, enhanced participant engagement, and greater overall study efficiency [44]. Comparing traditional and modern management control practices (MCP) in public health policies highlights the distinct managerial approaches adopted by individuals with clinical versus business backgrounds. Clinical-oriented managers tend to implement MCP in ways that emphasize empowerment and collaboration, fostering a more inclusive approach.

On the other hand, managers with a business-oriented background may focus on different management information and control methods, which can significantly impact strategic healthcare management decisions [45]. Additionally, in the realm of construction techniques, a comparative study explores conventional and modern building envelope methods, particularly in hot and humid environments. The research emphasizes assessing thermal comfort and energy efficiency while examining how traditional architectural principles can be incorporated into modern construction practices. The overarching goal is to improve sustainability and occupant comfort in building design by drawing lessons from vernacular architectural approaches [46].

PROs

PROs serve as essential metrics for evaluating the success of THA, encompassing critical factors such as patient satisfaction, pain relief, and functional improvement. A recent large-scale, multicenter study conducted in the United States compared PROs based on different surgical approaches for THA. The study found no significant differences in improvements between the anterior and posterior approaches at 3 and 6 months postoperatively. However, patients who underwent the transgluteal approach exhibited significantly worse PRO improvements at the 6-month follow-up compared to those who received the posterior approach. These findings emphasize the importance of carefully selecting the surgical approach, as it can have varying effects on long-term patient outcomes. The study also underscores the need for further exploration into the influence of surgical technique on post-operative recovery and QoL [47]. In addition, primary preoperative factors such as age, sex, and preoperative pain levels were found to impact PROs following THA significantly. Specifically, patients who reported higher levels of pain before surgery tended to experience less favorable PROs after the procedure. Conversely, individuals with higher preoperative functional scores showed better outcomes post-THA. These findings highlight the importance of assessing and addressing these preoperative factors in clinical practice, as they can serve as valuable predictors of post-surgical recovery and long-term patient satisfaction.

Such insights suggest that personalized preoperative interventions could be beneficial in optimizing post-THA outcomes [48]. A comprehensive review of PROs following THA demonstrated overall high levels of patient satisfaction and notable improvements in physical function after surgery. The majority of patients reported significant pain relief and improved mobility and daily functioning. However, a smaller group of patients continued to experience persistent pain and expressed dissatisfaction with their surgical results. This variation underscores the complexity of THA outcomes and suggests the need for more individualized approaches to preoperative planning, surgical techniques, and postoperative management. It also highlights the importance of addressing factors such as patient expectations and psychosocial aspects that may influence overall satisfaction and recovery [47]. A longitudinal cohort study examined the impact of cognitive appraisal processes on outcomes following THA within the first year after the surgery. The study identified that certain cognitive appraisals, particularly those centered around healthcare challenges or difficulties related to living situations, were associated with poorer outcomes during the first six weeks after THA.

On the other hand, appraisals that involved preparing family members for potential health changes and adjusting to new circumstances were linked to more favorable outcomes during the same period. These findings suggest that patients' cognitive and emotional responses to their health status and recovery can significantly influence their postoperative recovery, emphasizing the importance of psychological support and effective coping strategies in enhancing recovery outcomes following THA [49]. A longitudinal cohort study examined the impact of cognitive appraisal processes on outcomes following THA within the first year after the surgery. The study identified that certain cognitive appraisals, particularly those centered around healthcare challenges or difficulties related to living situations, were associated with poorer outcomes during the first six weeks after THA. On the other hand, appraisals that involved preparing family members for potential health changes and adjusting to new circumstances were linked to more favorable outcomes during the same period. These findings suggest that patients' cognitive and emotional responses to their health status and recovery can significantly influence their postoperative recovery, emphasizing the importance of psychological support and effective coping strategies in enhancing recovery outcomes following THA [50].

Cost-effectiveness Considerations

Cost-effectiveness plays a critical role in assessing the overall value and efficacy of THA procedures. Numerous studies have highlighted the favorable cost-effectiveness of THA when compared to non-operative management, especially for patients over the age of 80. These findings suggest that, despite the higher upfront costs of surgery, THA offers long-term benefits—reduced pain, improved mobility, and better QoL —that contribute to a substantial reduction in the overall economic burden. For older patients, THA not only provides clinical improvements but also proves to be more cost-effective by minimizing the need for ongoing non-operative treatments, hospital visits, and long-term care. Therefore, incorporating a cost-effectiveness analysis into clinical decision-making can help healthcare providers allocate resources more efficiently and improve patient outcomes in this age group [51]. The cost-effectiveness of primary THR has been well-established, particularly within specific patient cohorts. In the UK alone, an estimated 50000 THR procedures are performed annually. These surgeries have demonstrated strong value in improving patient QoL, reducing pain, and enhancing mobility, all while proving to be cost-effective compared to continued non-operative management or alternative treatments. Given the substantial volume of procedures and their positive impact on patients, THR is considered a cornerstone of healthcare for addressing hip osteoarthritis and other hip-related conditions, making it an important area of focus for cost-effectiveness evaluations in both public health policy and clinical practice [52]. Decision-analytic models have been developed to assess the cost-effectiveness of hip replacement procedures, incorporating a wide range of factors such as implant costs, revision rates, mortality rates, QoL outcomes, and the broader impact on healthcare expenditures. These models provide a comprehensive framework for understanding the long-term economic benefits of hip replacement surgeries, helping policymakers and healthcare providers make informed decisions about resource allocation. By considering the interplay between clinical outcomes and costs, decision-analytic models offer valuable insights into the sustainability and effectiveness of hip replacement procedures, ultimately supporting strategies to optimize both patient care and healthcare system efficiency [52]. In a comparative study between THA and resurfacing arthroplasty, the latter demonstrated short-term efficiency benefits in a specific patient population. Patients who underwent resurfacing arthroplasty reported improvements in QoL and achieved higher quality-adjusted life years (QALYs) than those receiving THA, albeit at a slightly higher cost. This finding suggests that while resurfacing arthroplasty may provide superior functional outcomes in the short term, the increased cost must be carefully weighed against the long-term benefits and cost-effectiveness for different patient groups. The study highlights the importance of considering both clinical and economic factors when selecting the most appropriate surgical approach for individual patients [53]. The cost per QALY for resurfacing arthroplasty was considered cost-effective within the first 12 months of treatment. However, the economic justification for this procedure was found to be more compelling for men than women. This result indicates that while resurfacing arthroplasty may offer favorable cost-effectiveness in the short term, the benefits may vary depending on patient demographics, particularly gender. Such findings emphasize the importance of tailoring treatment decisions not only based on clinical factors but also on economic considerations to optimize both patient outcomes and healthcare resource utilization [53]. Additionally, a 5-year follow-up study, part of the Exeter Primary Outcomes Study, examined changes in both QoL and costs among patients undergoing primary THR. The findings showed that patients experienced an average gain of approximately 0.8 QALYs over 5 years. Importantly, the study identified several factors associated with improved outcomes, including younger age, male gender, lower BMI, and poorer preoperative hip scores. These insights highlight the need for personalized treatment strategies, as these demographic and clinical factors can significantly influence long-term outcomes in THR procedures [54]. The cost per QALY for THR was found to be below widely accepted thresholds, confirming its cost-effectiveness when compared to non-surgical management. In most cases, the cost per QALY remained well below the threshold of 20000 pound, reinforcing the economic viability of THR as a treatment option for patients with hip osteoarthritis or similar conditions. This finding suggests that, not only does the procedure provide significant clinical benefits, but it also represents a prudent investment in healthcare resources [54]. The future of improving artificial hip joints and their associated arthroplasty technologies focuses on developing innovative biomaterials that create a more favorable immune environment at the implant site. These advancements aim to enhance the integration of the implant with the body, thereby promoting long-term stability and reducing the need for revision surgeries. By addressing issues related to immune responses and implant-tissue interaction, these novel materials could significantly improve the durability and performance of artificial hip joints, leading to better patient outcomes and fewer complications [55].

Furthermore, personalized orthopedics, which customizes healthcare interventions by considering individuals' genetic makeup, lifestyle choices, and environmental influences, is rapidly gaining global traction. This approach aims to optimize treatment outcomes by aligning medical strategies with each patient's unique characteristics, thereby ensuring more effective, targeted care. As advancements in genomics, data analytics, and precision medicine continue to evolve, personalized orthopedics holds the potential to revolutionize the way musculoskeletal conditions are diagnosed, treated, and managed, leading to more efficient and patient-centered healthcare solutions [55]. Recent technological advancements, such as the application of 3D printing for the fabrication of device components and instrumentation, are playing a significant role in enhancing outcomes in THA. Nevertheless, the success of THA is increasingly recognized as dependent on achieving biomechanical alignment tailored to each patient's individual characteristics. This personalized approach aims to optimize the functionality and longevity of the hip implant, ensuring that it more closely mimics the natural movement and stresses of the patient's unique anatomy. As such, a patient-centered focus on biomechanics is becoming a critical factor in improving the effectiveness and durability of THA procedures [56].

In the field of revision THA, acetabular reconstruction remains a significant challenge, as each reconstructive approach offers unique advantages and limitations. These methods vary in terms of complexity, success rates, and the extent to which they address issues such as bone loss, implant stability, and long-term outcomes. The selection of an appropriate technique depends on several factors, including the extent of acetabular damage, the patient's anatomy, and prior surgical interventions. Consequently, understanding the strengths and drawbacks of each reconstruction option is crucial for achieving optimal results in revision THA [57]. Utilizing advanced MRI techniques offers a promising solution to the challenges typically encountered in imaging hip arthroplasty, providing valuable insights for diagnosing and managing potential complications. These enhanced imaging methods enable greater precision in assessing implant positioning, detecting prosthetic-related issues such as loosening or wear, and identifying soft tissue pathologies around the joint. By improving the accuracy of post-operative evaluations, advanced MRI can facilitate timely interventions, potentially leading to better long-term outcomes and a reduction in revision surgeries for patients with hip replacements [56].

Nutritional Markers

A study examining the nutritional status of patients undergoing primary total joint arthroplasty (TJA) assessed the prevalence and consistency of abnormal dietary markers. Out of 819 patients, abnormalities were found in albumin (2.6%), transferrin (5.6%), and total lymphocyte count (25%). Only 1.7% of patients had abnormalities in two markers simultaneously. Factors such as age, race, and comorbidities were linked to these abnormalities. The results suggest that nutritional deficiencies are relatively rare and there is no significant correlation between abnormal markers, implying that routine nutritional screening may not be necessary for otherwise healthy patients before TJA [58]. A retrospective study involving 12249 patients undergoing revision THA revealed a significant correlation between malnutrition and postoperative complications. Malnutrition, characterized by serum albumin levels <3.5 g/dL, was more common among underweight patients (1.8%) and those with insulin-dependent diabetes mellitus (IDDM). Malnourished patients faced a higher risk of complications, including surgical site infections, urinary tract infections, the need for blood transfusions, sepsis, and septic shock (all $P<0.001$). Furthermore, malnutrition negatively impacted pulmonary and renal function after surgery. These results underscore the necessity of screening underweight and IDDM patients for malnutrition before revision THA to reduce the risk of postoperative complications [59].

Diabetes

A retrospective cohort study of 2467215 patients undergoing primary THA in the US between 2016 and 2020 demonstrated a significant association between diabetes and adverse postoperative outcomes. Among these patients, 17% had diabetes. Multivariable-adjusted analyses revealed that diabetes was linked to increased odds of prolonged hospital stays (aOR=1.38), higher total hospital charges (aOR=1.11), non-routine discharge (aOR=1.18), blood transfusion (aOR=1.19), postprocedural infection (aOR=1.62), and periprosthetic joint infection (aOR=1.91). These associations were less evident in cohorts with avascular necrosis and inflammatory arthritis. The findings suggest that preoperative diabetes optimization and tailored postoperative care pathways may mitigate risks and improve outcomes in patients with diabetes undergoing primary THA. Further research is warranted for specific patient subgroups, including those with avascular necrosis or inflammatory arthritis [60].

Obesity

A review of 1207 consecutive primary hip arthroplasties in Australia examined the relationship between obesity and acute periprosthetic infection. Patients were categorized into normal weight, overweight, obese, and morbidly obese groups. The study found a significantly higher infection rate in obese patients, establishing obesity as an independent risk factor for periprosthetic infection, irrespective of comorbidities such as diabetes and cardiovascular disease. Notably, the posterior surgical approach was associated with increased infection rates in obese patients. Factors such as operative time, blood transfusions, use of drains, and cementation practices did not influence infection rates. These findings underscore the need for targeted strategies to mitigate infection risks in obese patients undergoing primary hip arthroplasty [61]. One study assessed the outcomes of 529737 patients who underwent primary, elective total knee and THA using data from the 2015–2020 American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP). The findings challenge the conventional reliance on BMI as a sole criterion for surgical eligibility. Instead, metabolic syndrome (MetS) and its defining components—hypertension, diabetes, and obesity—were identified as more comprehensive predictors of postoperative outcomes. MetS was associated with increased complications and mortality, while hypertension and diabetes were linked to higher complication rates without affecting mortality. Interestingly, obesity was associated with increased complications but exhibited a protective effect, reducing mortality compared to non-obese patients. These results highlight the need for more nuanced patient selection criteria, moving beyond strict BMI cutoffs to better stratify risk and optimize surgical outcomes [62]. In a study assessing the implementation of a preoperative optimization protocol for TJA, 74% of patients were found to have at least one modifiable risk factor, such as obstructive sleep apnea, depression, or obesity. Despite 20% of patients not adhering to recommended optimization measures, the protocol significantly reduced hospital length of stay (1.9 vs 2.2 days, $P<0.001$) and direct variable costs excluding implants (5409 vs 5852 USD, $P<0.001$), without affecting discharge destinations or 90-day readmission rates. These findings suggest that preoperative optimization enhances the value of TJA care by reducing resource utilization while maintaining clinical outcomes [63].

Pain Management

In pain management following THA, prioritizing information about postoperative pain is more crucial than providing details about the pathoanatomy, biomedical model of anatomy, or the biomechanics of the disease and procedure. Educating patients on how to manage their pain post-surgery helps set realistic expectations and promotes better adherence to recovery protocols, leading to improved outcomes and satisfaction. While understanding the technical aspects of THA is valuable, emphasizing pain management can significantly enhance the patient’s experience and contribute to a more successful recovery process [64]. Educational sessions aim to enhance patient knowledge of pain science and pain processing. By providing patients with information about how the nervous system processes pain, we can help reduce fear and anxiety, ultimately contributing to the alleviation of postoperative pain. Understanding the physiological mechanisms behind pain can empower patients, making them feel more in control of their recovery and fostering a sense of reassurance. This knowledge may enhance their coping strategies and facilitate a smoother, less distressing recovery process after THA. Reducing anxiety through education not only helps manage pain but can also lead to better outcomes in terms of overall patient satisfaction and healing [64, 65]. Enhancing a patient’s understanding of pain science can significantly alter their perception of pain as a threat, which in turn may reduce fear and anxiety. This improved knowledge enables patients to understand better the physiological processes underlying their pain, which can help modulate their pain experience. As patients become more informed, they may feel less pain, not only because they are less stressed but also because they are better equipped to cope with the discomfort. Research has shown that anxiety can amplify pain sensitivity, while reducing anxiety has the potential to alleviate pain, further emphasizing the value of pain education in clinical settings [66].

Cryotherapy

Cryotherapy involves the use of ice packs or cooled water applied to the skin around an injured or operated area, and it has long been utilized in post-operative recovery. The cold penetrates the soft tissues, and when applied over a joint, it reduces tissue metabolism by lowering enzymatic activity. This decrease in metabolic processes helps prevent tissue damage and minimizes inflammation caused by injury, promoting faster recovery and reducing discomfort [67, 68]. Cryotherapy can decrease leukocyte migration and slow nerve signal transmission, thereby reducing inflammation and providing a short-term analgesic effect. The application of local hypothermia induces vasoconstriction, limiting the extravasation of blood into surrounding tissues. This condition helps to minimize local inflammation and the production of edema, promoting a faster recovery process and alleviating discomfort [69, 70]. Numerous studies investigating the effects of cryotherapy on recovery following total knee arthroplasty have demonstrated a reduction in blood loss. The application of cryotherapy has been shown to minimize blood loss during and after the procedure, likely by inducing vasoconstriction and reducing local inflammation. This reduction in blood loss contributes to a more stable postoperative course, potentially decreasing the need for blood transfusions and enhancing overall recovery outcomes [71, 72].

However, the clinical benefits of cryotherapy on pain management and range of motion following total knee arthroplasty have been inconsistent. While some studies report significant improvements in pain reduction and enhanced range of motion in patients receiving cryotherapy, other studies show no notable differences between the treatment and control groups. These mixed results suggest that while cryotherapy may offer certain advantages in reducing blood loss and inflammation, its effects on pain relief and functional recovery may vary depending on individual patient factors or treatment protocols [73-77]. Due to the limitations of many studies, which often involve small sample sizes, non-randomized designs, unblinded methodologies, and cohort-based approaches, as well as the scarcity of research specifically focused on cryotherapy in hip arthroplasty, further rigorous evaluation is necessary. High-quality, randomized controlled trials with larger patient populations are needed better to assess the true benefits of cryotherapy in this context and to determine its effectiveness in improving postoperative outcomes such as pain management, functional recovery, and overall patient satisfaction following hip arthroplasty.

Multimodal analgesia

The multimodal analgesia strategy integrates analgesics with distinct mechanisms of action to enhance postoperative pain management. By targeting various nociceptive pathways and neurotransmitters involved in pain perception, this approach can help reduce the need for high doses of individual analgesic agents. The inclusion of non-opioid adjuncts allows for a reduction in perioperative opioid consumption, subsequently minimizing opioid-related adverse effects such as nausea, vomiting, sedation, respiratory depression, urinary retention, and constipation. This method not only improves pain control but also contributes to a safer and more comfortable postoperative experience for patients [78]. This section reviews key multimodal analgesic adjuncts, including acetaminophen, nonsteroidal anti-inflammatory drugs (NSAIDs), selective cyclo-oxygenase-2 (COX-2) inhibitors, and gabapentinoids. Each of these agents plays a critical role in targeting specific pathways of nociception, contributing to effective pain management and reducing reliance on opioids. Their mechanisms of action, benefits, and considerations for perioperative use are explored in detail to highlight their contributions to the multimodal analgesia approach.

Acetaminophen

Acetaminophen, though considered a weak analgesic with limited opioid-sparing capability, remains a fundamental component of multimodal analgesia regimens due to its favorable safety profile. Evidence from meta-analyses and a Cochrane review indicates that regular dosing of acetaminophen significantly reduces visual analogue pain scores (VAPS), decreases opioid consumption, mitigates opioid-related adverse effects, and enhances postoperative mobility. These findings underscore its value as a reliable and effective adjunct in pain management strategies [79, 80]. NSAIDs or COX-2 inhibitors may be included in the multimodal analgesia regimen, provided there are no contraindications. While these agents are effective in reducing inflammation and pain, caution is warranted due to the potential for hepatotoxicity when doses exceed 4 g within 24 hours in healthy adults. As such, it is advisable to reduce the dosage in elderly patients, and their use should be limited in individuals with compromised hepatic function to minimize the risk of adverse effects.

NSAIDs and COX-2 inhibitors

NSAIDs have strong evidence supporting their efficacy in perioperative analgesia. There is a wide variety of NSAIDs available, each differing in terms of onset and duration of action, route of administration, effectiveness, and side-effect profile. This diversity allows for the selection of the most appropriate NSAID based on the specific needs of the patient and the surgical context. Careful consideration of these factors can optimize pain management while minimizing potential adverse effects [79]. The procedure-specific postoperative pain management group conducted a comprehensive review of the existing literature on perioperative analgesia, specifically for patients undergoing THA. This summary aimed to identify the most effective strategies for managing postoperative pain in THA patients, accounting for various analgesic options and their clinical efficacy. The group highlighted key findings that could guide the selection of appropriate pain management protocols to improve patient outcomes and enhance recovery following THA [81]. The procedure-specific postoperative pain management group found that NSAIDs significantly reduced morphine consumption and VAPS by 4 to 10 mm up to 32 hours postoperatively, compared to a placebo. This finding highlights the efficacy of NSAIDs in managing postoperative pain following THA, offering a valuable adjunct to more traditional analgesic approaches like opioids, and contributing to improved pain control during the early recovery period [81].

The side effects of NSAIDs include gastrointestinal mucosal damage, renal dysfunction, and platelet dysfunction, which can pose risks, particularly in the perioperative setting. Selective COX-2 inhibitors, on the other hand, have minimal adverse effects on the gastrointestinal system and platelet function, making them a preferable option in such cases. Several studies have demonstrated that COX-2 inhibitors enhance postoperative analgesia and reduce opioid consumption in patients undergoing THA, offering an effective alternative for managing pain while minimizing opioid-related side effects [82]. Several COX-2 inhibitors have been withdrawn from the market due to adverse cardiovascular effects. However, agents such as celecoxib and meloxicam remain available, as studies have shown that the cardiovascular risk associated with these drugs is no higher than that of nonselective NSAIDs. Despite this, the widespread use of COX-2 inhibitors has been linked to an increased risk of cardiovascular events, particularly among elderly populations. This finding underscores the importance of carefully considering the risks and benefits when selecting pain management strategies for patients, especially those with preexisting cardiovascular conditions [83]. Recently, some authors have reported that using a fixed-dose combination of NSAIDs and a proton pump inhibitor may be both cost-effective and safer compared to COX-2 inhibitors. This combination helps mitigate the gastrointestinal side effects commonly associated with NSAID use by reducing gastric acid secretion, while still providing the analgesic benefits of NSAIDs.

Additionally, the lower cost of this combination therapy, as compared to COX-2 inhibitors, makes it a potentially more affordable option for patients, particularly in settings where long-term use of analgesics is required [84]. Therefore, the use of NSAIDs in combination with a proton pump inhibitor could present a viable alternative treatment option for patients at high risk of cardiovascular events. This combination not only offers pain relief but also helps mitigate gastrointestinal risks, making it a safer option in such populations. However, concerns persist regarding the potential inhibitory effects of both NSAIDs and COX-2 inhibitors on bone healing. Animal studies have suggested that these agents may hinder new bone formation by affecting osteoblast and osteoclast function. Despite these findings, the impact of short-term, low-dose administration of these drugs on human bone healing remains inconclusive and warrants further investigation to determine any potential risks in clinical settings [85].

Gabapentinoids

Gabapentinoids are effective postoperative analgesics that have been shown to reduce opioid consumption by up to 50% compared with placebo. These agents, including gabapentin and pregabalin, work by modulating the central nervous system's response to pain, particularly by inhibiting the release of excitatory neurotransmitters and reducing neuronal excitability. As a result, they help decrease the need for opioids, potentially reducing opioid-related side effects such as nausea, sedation, and respiratory depression. Gabapentinoids are commonly used as part of a multimodal analgesia strategy, particularly in the management of pain after procedures such as THA [86]. Gabapentin and pregabalin are both classified as gabapentinoids, with pregabalin offering advantages over gabapentin, including faster onset and more reliable, dose-dependent bioavailability due to its improved absorption profile. This finding makes pregabalin a potentially more effective option for postoperative pain management. However, both drugs share common side effects, such as somnolence and dizziness, which can limit their use. These side effects can often be minimized through careful dose reduction or gradual titration to an optimal therapeutic dose.

Despite these potential side effects, gabapentinoids remain a valuable component of multimodal analgesia regimens, helping to reduce opioid consumption and improve pain management outcomes [87]. Published data suggest that the use of gabapentinoids alone for analgesia following major orthopedic surgery results in a reduction in opioid consumption. However, these studies have found no significant differences in pain scores when compared with a placebo. This finding indicates that while gabapentinoids may contribute to minimizing opioid use, their direct impact on pain relief might be less pronounced. The reduction in opioid consumption is likely a key benefit of gabapentinoids, which can help minimize opioid-related side effects and complications. However, additional analgesic strategies may still be necessary to optimize pain management in these patients [86]. In addition to their role in providing analgesia and reducing opioid consumption, gabapentinoids may offer several ancillary benefits during the early perioperative period. These benefits include potential reductions in postoperative anxiety, improved sleep quality, and enhanced patient satisfaction due to their calming effects. Gabapentinoids may also help with preventing or managing neuropathic pain, which can be common following major orthopedic surgeries. By providing these additional benefits, gabapentinoids may contribute to a more comprehensive and favorable recovery experience, though their primary advantage lies in the reduction of opioid usage and associated side effects.

Anesthesia and nerve block

Anesthesia

The most recent trend in pain management for TJA advocates for a multimodal approach, utilizing two or more analgesic modalities with distinct mechanisms of action. This strategy aims to provide effective analgesia while minimizing side effects and adverse events. By targeting different pathways involved in pain perception, such as the use of non-opioid medications alongside opioids or regional anesthesia, multimodal analgesia can enhance pain relief and promote faster recovery. The goal is to reduce opioid consumption, thereby decreasing the risks associated with opioid use, including nausea, constipation, and respiratory depression, while improving overall patient outcomes following TJA [88]. Regional anesthesia has been recommended for TJA due to its significant advantages over general anesthesia. Specifically, regional anesthesia is associated with reduced intraoperative blood loss, lower incidence of deep vein thrombosis (DVT), and improved postoperative pain management. By targeting specific nerve regions, regional anesthesia can provide effective pain relief during and after the procedure, reducing the need for systemic analgesics and improving recovery time. These benefits contribute to better overall patient outcomes, including enhanced mobility and a decreased risk of complications such as bleeding and venous thromboembolism following surgery [88]. Regional anesthesia for hip arthroplasty can be effectively performed using various techniques, each offering distinct advantages. Spinal anesthesia is a commonly used method that provides excellent analgesia and muscle relaxation during the procedure. Epidural anesthesia can be administered either with or without the use of an indwelling catheter for continued analgesia postoperatively, with catheters typically left in place for 24 to 48 hours. Intrathecal morphine is another option, providing long-lasting pain relief by delivering morphine directly to the spinal fluid. Additionally, a combination of epidural anesthesia with spinal anesthesia or general anesthesia may be utilized to achieve optimal pain management and ensure patient comfort during the procedure. Each technique can be tailored to the individual patient's needs, and the choice of anesthesia depends on factors such as patient preferences, comorbidities, and surgical requirements [88-90].

Single-shot spinal anesthesia is typically preferred for hip arthroplasty due to its effectiveness, simplicity, and relatively low complication rate. This technique involves the administration of a local anesthetic directly into the subarachnoid space, providing a rapid onset of sensory and motor block. It offers excellent analgesia during the procedure, with the added benefit of facilitating muscle relaxation and reducing intraoperative blood loss. The duration of anesthesia is generally sufficient for the duration of the surgery, and it avoids the need for catheter placement or ongoing infusion, which can reduce the risk of complications such as infection or catheter-related issues. Single-shot spinal anesthesia is considered a safe and reliable option for most patients undergoing hip arthroplasty, particularly in those without contraindications [88, 91, 92]. Epidural anesthesia offers superior pain management during the perioperative period for TJA compared to other analgesic modalities. It provides excellent pain control and facilitates earlier mobilization, which can positively impact recovery. The localized delivery of anesthetics directly to the epidural space ensures effective pain relief, reducing the need for systemic opioids and enhancing overall comfort. However, despite its benefits, epidural analgesia is associated with some drawbacks, including higher rates of postoperative urinary retention, hypotension, and pruritus (itchiness). These side effects must be carefully monitored and managed to ensure optimal patient outcomes and minimize discomfort during the recovery process [93, 94]. Absolute contraindications for regional anesthesia include uncorrected hypovolemia, increased intracranial pressure, infection or allergy to local anesthetic agents, and coagulopathy. These conditions pose significant risks during the administration of regional anesthesia, as they can compromise patient safety. Uncorrected hypovolemia can lead to inadequate perfusion and hypotension. At the same time, increased intracranial pressure can worsen neurological outcomes. Infection at the site of injection increases the risk of introducing pathogens into the central nervous system, and an allergy to the anesthetic agent can lead to severe allergic reactions. Coagulopathy increases the risk of bleeding, particularly in the epidural or spinal spaces, where hematoma formation can occur and cause nerve damage. It is crucial to thoroughly assess patients for these contraindications before administering regional anesthesia to ensure safe and effective management [91, 94]. Epidural hematoma, although a rare complication, is a potentially serious concern for patients undergoing hip arthroplasty who receive postoperative thromboprophylaxis. Thromboprophylaxis is commonly administered to prevent DVT and other thromboembolic events following surgery. However, it increases the risk of bleeding, which can lead to the formation of an epidural hematoma. This condition occurs when blood accumulates in the epidural space, exerting pressure on the spinal cord and nerves and potentially causing neurological deficits. Although the incidence of epidural hematoma is low, its impact can be devastating, highlighting the importance of careful patient selection, monitoring, and managing anticoagulation therapy in patients receiving epidural analgesia postoperatively. Close collaboration between the surgical and anesthesiology teams is crucial to mitigate this risk while ensuring optimal pain control and prevention of thromboembolic events [93-95]. When administering regional anesthesia, it is essential to ensure that the correct anesthesia level and a safe analgesic dose are achieved through a precise and skilled technique, in order to minimize the risk of anesthesia-related complications

Nerve block

Peripheral nerve blocks serve as effective adjuncts for pain management in hip arthroplasty, enhancing postoperative analgesia and improving patient outcomes [94]. The use of nerve blocks has been demonstrated to be highly effective in controlling pain and reducing the need for narcotics following hip arthroplasty [96, 97]. Various nerve block techniques, such as femoral block, sciatic block, posterior lumbar plexus block, fascia iliaca block, and periarticular local anesthetic infiltration, are utilized as effective adjuncts for pain management in hip arthroplasty [95]. Peripheral nerve blocks provide analgesia comparable to epidural anesthesia and are more effective than systemic opioids for pain relief [96, 98]. Peripheral nerve blocks help preserve contralateral limb strength, which can enhance postoperative rehabilitation, in contrast to the bilateral lower extremity sensorimotor block that may occur with epidural analgesia [91, 98]. Moreover, peripheral nerve blocks are associated with fewer complications, such as hypotension and urinary retention, compared to epidural anesthesia. However, the drawbacks of nerve blocks include the increased time required for placement during the perioperative period and the potential for motor blockade-related injuries, which can hinder functional recovery and delay rehabilitation [97]. Peripheral nerve blockade can be an adjunctive option for managing postoperative pain after hip arthroplasty [99, 100]. Both single-injection and continuous peripheral nerve block techniques have been shown to reduce perioperative complications, shorten hospital length of stay, conserve hospital resources, and improve patient satisfaction [101-104].

Patient-controlled analgesia (PCA) and epidural injection

PCA is a system that allows patients to self-administer small, predetermined doses of analgesic medication to manage pain. This system relies on a sophisticated microprocessor-controlled infusion pump. PCA was first developed in the early 1980s [105, 106].

Common adverse effects associated with PCA include nausea and vomiting, pruritus, respiratory depression, sedation, confusion, and urinary retention. Over recent decades, alternative PCA delivery routes have been developed, though intravenous (IV) PCA remains the most widely utilized method. In addition to IV PCA, various other modalities, such as peripheral regional, intranasal, and transdermal PCA, have been introduced to offer diverse options for pain management and potentially reduce side effects associated with traditional IV administration [92, 107].

Epidural analgesia is widely regarded as one of the most effective methods for postoperative pain relief. The procedure involves administering anesthetic agents into the epidural space surrounding the spinal cord. Compared to spinal block, epidural analgesia typically requires a larger dose of the drug, and the onset of analgesia is slower. While both methods provide effective pain control, epidural analgesia often involves a more gradual onset due to the larger volume of medication and its absorption properties [95]. Epidural block is contraindicated in cases of uncorrected hypovolemia, increased intracranial pressure, coagulopathy, and prior spinal surgery. Adverse events associated with epidural anesthesia may include tachycardia, hypertension, mild headache, metallic taste, tinnitus, and facial numbness. These side effects are typically transient, but they should be monitored closely during the perioperative period.

Periarticular injection

Intraoperative periarticular injection of multimodal drugs plays a crucial role in the multimodal pain management protocol, providing significant benefits in controlling postoperative pain. This technique involves the administration of a combination of analgesics directly into the joint space during surgery, which targets various pain pathways and helps reduce the reliance on systemic opioids. By utilizing different mechanisms of action, it enhances pain relief while minimizing side effects, leading to better overall recovery and patient satisfaction [92, 108, 109]. The injection of opioids and local anesthetics into injured or stretched nerves or tissues, typically performed under the guidance of a surgeon, can effectively block axonal sodium channels and inhibit pain signal conduction. This targeted approach helps reduce the transmission of nociceptive pain at its source. Wound infiltration with local anesthetics specifically acts locally to alleviate peripheral nociception, offering pain relief with minimal systemic side effects. This method plays a crucial role in enhancing postoperative pain management, reducing the need for systemic analgesics, and improving overall recovery outcomes [109, 110].

Several studies have reported the effectiveness of periarticular injection of multimodal analgesics in reducing postoperative pain and enhancing postoperative mobility following THA. These injections, typically combining local anesthetics with opioids or other analgesics, provide targeted pain relief at the surgical site, contributing to a smoother recovery process. By reducing pain and minimizing the need for systemic opioids, patients can experience improved mobility and a faster return to functional activities after surgery [111-114]. However, there is ongoing debate regarding the optimal dosage and composition of the injection drugs, as well as the techniques used for injection. The efficacy of periarticular injections in reducing opioid consumption remains unclear, with some studies showing benefits while others report minimal or no significant impact. Variations in the types of analgesics used, their dosages, and the methods of administration contribute to inconsistent results. As such, further research is needed to establish standardized protocols for these injections and to determine their true effect on opioid consumption and overall postoperative pain management [114].

The most commonly used drugs for periarticular injections include local anesthetics, such as bupivacaine and ropivacaine, as well as analgesics like ketorolac, morphine, clonidine, and steroids. These agents work by targeting specific receptors at the surgical site. For example, local anesthetics block sodium channels to prevent nerve conduction, while ketorolac and morphine activate mu-opioid receptors, reducing pain transmission. Clonidine may contribute to analgesia by stimulating alpha-2 adrenergic receptors, which inhibit the release of norepinephrine, further suppressing pain. Steroids, on the other hand, help manage inflammation by inhibiting the production of inflammatory mediators. Together, these drugs work synergistically to manage postoperative pain by reducing both nociceptive input and the inflammatory response at the surgical site [114]. Steroids are effective in prolonging the duration of action of periarticular injections by reducing inflammation and enhancing the analgesic effects. However, caution is required when using them in patients who are at high risk of infection, such as those with diabetes or those who are immunocompromised. Steroids can impair immune function, potentially increasing the risk of surgical-site infection. Therefore, their use should be carefully considered and monitored in these patient populations to minimize any complications [92, 109].

Additional drugs, such as epinephrine, can be included in periarticular injections to prolong the duration of analgesia by causing vasoconstriction, which reduces the rate of drug absorption and enhances local anesthetic effects. Antibiotics can also be added to reduce the risk of infection, especially in high-risk patients. Since 2006, authors have advocated for the use of periarticular injections as part of a multimodal pain control protocol, recognizing the benefits of combining local anesthetics, anti-inflammatory drugs, and other adjuncts to optimize pain management and reduce opioid consumption. This approach aims to improve postoperative outcomes by providing effective pain relief while minimizing the risks associated with systemic analgesics [92, 115].

About the Revision Hip Arthroplasty (RHA) Outcome

A study investigated the use of open-source 3D reconstruction software (3D Slicer) and low-cost 3D-printed anatomical models for pre-surgical planning in RHA, particularly in cases with complex acetabular defects, such as Paprosky types II and III. Ten patients underwent CT scans before and one week after surgery. The reconstructed data were used to plan and evaluate the COR and acetabular cup placement, including inclination and anteversion angles. Results showed no significant differences in the COR position on the X-axis (1.5 mm, P=0.5868) or inclination angle (3.9°, P=0.3092), while significant differences were noted on the Y-axis (4.7 mm, P=0.0194) with strong correlation (r=0.9438, P=0.0014). Anteversion angle differences were not significant (1.9°, P=0.4192). This study highlights the effectiveness of 3D reconstruction software and low-cost anatomical models for RHA pre-surgical planning, emphasizing their utility in managing complex acetabular defects and ensuring proper cup placement [116]. The findings of one study demonstrate that meticulous pre-operative planning, comprehensive diagnostic investigations, and the use of appropriate implants and instruments significantly optimize the conditions for successful RHA. Clinical and functional outcomes, as measured by the Oxford hip score, showed statistically significant improvements at the final follow-up. This finding highlights the importance of a multidisciplinary approach that combines surgical expertise, thorough documentation, and a tailored postoperative rehabilitation protocol focused on adequate nutritional support. These measures collectively enhance the success rates and patient satisfaction in revision hip replacement surgeries, paving the way for improved standards in surgical practice [117].

Conclusion

Advancements in biomechanics, surgical techniques, and patient-centered innovations have significantly shaped the evolution of THA. Accurate acetabular positioning remains a cornerstone of successful THA, with emerging technologies and personalized strategies offering new avenues to improve outcomes. By addressing patient-specific anatomical and biomechanical needs, modern approaches, such as robotic-assisted surgery and PSI, have enhanced the precision and durability of implants. Moreover, optimizing preoperative conditions and leveraging innovative materials and imaging technologies helps reduce complications and accelerate recovery. Future research should continue to focus on integrating advanced techniques with personalized care to ensure improved functionality, longevity, and patient satisfaction in THA.

Ethical Considerations

Compliance with ethical guidelines

There were no ethical considerations to be considered in this research.

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Authors' contributions

Conceptualization, supervision, project administration and funding acquisition: Siamak Kazemi; Investigation: Khatere Mokhtari; Writing the original draft: Kaveh Gharanizadeh and Khatere Mokhtari; Review and editing: All authors.

Conflict of interest

The authors declared no conflict of interest.

References

[1] Kim SH, Meehan JP, Blumenfeld T, Szabo RM. Hip fractures in the United States: 2008 nationwide emergency department sample. Arthritis Care Res (Hoboken). 2012; 64(5):751-7. [DOI:10.1002/acr.21580] [PMID]

[2] Stevens JA, Rudd RA. The impact of decreasing U.S. hip fracture rates on future hip fracture estimates. Osteoporos Int. 2013; 24(10):2725-8. [DOI:10.1007/s00198-013-2375-9] [PMID]

[3] Krause PC, Braud JL, Whatley JM. Total hip arthroplasty after previous fracture surgery. Orthop Clin North Am. 2015; 46(2):193-213. [DOI:10.1016/j.ocl.2014.11.006] [PMID]

[4] Zhu ZG, Yu YY, Hou Lin-jun, Gai W, Yang Y. [Treatment of femoral shaft fractures by closed reduction and interlocking intramedullary nailing (Chinese)]. Zhongguo Gu Shang. 2014; 27(10):819-22. [PMID]

[5] Archibeck MJ, Carothers JT, Tripuraneni KR, White RE Jr. Total hip arthroplasty after failed internal fixation of proximal femoral fractures. J Arthroplasty. 2013; 28(1):168-71. [DOI:10.1016/j.arth.2012.04.003] [PMID]

[6] D'Arrigo C, Perugia D, Carcangiu A, Monaco E, Speranza A, Ferretti A. Hip arthroplasty for failed treatment of proximal femoral fractures. Int Orthop. 2010; 34(7):939-42. [DOI:10.1007/s00264-009-0834-x] [PMID]

[7] Mohanty SS, Agashe MV, Sheth BA, Dash KK. Outcome of total hip arthroplasty as a salvage procedure for failed infected internal fixation of hip fractures. Indian J Orthop. 2013; 47(1):87-92. [DOI:10.4103/0019-5413.106921] [PMID]

[8] Srivastav S, Mittal V, Agarwal S. Total hip arthroplasty following failed fixation of proximal hip fractures. Indian J Orthop. 2008; 42(3):279-86. [DOI:10.4103/0019-5413.41851] [PMID]

[9] Winemaker M, Gamble P, Petruccelli D, Kaspar S, de Beer J. Short-term outcomes of total hip arthroplasty after complications of open reduction internal fixation for hip fracture. J Arthroplasty. 2006; 21(5):682-8. [DOI:10.1016/j.arth.2005.08.013] [PMID]

[10] Min BW, Kim SJ. Avascular necrosis of the femoral head after osteosynthesis of femoral neck fracture. Orthopedics. 2011; 34(5):349. [DOI:10.3928/01477447-20110317-13] [PMID]

[11] Schwarzkopf R, Baghoolizadeh M. Conversion total hip arthroplasty: Primary or revision total hip arthroplasty. World J Orthop. 2015; 6(10):750-3. [DOI:10.5312/wjo.v6.i10.750] [PMID]

[12] Bhaskar D, Rajpura A, Board T. Current concepts in acetabular positioning in total hip arthroplasty. Indian J Orthop. 2017; 51(4):386-96. [DOI:10.4103/ortho.IJOrtho_144_17] [PMID]

[13] Sai Sathikumar A, Jacob G, Thomas AB, Varghese J, Menon V. Acetabular cup positioning in primary routine total hip arthroplasty-a review of current concepts and technologies. Arthroplasty. 2023; 5(1):59. [DOI:10.1186/s42836-023-00213-3] [PMID]

[14] D'Lima DD, Urquhart AG, Buehler KO, Walker RH, Colwell CW Jr. The effect of the orientation of the acetabular and femoral components on the range of motion of the hip at different head-neck ratios. J Bone Joint Surg Am. 2000; 82(3):315-21. [DOI:10.2106/00004623-200003000-00003] [PMID]

[15] Teja T, Shrivastava S, Choudhary A, Rathod V, Balusani P. Optimizing acetabular positioning: A comprehensive review of contemporary strategies in total hip arthroplasty. Cureus. 2024; 16(4):e59114. [DOI:10.7759/cureus.59114]

[16] Inam M, Palh HB, Raza T, Alam F, Ahmed I, Abidi SAR, et al. Acetabular fracture; its management and early functional outcome. Pak J Med Health Sci. 2024; 18(01):51. [DOI:10.53350/pjmhs0202418151]

[17] Matta JM, Sah AP. Anterior Hip Replacement: From Origin to Current Advanced Techniques. Berlin: Springer Nature; 2022. [Link]

[18] Centers FH, Board S. Positioning of the acetabular component: Intraoperative considerations. Clavadelerstrasse: AO Foundation; 2025. [Link]

[19] Viglietta E, Previ L, Giuliani V, Rescigno G, Gugliotta Y, Redler A, et al. “Single-use peripheral” vs “conventional” reaming in total hip arthroplasty: How to respect native centre of rotation and acetabular offset? A CT study. Int Orthop 2023; 47(11):2893. [DOI:10.1007/s00264-023-05986-5]

[20] Zhou Y, Shao H, Huang Y, Deng W, Yang D, Bian T. Does robotic assisted technology improve the accuracy of acetabular component positioning in patients with DDH? J Orthop Surg (Hong Kong). 2021; 29(2):23094990211025325. [DOI:10.1177/23094990211025325] [PMID]

[21] Charissoux JL, Asloum Y, Marcheix PS. Surgical management of recurrent dislocation after total hip arthroplasty. Orthop Traumatol Surg Res. 2014; 100(1 Suppl):S25-34. [DOI:10.1016/j.otsr.2013.11.008] [PMID]

[22] Lombard C, Gillet P, Germain E, Boubaker F, Blum A, Gondim Teixeira PA, et al. Imaging in hip arthroplasty management part 2: Postoperative diagnostic imaging strategy. J Clin Med. 2022; 11(15):4416. [DOI:10.3390/jcm11154416] [PMID]

[23] Carvajal Alba JA, Elpers ME, Rosenberg AE, Robinson RP. Suboptimal component position leading to severe wear of an alumina-alumina total hip coupling: Biomechanical analysis and documentation of limited tissue response. HSS J. 2015; 11(2):166-71. [DOI:10.1007/s11420-015-9443-y] [PMID]

[24] Alkhayatt NM, Alzahrani HH, Ahmed S, Alotaibi BM, Alsaggaf RM, ALAlmuaysh AM, et al. Computer-assisted navigation in oral and maxillofacial surgery: A systematic review. Saudi Dent J. 2024; 36(3):387-94. [DOI:10.1016/j.sdentj.2023.12.002] [PMID]

[25] Sukegawa S, Kanno T, Furuki Y. Application of computer-assisted navigation systems in oral and maxillofacial surgery. Jpn Dent Sci Rev. 2018; 54(3):139-49. [DOI:10.1016/j.jdsr.2018.03.005] [PMID]

[26] Bae DK, Song SJ. Computer assisted navigation in knee arthroplasty. Clin Orthop Surg. 2011; 3(4):259-67. [DOI:10.4055/cios.2011.3.4.259] [PMID]

[27] Mavrogenis AF, Savvidou OD, Mimidis G, Papanastasiou J, Koulalis D, Demertzis N, et al. Computer-assisted navigation in orthopedic surgery. Orthopedics. 2013; 36(8):631-42. [DOI:10.3928/01477447-20130724-10] [PMID]

[28] Chen X, Li S, Wang Y, Liu X, Zhang Y, Qiu G, et al. Artificially intelligent three-dimensionally-printed patient-specific instrument improves total hip arthroplasty accuracy. J Arthroplasty. 2023; 38(10):2060-7.e1. [DOI:10.1016/j.arth.2022.12.017] [PMID]

[29] Spencer-Gardner L, Pierrepont J, Topham M, Baré J, McMahon S, Shimmin AJ. Patient-specific instrumentation improves the accuracy of acetabular component placement in total hip arthroplasty. Bone Joint J. 2016; 98-B(10):1342-6. [DOI:10.1302/0301-620X.98B10.37808] [PMID]

[30] Trung HP, Sy Quyen NV, Tu NV, Trung DT, Dinh TD. Early outcomes of total hip arthroplasty using point-of-care manufactured patient-specific instruments: A single university hospital's initial experience. BMC Surg. 2023; 23(1):369. [PMID]

[31] Andriollo G. Robotic-Assisted Surgery in Healthcare Institutions: Assessing Benefits, Obstacles, and Implementation Success Factors. Lisbon: Universidade Catolica Portuguesa (Portugal); 2024. [Link]

[32] Garbarino GM, Costa G, Frezza B, Biancafarina A, Balducci G, Mercantini P, et al. Robotic versus open oncological gastric surgery in the elderly: A propensity score-matched analysis. J Robot Surg. 2021; 15(5):741-9. [DOI:10.1007/s11701-020-01168-2] [PMID]

[33] Moralidou M, Di Laura A, Henckel J, Hothi H, Hart AJ. Three-dimensional pre-operative planning of primary hip arthroplasty: A systematic literature review. EFORT Open Rev. 2020; 5(12):845-55. [DOI:10.1302/2058-5241.5.200046] [PMID]

[34] Huo J, Huang G, Han D, Wang X, Bu Y, Chen Y, et al. Value of 3D preoperative planning for primary total hip arthroplasty based on artificial intelligence technology. J Orthop Surg Res. 2021; 16(1):156. [DOI:10.1186/s13018-021-02294-9] [PMID]

[35] Germain E, Lombard C, Boubaker F, Louis M, Blum A, Gondim-Teixeira PA, et al. Imaging in hip arthroplasty management-part 1: Templating: past, present and future. J Clin Med. 2022; 11(18):5465. [DOI:10.3390/jcm11185465] [PMID]

[36] Colombi A, Schena D, Castelli CC. Total hip arthroplasty planning. EFORT Open Rev. 2019; 4(11):626-32. [DOI:10.1302/2058-5241.4.180075] [PMID]

[37] Stahl CM, Meisinger QC, Andre MP, Kinney TB, Newton IG. Radiation risk to the fluoroscopy operator and staff. AJR Am J Roentgenol. 2016; 207(4):737-44. [DOI:10.2214/AJR.16.16555] [PMID]

[38] Ross JR, Bedi A, Stone RM, Sibilsky Enselman E, Leunig M, Kelly BT, et al. Intraoperative fluoroscopic imaging to treat cam deformities: Correlation with 3-dimensional computed tomography. Am J Sports Med. 2014; 42(6):1370-6. [DOI:10.1177/0363546514529515] [PMID]

[39] Nelson EM, Monazzam SM, Kim KD, Seibert JA, Klineberg EO. Intraoperative fluoroscopy, portable X-ray, and CT: patient and operating room personnel radiation exposure in spinal surgery. Spine J. 2014; 14(12):2985-91. [DOI:10.1016/j.spinee.2014.06.003] [PMID]

[40] Bratschitsch G, Leitner L, Stücklschweiger G, Guss H, Sadoghi P, Puchwein P, et al. Radiation exposure of patient and operating room personnel by fluoroscopy and navigation during spinal surgery. Sci Rep. 2019; 9(1):17652. [DOI:10.1038/s41598-019-53472-z] [PMID]

[41] Romagnoli M, Zaffagnini M, Carillo E, Raggi F, Casali M, Leardini A, et AL. Custom-made implants for massive acetabular bone loss: Accuracy with CT assessment. J Orthop Surg Res. 2023; 18(1):742. [DOI:10.1186/s13018-023-04230-5] [PMID]

[42] Tsiampas DT, Pakos EE, Georgiadis GC, Xenakis TA. Custom-made femoral implants in total hip arthroplasty due to congenital disease of the hip: A review. Hip Int. 2016; 26(3):209-14. [DOI:10.5301/hipint.5000355] [PMID]

[43] Moseson H, Kumar S, Juusola JL. Comparison of study samples recruited with virtual versus traditional recruitment methods. Contemp Clin Trials Commun. 2020; 19:100590. [DOI:10.1016/j.conctc.2020.100590] [PMID]

[44] Rosa C, Marsch LA, Winstanley EL, Brunner M, Campbell AN. Using digital technologies in clinical trials: Current and future applications. Contemp Clin Trials. 2021; 100:106219. [DOI:10.1016/j.cct.2020.106219] [PMID]

[45] Naranjo-Gil D, Sánchez-Expósito MJ, Gómez-Ruiz L. Traditional vs. Contemporary management control practices for developing public health policies. Int J Environ Res Public Health. 2016; 13(7):713. [DOI:10.3390/ijerph13070713] [PMID]

[46] Lotfabadi P, Hançer P. A comparative study of traditional and contemporary building envelope construction techniques in terms of thermal comfort and energy efficiency in hot and humid climates. Sustainability. 2019; 11(13):3582. [DOI:10.3390/su11133582]

[47] Finch DJ, Martin BI, Franklin PD, Magder LS, Pellegrini VD Jr; PEPPER Investigators. Patient-reported outcomes following total hip arthroplasty: A multicenter comparison based on surgical approaches. J Arthroplasty. 2020; 35(4):1029-35.e3. [DOI:10.1016/j.arth.2019.10.017] [PMID]

[48] Aggarwal A, Naylor JM, Adie S, Liu VK, Harris IA. Preoperative factors and patient-reported outcomes after total hip arthroplasty: Multivariable prediction modeling. J Arthroplasty. 2022; 37(4):714-720.e4. [DOI:10.1016/j.arth.2021.12.036] [PMID]

[49] Schwartz CE, Rapkin BD, Sniderman J, Finkelstein JA. Appraisal and patient-reported outcomes following total hip arthroplasty: A longitudinal cohort study. J Patient Rep Outcomes. 2022; 6(1):93. [DOI:10.1186/s41687-022-00498-z] [PMID]

[50] Gojło MK, Lundqvist R, Paradowski PT. Short-term patient-reported outcomes following total hip replacement: Is the success picture overrated? Osteoarthr Cartil Open. 2021; 3(3):100192. [DOI:10.1016/j.ocarto.2021.100192] [PMID]

[51] Kunkel ST, Sabatino MJ, Kang R, Jevsevar DS, Moschetti WE. The cost-effectiveness of total hip arthroplasty in patients 80 years of age and older. J Arthroplasty. 2018; 33(5):1359-67. [DOI:10.1016/j.arth.2017.11.063] [PMID]

[52] Briggs A, Sculpher M, Dawson J, Fitzpatrick R, Murray D, Malchau H. Modelling the cost-effectiveness of primary hip replacement: How cost-effective is the Spectron compared to the Charnley prosthesis? York: University of York; 2003. [Link]

[53] Edlin R, Tubeuf S, Achten J, Parsons N, Costa M. Cost-effectiveness of total hip arthroplasty versus resurfacing arthroplasty: Economic evaluation alongside a clinical trial. BMJ Open. 2012; 2(5):e001162. [DOI:10.1136/bmjopen-2012-001162] [PMID]

[54] Fordham R, Skinner J, Wang X, Nolan J; Exeter Primary Outcome Study Group. The economic benefit of hip replacement: A 5-year follow-up of costs and outcomes in the Exeter Primary Outcomes Study. BMJ Open. 2012; 2(3):e000752. [DOI:10.1136/bmjopen-2011-000752] [PMID]

[55] Poliakov A, Pakhaliuk V, Popov VL. Current trends in improving of artificial joints design and technologies for their arthroplasty. Front Mech Eng. 2020; 6:4. [Link]

[56] Di Martino A. Observations on the Present and the Future of Hip Surgery. J Clin Med. 2023; 12(10):3464. [DOI:10.3390/jcm12103464] [PMID]

[57] Shaikh HJF, Hasan SS, Woo JJ, Lavoie-Gagne O, Long WJ, Ramkumar PN. Exposure to extended reality and artificial intelligence-based manifestations: A primer on the future of hip and knee arthroplasty. J Arthroplasty. 2023; 38(10):2096-104. [DOI:10.1016/j.arth.2023.05.015] [PMID]

[58] Rao SS, Chaudhry YP, Solano MA, Sterling RS, Oni JK, et al. Routine preoperative nutritional screening in all primary total joint arthroplasty patients has little utility. J Arthroplasty. 2020; 35(12):3505-11. [DOI:10.1016/j.arth.2020.06.073] [PMID]

[59] Heimroth JC, Neufeld EV, Sodhi N, Walden T, Willinger ML, Boraiah S. Relationship between preoperative nutritional status and predicting short-term complications following revision total hip arthroplasty. J Arthroplasty. 2023; 38(7):1326-9. [DOI:10.1016/j.arth.2023.02.077] [PMID]

[60] Chandrupatla S, Rumalla K, Singh JA. Association between diabetes mellitus and total hip arthroplasty outcomes: An observational study using the US National Inpatient Sample. BMJ Open. 2024; 14(7):e085400. [DOI:10.1136/bmjopen-2024-085400] [PMID]

[61] Dowsey MM, Choong PF. Obesity is a major risk factor for prosthetic infection after primary hip arthroplasty. Clin Orthop Relat Res. 2008; 466(1):153-8. [DOI:10.1007/s11999-007-0016-3] [PMID]

[62] Kotzur T, Singh A, Vivancos Koopman I, Armstrong C, Brady N, et al. The Impact of metabolic syndrome and obesity on perioperative total joint arthroplasty outcomes: The obesity paradox and risk assessment in total joint arthroplasty. Arthroplast Today. 2023; 21:101139. [DOI:10.1016/j.artd.2023.101139] [PMID]

[63] Bernstein DN, Liu TC, Winegar AL, Jackson LW, Darnutzer JL, Wulf KM, et al. Evaluation of a preoperative optimization protocol for primary hip and knee arthroplasty patients. J Arthroplasty. 2018; 33(12):3642-8. [DOI:10.1016/j.arth.2018.08.018] [PMID]

[64] Ranawat AS, Ranawat CS. Pain management and accelerated rehabilitation for total hip and total knee arthroplasty. J Arthroplasty. 2007; 22(7 Suppl 3):12-5. [DOI:10.1016/j.arth.2007.05.040] [PMID]

[65] Louw A, Diener I, Butler DS, Puentedura EJ. Preoperative education addressing postoperative pain in total joint arthroplasty: Review of content and educational delivery methods. Physiother Theory Pract. 2013; 29(3):175-94. [DOI:10.10.3109/09593985.2012.727527] [PMID]

[66] Giraudet-Le Quintrec JS, Coste J, Vastel L, Pacault V, Jeanne L, et al. Positive effect of patient education for hip surgery: A randomized trial. Clin Orthop Relat Res. 2003; (414):112-20. [DOI:10.1097/01.blo.0000079268.91782.bc] [PMID]

[67] Wright JG, Araki CT, Belkin M, Hobson RW 2nd. Postischemic hypothermia diminishes skeletal muscle reperfusion edema. J Surg Res. 1989; 47(5):389-96. [DOI:10.1016/0022-4804(89)90089-9] [PMID]

[68] Ohkoshi Y, Ohkoshi M, Nagasaki S, Ono A, Hashimoto T, Yamane S. The effect of cryotherapy on intraarticular temperature and postoperative care after anterior cruciate ligament reconstruction. Am J Sports Med. 1999; 27(3):357-62. [DOI:10.1177/03635465990270031601] [PMID]

[69] Ho SS, Coel MN, Kagawa R, Richardson AB. The effects of ice on blood flow and bone metabolism in knees. Am J Sports Med. 1994; 22(4):537-40. [DOI:10.1177/036354659402200417] [PMID]

[70] McMaster WC, Liddle S. Cryotherapy influence on posttraumatic limb edema. Clin Orthop Relat Res. 1980; (150):283-7.[PMID]

[71] Gibbons CE, Solan MC, Ricketts DM, Patterson M. Cryotherapy compared with Robert Jones bandage after total knee replacement: A prospective randomized trial. Int Orthop. 2001; 25(4):250-2. [DOI:10.1007/s002640100227] [PMID]

[72] Levy AS, Marmar E. The role of cold compression dressings in the postoperative treatment of total knee arthroplasty. Clin Orthop Relat Res. 1993; (297):174-8. [PMID]

[73] Webb JM, Williams D, Ivory JP, Day S, Williamson DM. The use of cold compression dressings after total knee replacement: A randomized controlled trial. Orthopedics. 1998; 21(1):59-61. [DOI:10.3928/0147-7447-19980101-14] [PMID]

[74] Kullenberg B, Ylipää S, Söderlund K, Resch S. Postoperative cryotherapy after total knee arthroplasty: A prospective study of 86 patients. J Arthroplasty. 2006; 21(8):1175-9. [DOI:10.1016/j.arth.2006.02.159] [PMID]

[75] Morsi E. Continuous-flow cold therapy after total knee arthroplasty. J Arthroplasty. 2002; 17(6):718-22. [DOI:10.1054/arth.2002.33562] [PMID]

[76] Healy WL, Seidman J, Pfeifer BA, Brown DG. Cold compressive dressing after total knee arthroplasty. Clin Orthop Relat Res. 1994; (299):143-6. [PMID]

[77] Scarcella JB, Cohn BT. The effect of cold therapy on the postoperative course of total hip and knee arthroplasty patients. Am J Orthop (Belle Mead NJ). 1995; 24(11):847-52. [PMID]

[78] Oshodi TO. The impact of preoperative education on postoperative pain. Part 2. Br J Nurs. 2007; 16(13):790-7. [DOI:10.12968/bjon.2007.16.13.24244] [PMID]

[79] Guignard B, Bossard AE, Coste C, Sessler DI, Lebrault C, Alfonsi P, et al. Acute opioid tolerance: Intraoperative remifentanil increases postoperative pain and morphine requirement. Anesthesiology. 2000; 93(2):409-17. [DOI:10.1097/00000542-200008000-00019] [PMID]

[80] Elia N, Lysakowski C, Tramèr MR. Does multimodal analgesia with acetaminophen, nonsteroidal antiinflammatory drugs, or selective cyclooxygenase-2 inhibitors and patient-controlled analgesia morphine offer advantages over morphine alone? Meta-analyses of randomized trials. Anesthesiology. 2005;103(6):1296-304. [DOI:10.1097/00000542-200512000-00025] [PMID]

[81] Fischer HB, Simanski CJ. A procedure-specific systematic review and consensus recommendations for analgesia after total hip replacement. Anaesthesia. 2005; 60(12):1189-202. [DOI:10.1111/j.1365-2044.2005.04382.x] [PMID]

[82] Toms L, McQuay HJ, Derry S, Moore RA. Single dose oral paracetamol (acetaminophen) for postoperative pain in adults. Cochrane Database Syst Rev. 2008; 2008(4):CD004602. [DOI:10.1002/14651858.CD004602.pub2] [PMID]

[83] Kearney PM, Baigent C, Godwin J, Halls H, Emberson JR, Patrono C. Do selective cyclo-oxygenase-2 inhibitors and traditional non-steroidal anti-inflammatory drugs increase the risk of atherothrombosis? Meta-analysis of randomised trials. BMJ. 2006; (7553):1302-8. [DOI:10.1136/bmj.332.7553.1302] [PMID]

[84] Capel M, Tornero J, Zamorano JL, Oyagüez I, Casado MÁ, Sánchez-Covisa J, et al. Efficiency of naproxen/esomeprazole in association for osteoarthrosis treatment in Spain. Reumatol Clin. 2014; 10(4):210-7. [DOI:10.1016/j.reuma.2013.11.009]

[85] Malan TP Jr, Marsh G, Hakki SI, Grossman E, Traylor L, Hubbard RC. Parecoxib sodium, a parenteral cyclooxygenase 2 selective inhibitor, improves morphine analgesia and is opioid-sparing following total hip arthroplasty. Anesthesiology. 2003; 98(4):950-6. [DOI:10.1097/00000542-200304000-00023] [PMID]

[86] Harder AT, An YH. The mechanisms of the inhibitory effects of nonsteroidal anti-inflammatory drugs on bone healing: A concise review. J Clin Pharmacol. 2003; 43(8):807-15. [DOI:10.1177/0091270003256061] [PMID]

[87] Mathiesen O, Jacobsen LS, Holm HE, Randall S, Adamiec-Malmstroem L, Graungaard BK, et al. Pregabalin and dexamethasone for postoperative pain control: A randomized controlled study in hip arthroplasty. Br J Anaesth. 2008; 101(4):535-41. [DOI:10.1093/bja/aen215] [PMID]

[88] American Society of Anesthesiologists Task Force on Acute Pain Management. Practice guidelines for acute pain management in the perioperative setting: An updated report by the American Society of Anesthesiologists Task Force on Acute Pain Management. Anesthesiology. 2012; 116(2):248-73. [DOI:10.1097/ALN.0b013e31823c1030] [PMID]

[89] Indelli PF, Grant SA, Nielsen K, Vail TP. Regional anesthesia in hip surgery. Clin Orthop Relat Res. 2005; 441:250-5. [DOI:10.1097/01.blo.0000192355.71966.8e] [PMID]

[90] Ilfeld BM, Le LT, Meyer RS, Mariano ER, Vandenborne K, Duncan PW, et al. Ambulatory continuous femoral nerve blocks decrease time to discharge readiness after tricompartment total knee arthroplasty: A randomized, triple-masked, placebo-controlled study. Anesthesiology. 2008; 108(4):703-13. [DOI:10.1097/ALN.0b013e318167af46] [PMID]

[91] Viscusi ER, Parvizi J, Tarity TD. Developments in spinal and epidural anesthesia and nerve blocks for total joint arthroplasty: What is new and exciting in pain management. Instr Course Lect. 2007; 56:139-45. [PMID]

[92] Lundblad H, Kreicbergs A, Jansson K-Å. Prediction of persistent pain after total knee replacement for osteoarthritis. J Bone Joint Surg Br. 2008; 90(2):166-71. [DOI:10.1302/0301-620X.90B2.19640] [PMID]

[93] Tang R, Evans H, Chaput A, Kim C. Multimodal analgesia for hip arthroplasty. Orthop Clin North Am. 2009; 40(3):377-87. [DOI:10.1016/j.ocl.2009.04.001] [PMID]

[94] Choi PT, Bhandari M, Scott J, Douketis J. Epidural analgesia for pain relief following hip or knee replacement. Cochrane Database Syst Rev. 2003; 2003(3):CD003071. [DOI:10.1002/14651858.CD003071] [PMID]

[95] Stowers MD, Lemanu DP, Coleman B, Hill AG, Munro JT. Review article: Perioperative care in enhanced recovery for total hip and knee arthroplasty. J Orthop Surg (Hong Kong). 2014; 22(3):383-92. [DOI:10.1177/230949901402200324] [PMID]

[96] Meding JB. Patient-controlled epidural analgesia after total hip arthroplasty: Ready for prime time?: Commentary on an article by Kethy M. Jules-Elysee, MD, et al.: Patient-controlled epidural analgesia or multimodal pain regimen with periarticular injection after total hip arthroplasty. A randomized, double-blind, placebo-controlled study. JBJS. 2015; 97(10):e46. [DOI: 10.2106/JBJS.O.00256]

[97] Tetsunaga T, Sato T, Shiota N, Tetsunaga T, Yoshida M, Okazaki Y, et al. Comparison of continuous epidural analgesia, patient-controlled analgesia with morphine, and continuous three-in-one femoral nerve block on postoperative outcomes after total hip arthroplasty. Clin Orthop Surg. 2015; 7(2):164-70. [DOI:10.4055/cios.2015.7.2.164] [PMID]

[98] Pagnano MW, Hebl J, Horlocker T. Assuring a painless total hip arthroplasty: A multimodal approach emphasizing peripheral nerve blocks. J Arthroplasty. 2006; 21(4 Suppl 1):80-4. [DOI:10.1016/j.arth.2006.03.001] [PMID]

[99] Horlocker TT, Kopp SL, Pagnano MW, Hebl JR. Analgesia for total hip and knee arthroplasty: A multimodal pathway featuring peripheral nerve block. J Am Acad Orthop Surg. 2006; 14(3):126-35. [DOI:10.5435/00124635-200603000-00003] [PMID]

[100] Hebl JR, Dilger JA, Byer DE, Kopp SL, Stevens SR, Pagnano MW, et al. A pre-emptive multimodal pathway featuring peripheral nerve block improves perioperative outcomes after major orthopedic surgery. Reg Anesth Pain Med. 2008; 33(6):510-7. [PMID]

[101] Hebl JR, Kopp SL, Ali MH, Horlocker TT, Dilger JA, Lennon RL, et al. A comprehensive anesthesia protocol that emphasizes peripheral nerve blockade for total knee and total hip arthroplasty. J Bone Joint Surg Am. 2005; 87 (Suppl 2):63-70. [DOI:10.2106/JBJS.E.00491] [PMID]

[102] Biboulet P, Morau D, Aubas P, Bringuier-Branchereau S, Capdevila X. Postoperative analgesia after total-hip arthroplasty: Comparison of intravenous patient-controlled analgesia with morphine and single injection of femoral nerve or psoas compartment block. A prospective, randomized, double-blind study. Reg Anesth Pain Med. 2004; 29(2):102-9. [DOI:10.1016/j.rapm.2003.11.006] [PMID]

[103] Szczukowski MJ Jr, Hines JA, Snell JA, Sisca TS. Femoral nerve block for total knee arthroplasty patients: a method to control postoperative pain. J Arthroplasty. 2004; 19(6):720-5. [DOI:10.1016/j.arth.2004.02.043] [PMID]

[104] YaDeau JT, Cahill JB, Zawadsky MW, Sharrock NE, Bottner F, Morelli CM, et al. The effects of femoral nerve blockade in conjunction with epidural analgesia after total knee arthroplasty. Anesth Analg. 2005; 101(3):891-5. [DOI:10.1213/01.ANE.0000159150.79908.21] [PMID]

[105] Momeni M, Crucitti M, De Kock M. Patient-controlled analgesia in the management of postoperative pain. Drugs. 2006; 66(18):2321-37. [DOI:10.2165/00003495-200666180-00005] [PMID]

[106] Bollish S, Collins C, Kirking D, Bartlett R. Efficacy of patient-controlled versus conventional analgesia for postoperative pain. Clin Pharm. 1985; 4(1):48-52. [PMID]

[107] Palmer PP, Miller RD. Current and developing methods of patient-controlled analgesia. Anesthesiol Clin. 2010; 28(4):587-99. [DOI:10.1016/j.anclin.2010.08.010] [PMID]

[108] Viscusi ER. Patient-controlled drug delivery for acute postoperative pain management: A review of current and emerging technologies. Reg Anesth Pain Med. 2008; 33(2):146-58. [DOI:10.1016/j.rapm.2007.11.005] [PMID]

[109] Parvataneni HK, Ranawat AS, Ranawat CS. The use of local periarticular injections in the management of postoperative pain after total hip and knee replacement: A multimodal approach. Instr Course Lect. 2007; 56:125-31. [PMID]

[110] Korean Knee Society. Guidelines for the management of postoperative pain after total knee arthroplasty. Knee Surg Relat Res. 2012; 24(4):201-7. [DOI:10.5792/ksrr.2012.24.4.201] [PMID]

[111] Vendittoli PA, Makinen P, Drolet P, Lavigne M, Fallaha M, Guertin MC, et al. A multimodal analgesia protocol for total knee arthroplasty. A randomized, controlled study. J Bone Joint Surg Am. 2006; 88(2):282-9. [DOI:10.2106/jbjs.e.00173] [PMID]

[112] Parvataneni HK, Shah VP, Howard H, Cole N, Ranawat AS, Ranawat CS. Controlling pain after total hip and knee arthroplasty using a multimodal protocol with local periarticular injections: A prospective randomized study. J Arthroplasty. 2007; 22(6 Suppl 2):33-8. [DOI:10.1016/j.arth.2007.03.034] [PMID]

[113] Bottros J, Klika AK, Milidonis MK, Toetz A, Fehribach A, Barsoum WK. A rapid recovery program after total hip arthroplasty. Curr Orthop Prac. 2010; 21(4):381-4. [Link]

[114] Wellman SS, Murphy AC, Gulcynski D, Murphy SB. Implementation of an accelerated mobilization protocol following primary total hip arthroplasty: Impact on length of stay and disposition. Curr Rev Musculoskelet Med. 2011; 4(3):84-90. [DOI:10.1007/s12178-011-9091-x] [PMID]

[115] Lee KJ, Min BW, Bae KC, Cho CH, Kwon DH. Efficacy of multimodal pain control protocol in the setting of total hip arthroplasty. Clin Orthop Surg. 2009; 1(3):155-60. [DOI:10.4055/cios.2009.1.3.155] [PMID]

[116] Andrzejewski K, Domżalski M, Komorowski P, Poszepczyński J, Rokita B, Elgalal M. Optimization of revision hip arthroplasty workflow by means of detailed pre-surgical planning using computed tomography data, open-source software and three-dimensional-printed models. Diagnostics (Basel). 2023; 13(15):2516. [DOI:10.3390/diagnostics13152516] [PMID]

[117] Agrawal AK, Gandhi M, Jain M, Desai S, Golwala P. Clinical and functional outcomes of revision hip replacement surgeries. J Orthop Rep. 2024; 3(3):100256. [DOI:10.1016/j.jorep.2023.100256]

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