VILNIUS UNIVERSITY

MEDICAL FACULTY

The Final Thesis

Accuracy of Preoperative Planning for Different Approaches in Total Hip replacement

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2024

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Table of Contents

1. Abstract

This thesis evaluates the accuracy of preoperative planning for Total Hip Replacement across various surgical approaches. Through a literature review, traditional two-dimensional and advanced three-dimensional templating as well as the use of artificial intelligence are compared with regard to their advantages and disadvantages in preoperative planning for Total Hip Replacement.
The thesis compares the precision of implant placement and outcome predictability across the anterior, anterolateral, posterior and direct lateral approach of Total Hip Replacement.
Findings indicate that 3D templating and AI-assisted methods considerably improve preoperative planning accuracy over traditional 2D methods. This planning precision is suggested to reduce complication rates and overall healthcare costs.

Keywords: Total Hip Replacement (THR), Total Hip Arthroplasty (THA), Total Joint Arthroplasty (TJA), Preoperative Planning, Surgical Approaches, Anterior Approach, Anterolateral Approach, Posterior Approach, Direct Lateral Approach, 3D Templating, 2D Templating, Implant Accuracy, Templating Techniques

2. Introduction

Total Hip Replacement surgery stands as an intervention for improving the quality of life, in patients suffering from debilitating hip joint conditions. In this context, my research delves into a critical question: How does the accuracy of preoperative planning vary among different surgical approaches to Total Hip Replacement and what implications does this have for surgical outcomes and patient satisfaction?
The goal of this review is to collect and bring together the current literature, latest publications, studies and research results. Another goal is to evaluate the accuracy and effectiveness of different techniques of preoperative planning in combination with different approaches of THR surgeries. With this literature review, I aim to provide healthcare professionals with valuable insights and recommendations to improve their understanding of the complexities of preoperative planning. By applying this knowledge, healthcare providers can provide superior patient care, ultimately improving both surgical outcomes and patient satisfaction.

3. Literature Selection Strategy

This research focuses on the accuracy of preoperative planning techniques in THR, ensuring relevance to the study question. It considers only scientific papers, conference proceedings and peer-reviewed journals. Preference is given to systematic reviews, meta-analyses, RCTs, comparative studies and cohort studies in English, prioritizing methodologically sound studies with adequate sample sizes and statistical analyses.
A comprehensive search will be conducted in databases such as Google Scholar, PubMed and Embase, limited to studies published from 2014 onwards, with minor exceptions if the study is relevant to this topic.
Additionally, manual checks of references and consultations with experts will identify further relevant studies. The thesis reviews selected studies on hip replacement preoperative planning, noting the challenge of finding comparative analyses within a single study framework.

4. Clinical Description of Total Hip Replacement

Total Hip Replacement (THR), also known as Total Hip Arthroplasty (THA), is a highly successful orthopedic procedure recognized for its effectiveness in improving mobility, relieving pain and enhancing quality of life, particularly in patients with severe hip osteoarthritis[1]. It is considered the best treatment for various hip conditions including hip dysplasia, osteoarthritis, fractures and bone tumors [2].
Osteoarthritis is the most common reason for THR due to the breakdown of joint cartilage, leading to pain and limited mobility. Other reasons include rheumatoid arthritis and osteonecrosis, which occurs when reduced blood flow leads to bone death. Hip fractures and previous failed hip surgeries also often necessitate THR, although conditions like infections or severe osteoporosis may preclude it [3,4,5].
In THR, the surgeon removes damaged tissue and implants prosthetic components into the hip joint. Various surgical approaches, anterior, posterior and direct lateral, offer distinct advantages and recent innovations like robot-assisted THR enhance precision and accuracy in component placement. Prosthetics vary in material and may be cemented or uncemented for better integration [6].

Accurate preoperative planning is crucial to select the appropriate surgical approach and optimize outcomes, minimizing operation time and potential complications [7].
Since the 1960s, THR has significantly improved due to advances in surgical techniques and technology. Currently, over 450,000 THR are performed annually in the U.S., emphasizing its importance and acceptance [8]. There has also been an increase in global hip osteoarthritis cases, with the age-standardized rate rising from 17.02 per 100,000 in 1990 to 18.70 per 100,000 in 2019 [9]. Consequently, primary THR surgeries have surged by 177% from 2000 to 2019 [10].
In Europe, over 3.1 million primary THR have been conducted since the mid-20th century [11], with projections indicating a 559% increase in Total Joint Arthroplasty (TJA) by 2060, focusing on THR [10]. This significant projected growth of 5.2% annually highlights the need for precise healthcare planning and resource allocation, with THR potentially reaching an annual volume of 2,418,839 procedures by 2060 [10].
The prevalence of hip osteoarthritis in those aged 85 and older presents a 25% risk, with about 10% needing a hip replacement during their lifetime [12]. This risk varies by gender, with women facing a higher lifetime risk than men [13].
Despite the procedure's high success rate, risks include dislocation, infection and joint loosening, affecting around 5% of patients. Postoperative complications can also occur, such as blood clots and nerve damage [14,15,16,17]. Continuous improvements in surgical techniques and planning are essential to manage these risks and enhance patient outcomes [7].

5. General Preoperative Planning of a Total Hip Replacement

There are three primary methods for surgical templating: two-dimensional (2D), three-dimensional (3D) and using acetate templates on digital images. Digital templating on digital X-rays is the most precise and consistent method, aiding surgical planning by accurately predicting implant size and placement [18].
Although less precise, acetate templates on digital images offer time and cost efficiency. Traditional acetate templates on printed radiographs have limitations in repeatability, but advancements in technology have improved planning accuracy [18].
2D templating involves placing acetate templates or software over printed radiographs and is the standard method in clinical practice. This technique accurately predicts implant sizes in THR but is prone to errors from magnification and patient positioning. Additionally, it struggles with hip

biomechanics measurements, such as femoral offset during flexion and rotation and determining the optimal implant size in complex cases with abnormal hip anatomy, like developmental dysplasia or trauma [19]. The limitations of 2D templating have prompted the development of digital 2D and 3D planning techniques [7].

3D-Templating is done using computer software based on CT scans or an EOS® templating software. In comparison to 2D templating, this method provides a more precise prediction of implant size and location.

One of the advantages is an improved 3D depiction of hip anatomy for planning and decision-making purposes. Furthermore it helps to precisely anticipate femoral offset and center of rotation, which improves clinical outcomes and patient function.

It reduces issues including dislocation and polyethylene wear, while increasing implant longevity as well. Some of the challenges are that it requires access to CT scans or EOS imaging systems, which may not be accessible in all healthcare settings.

CT scans also use more radiation and have higher imaging costs than plain radiography.

There is limited evidence of therapeutic advantages, particularly in terms of better patient outcomes as well.

In terms of predicting implant sizes accurately, 2D templating demonstrates an accuracy between 25% and 85.7% for the acetabular component and between 32% and 49.15% for the femoral stem. 3D templating shows an accuracy range from 40% to 98% for the acetabular component and from 34% to 100% for the femoral stem [19].

3D templating, using CT data, offers superior precision and reliability, particularly for complex cases, but requires access to CT scans and involves higher radiation and higher costs [18].

The success of THR surgery largely depends on careful patient selection, detailed preoperative planning and the surgeon's expertise in addressing the hip's biomechanics [20].

Patient assessment involves evaluating factors such as age, gender, cognitive abilities, activity level, medical history, expected outcomes, life expectancy and the specific diagnosis. Clinical evaluations also consider abnormalities, the condition of the ipsilateral knee, hip mobility, gait, the lumbosacral spine and differences in pelvic tilt and limb length [18]. Given the variability in patient anatomy and bone quality, a standard approach to prosthetic selection is impractical, necessitating thorough reviews of comorbidities, allergies and previous surgeries. High-risk patients, particularly the elderly, might require additional tests such as chest X-rays, ECGs and blood tests. Prosthetic choices are influenced by the patient’s age, activity level, bone quality and anatomy and involve weight-bearing X-rays for thorough assessment [20].

Preoperative planning ideally includes 3D imaging to select appropriate implants for the patient's anatomical needs and thus improve biomechanical function [18]. Furthermore surgical templating is crucial because it provides legal protection against negligence claims [19].

The introduction of digital templating has refined accuracy, although its effectiveness depends on image calibration quality and the planner's proficiency [21]. Digital templating, particularly with 3D planning, has improved precision in implant sizing and fit, reduced surgical errors and lessened reliance on subjective judgment [2]. Challenges with 3D planning include costs, learning curves and potential increases in radiation exposure, yet it represents a significant advancement in surgical precision and efficiency [11].

Effective templating also requires precise radiographs to identify anatomical landmarks and adjustments for severe hip deformities [20]. Digital radiography is preferred for its safety, cost efficiency and superior image quality. A combined approach using digital and acetate templates may yield the best results, but studies show that digital on-screen templating is accurate and reliable. Digital radiographs have several benefits over hard-copy radiographs.

Advantages include lower radiation exposure, fewer unsatisfactory films, potential cost savings and higher image quality. The introduction of the digital templating algorithm led to its use by many surgeons, however research comparing it to acetate templating revealed acetate's superiority in some circumstances.

There is a need for a templating method that combines digital radiographs with readily available acetate templates. Previous research has described preoperative on-screen templating technologies and demonstrated their reliability and accuracy [22].

A meta-analysis indicated that 3D CT templating is the most accurate, outperforming other methods. While 3D templating is ideal for complex cases, 2D templating is still favored for simpler primary THR surgeries. The clinical benefits of 3D templating, however, need further research to confirm its efficacy in primary THR [19].

Another study found that digital templating achieved 87% accuracy for femoral components and 78% for acetabular components, with overweight patients experiencing greater inaccuracies [21]. Adjustments in acetabular cup placement should consider the spine-pelvis relationship, especially in patients with specific conditions. The Kinematic alignment technique aligns the cup based on spinal changes to optimize hip function, using the transverse acetabular ligament as a reference [18]. Spinopelvic alignment is crucial, influencing outcomes and dislocation risks [23]. Traditional 2D templating remains invaluable for providing information on the standing position to understand the spinopelvic connection [19].

Overall, collaboration between orthopedic surgeons and engineers is driving advances in 2D and 3D digital templating [18]. Additionally, the integration of Artificial Intelligence (AI) in orthopedic templating systems, like PeekMed and AI HIP, has automated bone segmentation, landmark detection and prosthetic sizing, significantly enhancing operational efficiency [2]. However, traditional X-ray and measurement templates often lack precision. Despite the potential of digital radiography to enhance accuracy, its consistency in matching actual implanted sizes varies [24].

6. Introduction to the Anterior Approach for Total Hip Replacement

The Direct Anterior Approach (DAA) for THR is increasingly popular due to its minimally invasive nature, which allows for tissue preservation. Originally noted in the late 19th and early 20th centuries, its use has surged recently, driven by trends towards outpatient and minimally invasive surgeries. Surgeons use this approach with the patient supine, using fluoroscopy and specific tools for precise incisions and implant placements [25].

The DAA has shown better early functional outcomes, such as higher Harris Hip Scores and lower WOMAC scores, compared to the lateral direct Hardinge approach and its modifications. It also correlates with shorter hospital stays, indicating quicker recovery and potential healthcare cost reductions [26].

The typical incision for DAA is between the greater trochanter and the anterior superior iliac spine, preserving surrounding structures and using special retractors to expose the hip joint [25].

Proponents of the DAA cite enhanced function and faster recovery, though its long-term advantages and risk of complications are still debated. Compared to the posterior approach (PA), DAA involves longer surgery times and similar implant positions, albeit with slightly increased anteversion and abduction [27, 26].

Studies show that DAA leads to better functional improvements and less pain six weeks post-surgery, with fewer analgesics required on the day of surgery and the first postoperative day [28].

A 2022 study highlighted potential issues with the DAA's radiographic precision in placing acetabular components, suggesting limited anatomical access might affect accuracy [6].

6.1. Preoperative Planning in the Anterior Approach

In the realm of THR surgeries employing the anterior approach, comprehensive preoperative imaging plays a pivotal role. Moreover, preoperative planning software enhances accuracy by facilitating detailed templating, thereby optimizing surgical outcomes [25].
The DAA for THR is associated with lower dislocation rates and faster rehabilitation but presents challenges like a steep learning curve and potential complications, particularly in the femoral region. Effective preoperative planning is essential to mitigate these issues. While 2D templating is common, it has limitations that 3D planning can overcome by improving accuracy.
A 2016 study examined the accuracy of 3D preoperative planning in THR using the DAA, focusing on minimizing complications and enhancing clinical outcomes over five years. This approach utilized HIP-PLAN® software and low-dose CT scans for detailed analysis and planning. The study demonstrated high consistency between the planned and actual positions of implants, with precise restoration of hip rotation centers, limb lengths and femoral offsets, showing minimal deviations. All things considered, 3D planning in THR with DAA proved to be a reliable method, resulting in safe and accurate outcomes and aligning with the best outcomes in contemporary research. It also allowed for customized surgical decisions, reducing the risk of dislocation and optimizing implant positioning. Further large-scale studies are necessary to confirm these findings over the long term [29].
Between March 2018 and March 2021, a retrospective cross-sectional study evaluated the accuracy of preoperative planning for cementless THA using the DAA. Preoperative planning utilized 2D digital templating with mediCAD® software Version 5.98, which aided in selecting implant sizes and types.
Preoperative pelvic X-rays were taken following a standardized protocol. Templating was performed by newcomer physicians using the mediCAD® software, considering various prosthesis options due to potential intraoperative changes by surgeons. Implant size selection during surgery was based on preoperative X-rays, patient anatomy, joint stability and leg length.
The criteria for accuracy involved a discrepancy of 1 mm in stem diameters and 2 mm in cup sizes. In femoral component templating, accuracy rates were 27.2% for exact size match, 61.0% within 1 mm and 78.6% within 2 mm. Patients with developmental dysplasia of the hip (DDH) showed notably higher accuracy in femoral stem size prediction. For the acetabular component, the mean size discrepancy was 2.79 mm. Accuracy rates for cup size estimations were 28.9% for exact match,

63.9% within 1 mm and 83.1% within 2 mm. Females and DDH patients demonstrated improved accuracy in predicting correct cup sizes.

Approximately 41.3% of cases had both femoral and acetabular components correctly templated within one size. No significant correlation was found between the accuracy of stem and cup size estimations. Digital templating has enhanced clinical outcomes, reduced postoperative complications, shortened treatment durations and decreased costs. The choice of templating tools and surgeon experience significantly affect accuracy, but emerging technologies like 3D software and AI-based solutions are promising in enhancing accuracy and efficiency [2].

Another retrospective study conducted between January 2016 and December 2018 examined the accuracy of preoperative planning for THR using the DAA. The planning process included standard AP pelvis radiographs and the use of manufacturer templates to determine implant sizes and positioning. Measurements such as the inclination angle (IA) and anteversion angle (AA) were taken to ensure alignment within established safe zones.

Radiological assessments revealed a high degree of accuracy in leg length discrepancy (LLD), with 88.5% of patients having less than 10 mm discrepancy and none exceeding 20 mm.

Moreover, 94.3% of cases maintained IA within safe limits. However, only 43.8% of cases remained within the safe range for AA.

The study highlighted a high consistency in measurements when conducted by the same observer (Intraclass Correlation Coefficient, ICC: 0.958 to 0.992), though inter-observer reliability was lower (ICC: 0.42 to 0.873). Notably, the use of the Pinnacle brand cups showed better adherence to safe zone standards compared to other brands.

No significant statistical correlations were found between LLD or AA and factors like gender, ASA classification, surgeon's experience, or the presence of THR on the opposite side. The average fluoroscopy time was minimal, with most procedures taking under 20 seconds, minimizing radiological exposure.

Overall, this study supports the effectiveness and precision of traditional preoperative planning methods in optimizing implant placement and minimizing discrepancies in THR procedures [30].

2D templates often have limitations that result in decreased accuracy in preoperative planning. In contrast, AI technologies such as the AIHIP software, which utilizes CMG-NET neural network technology, offer the potential for enhanced precision.

A 2023 study evaluated AIHIP's effectiveness in DAA for THR using data from 440 patients. This software analyzes CT scans to identify acetabular anatomy and optimally plan component position, size and orientation.
The study compared outcomes between a group using AIHIP and a control group using traditional 2D planning. Results showed that AI-assisted planning achieved significantly better prosthesis sizing accuracy. Patients in the AI group experienced less blood loss, fewer fluoroscopies and shorter surgeries. They also had improved postoperative outcomes, including reduced leg length discrepancies and higher Harris Hip Scores, suggesting that AIHIP substantially improves the accuracy of preoperative planning in THR [31].

A 2020 study examined robotic arm-assisted THR using the DAA in 534 patients, focusing on preoperative planning accuracy. Preoperative CT scans of the pelvis and knees provided detailed anatomical data for virtual planning via a workstation, with the MAKO® robotic system using this data for tailored surgical strategies. This approach ensured precise adjustments for pelvic tilt, leg length and hip offset. The study highlighted that robotic arm assistance enhances surgical precision, thereby reducing complications such as impingement, dislocation and muscle imbalance and supports the customized design of implants. The findings suggest that the robotic arm-assisted THR using DAA leads to reliable and predictable surgical outcomes [32].
Another study published in 2022 investigated the precision and accuracy of acetabular component placement in robot-assisted Total Hip Arthroplasty (RA-THA), comparing the DAA and the posterior approach (PA). Both approaches utilized robotic assistance and digital EBRA technology for radiographic analysis. This analysis involved comparing the intended placements of components with their actual postoperative positions.
The study found that both DAA and PA RA-THA provided high accuracy and precision in component alignment. For the DAA group, the results included a mean registration accuracy of 0.36 mm and standard deviations for inclination and anteversion angles at 3.2 and 4.0 degrees, respectively. The DAA group had fewer deviations from expected results, with only three notable cases. In contrast, the PA group showed a mean registration accuracy of 0.33 mm, with slightly more variation in the inclination and anteversion angles and 12 outliers in these measurements. Notably, no DAA patients had component placements outside the recognized safety zone, unlike some PA patients.
Overall, the study concluded that RA-THA achieves precise and accurate alignment of the acetabular components irrespective of the surgical approach used. Differences in accuracy and

precision between DAA and PA were minimal and not clinically significant, suggesting that both methods are viable for achieving desired surgical outcomes [6].

In 2022, a study compared the accuracy of computed tomography (CT)-based planning to acetate templating for predicting implant sizes and neck lengths in orthopedic surgery. The study examined the precision, reproducibility and influencing factors of both methods using both anterior and posterior surgical approaches. CT-based planning utilized AIHIP software with manual checks, while acetate templating used conventional pelvic radiographs. The study also involved surgical trials to adjust implants based on motion range and leg length.

Results showed that CT-based planning was generally more accurate than acetate templating. For CT-based planning, 52.63% of acetabular component predictions and 54.82% of femoral component predictions matched the actual implanted sizes. Additionally, over 90% of the predictions were within one size range of the actual implants. The mean absolute errors for acetabular and femoral components were 0.991 mm and 0.526 mm, respectively.

In contrast, acetate templating achieved exact size predictions in 46.49% for acetabular and 40.79% for femoral components, with about 75% accuracy within one size range. The corresponding mean absolute errors were larger: 1.588 mm and 0.956 mm. The reliability of size estimation also varied, with significant intra-observer and good inter-observer agreements.

The study highlighted CT-based planning's advantages in 3D visualization, which enhances accuracy, especially in complex cases. This method provides more realistic surgical simulations by considering multiple anatomical planes, thus proving superior to acetate templating [33].

A study comparing the accuracy of 3D computerized preoperative planning to traditional 2D templating in cementless THR was conducted between January 2008 and July 2009. This research involved 60 patients undergoing THR for primary osteoarthritis, divided into groups for 3D and 2D planning, to investigate the precision in predicting implant size and position. The study aimed to address leg length discrepancy (LLD) and femoral offset inaccuracies, which are prevalent issues leading to patient dissatisfaction and potential legal consequences for surgeons.

The hypothesis suggested that 3D planning, based on CT scans, would provide higher accuracy than 2D methods. The study utilized a DAA performed by a relatively inexperienced surgeon and examined different stem types compatible with the respective planning software used in each group.

Results indicated that the 3D planning group achieved significantly higher accuracy in predicting implant sizes and aligning the femoral head height and offset compared to the 2D group. This group also demonstrated improved precision in maintaining the center of rotation, which contributed to a more accurate restoration of leg length.

Conclusively, the study affirmed that 3D computerized planning surpasses conventional 2D templating in the preoperative planning of THR, offering a reliable alternative that enhances surgical accuracy, particularly useful in minimally invasive techniques like the DAA [34].

Factors such as acetabular protrusion and variations in the neck shaft angle, particularly in males with obesity and high muscularity, can complicate surgery by limiting exposure and access. While the DAA is associated with benefits like reduced pain, shorter recovery periods and decreased hospitalization time, it also poses risks including extended operation duration and increased likelihood of nerve damage and femur fractures [25].

Comparative studies show that early postoperative outcomes with DAA may be superior to other techniques, but these advantages are generally short-lived. Complications such as femur fractures, dislocations and nerve damage are notable, though they tend to decrease as surgeons gain more experience with this approach. Techniques like using tissue protectors and longer sterile dressings have been suggested to mitigate these risks. Despite its challenges, DAA remains a preferred method due to its minimally invasive nature and potential for better early functional outcomes. Surgeons must carefully weigh these risks and benefits due to the learning curve associated with the approach [25].

Studies comparing the DAA with the lateral approach (LA) found no significant differences in femur stem placement across several Randomized Controlled Trials (RCTs). However, variations in cup inclination and anteversion were observed, with DAA showing higher values in some cases. These variations could stem from differences in study designs, such as participant numbers and follow-up attrition [35].

Research has also highlighted common complications of DAA, such as nerve dysfunction and intraoperative fractures. Early use of DAA showed high complication rates without clear advantages over the posterior approach, underscoring the importance of selecting appropriate surgical methods based on specific femur morphologies and conditions like acetabular dysplasia [29].

7. Introduction to the Anterolateral Approach for Total Hip Replacement

The anterolateral approach for THR incorporates the abductor-splitting technique, which involves modifying 30%–40% of the anterior parts of the gluteus medius and minimus. This approach is advantageous for its potential to reduce dislocation rates post-surgery but comes with risks such as nerve damage leading to limps or a Trendelenburg gait and issues related to improper femoral component placement [36].

The patient is placed in a lateral decubitus position on a split table, with the side to be operated on facing upwards.

Slightly anterior location allows the contralateral leg to rest on the anterior leg component.

The posterior leg piece was removed to make room for lowering the operational leg during surgery.

Concerning the cut and separation, a front incision extends from the front upper edge of the iliac spine to the front upper point of the greater trochanter.

Blunt dissection between the anterior tensor fascia lata muscle and the posterior gluteus medius muscle. The head of the rectus femoris muscle separates medially from the capsule. Retractors are positioned above and below the upper and lower sections of the femoral neck. The capsule is cut parallel to the neck, extending from the intertrochanteric line to the acetabulum [37].

Studies suggest that the anterolateral technique may have lower complication rates compared to other procedures, highlighting its effectiveness in hip replacement surgeries [26].

7.1. Preoperative Planning in the Anterolateral Approach

A study published in 2017 sought to determine whether including an extra X-ray in antero-posterior (AP) hip view may improve planning precision. Bertin and Röttinger's minimally invasive approach allowed access to the hip only from the lateral position [24,37]

The study used MediCAD software to compare three groups in hip arthroplasty planning: Group 1 with 50 participants had only a digital pelvic overview; Group 2 with 50 patients included an additional AP hip view; and the control Group 0 with 50 patients utilized traditional analog planning. Group 2 showed the highest accuracy in acetabular cup sizing, achieving 96% within one size deviation. Femoral stem sizing in this group also had a high accuracy of 94%. The study found significant differences in planning accuracy among the groups, with digital methods outperforming analog in terms of component size matching and leg length discrepancy, which was less in the digital group. Overall, digital planning provided greater precision, particularly with the inclusion of an AP hip view, suggesting it should be standard in preoperative procedures for better outcomes [24].

3D preoperative planning is more precise for stem sizing compared to traditional 2D templating, although both methods have similar accuracy rates. Repeated tests with 3D planning consistently yielded the same results, demonstrating its reliability and consistency. Unlike 2D methods, 3D planning does not depend on femoral torsion or patient positioning, enhancing its accuracy with true-to-size, non-magnified images. While 2D templating may occasionally be less precise, CT-based 3D techniques generally show excellent accuracy in size planning. Additionally, bi-planar radiographs offer lower radiation exposure than CT scans and provide simultaneous frontal and lateral views, which help surgeons assess component sizes more effectively. The use of a feedback loop in planning can further increase the accuracy. Low-dose biplanar radiographs are a safer alternative, providing comprehensive views with less radiation and are practical for patients undergoing primary THR [7].

In their 2019 study, doctors assessed the use of a cementless curved short stem and a bi-hemispherical acetabular cup in total hip arthroplasty, using a minimally invasive anterolateral approach with the patient lying on their back. Preoperative planning involved a digital X-ray taken with the patient standing and legs rotated inward by 15°. A metallic ball on the symphysis pubis helped calculate image magnification and component sizes were planned using mediCAD® version 5.1 software. The study found that surgeons generally adhered to predetermined component sizes, with a preference for larger sizes in cases of joint instability. The accuracy of these size choices varied, with better adherence noted in female patients compared to male. Body mass index did not significantly affect the choice of component sizes. Surgeon experience also showed no significant impact on planning adherence. The main finding was a significant gender difference in selecting the appropriate joint component sizes, but body mass did not notably influence the planning outcomes [38].

The Japanese Orthopaedic Association (JOA) hip score is a validated clinical instrument designed to evaluate hip functionality and pain. This scoring system uses a 100-point scale, categorized into four domains: pain (40 points), range of motion (20 points), walking ability (20 points) and activities of daily living (20 points). A higher score on this scale represents superior hip function. The JOA hip score is commonly utilized to appraise hip conditions before and after therapeutic interventions, including surgeries [39].

A study published in 2016 with only subjects who underwent the anterolateral approach of THR, included 65 patients who had cementless THR, with a focus on Developmental dysplasia of the hip (DHH) cases. Clinical assessments were conducted using the JOA hip score both prior to and following surgery.

Radiological examinations are conducted to determine implant fixation, socket migration and stem stability. Preoperative 3D planning is used to assess combined anteversion and alter anteversion angles intraoperatively. The study showed significant improvement in JOA hip scores after surgery, suggesting improved hip function. There were no postoperative infections, dislocations or osteolysis. The strong correlation between planned and postoperative stem versions demonstrates the precision of preoperative planning. The majority of hips kept combined anteversion within the safe zone after surgery, showing that the implant was well positioned.

Intraoperative dislocation tendencies were successfully addressed without the need for further treatments. Preoperative 3D planning is essential for accurately estimating the postoperative stem version. Combined anteversion (CA) consideration is critical for good outcomes, especially in circumstances involving morphological differences. Preoperative planning and intraoperative navigation provide precise implant positioning in THR. The CA method helps to keep postoperative CA below acceptable ranges, especially in complicated cases like DDH. The study emphasizes the significance of tailored planning and exact implementation for the best THR results [40].

8. Introduction to the Posterior and Posterolateral Approach for Total Hip Replacement

Among the various techniques employed for this surgery, the posterior approach (PA) and the posterolateral approach stand out due to their widespread adoption and the unique anatomical considerations they involve.

The posterior approach, known for providing exceptional exposure of the hip joint, follows a meticulous sequence of steps. Initially, the procedure involves the splitting of the superficial plane through the gluteus maximus muscle. This is accompanied by a tenotomy of the short external rotators of the hip, alongside a posterior capsulotomy, to facilitate access to the hip joint. The dislocation of the femoral head is achieved by internally rotating the hip, which is then followed by the osteotomy of the neck, a critical step for the replacement [41]. Despite its advantages, the PA harbors a significant drawback; it poses a risk for posterior dislocation due to the disinsertion of the external rotators [27].

In contrast, the posterolateral approach, a variation of the posterior approach, incorporates a slightly curved incision over the greater trochanter. This technique is unique because it involves dividing the gluteus maximus muscle along its fibers and continuing the fascial cut downward to reveal the tendinous attachment of the gluteus maximus on the back of the femur. Like the posterior approach, the short external rotators are divided close to their insertion on the femur. However, they are preserved in length for later repair, aiming to mitigate the risk of postoperative complications [42].

Both approaches prioritize accessing the hip joint through precise anatomical incisions, focusing on the careful dissection around critical structures like the greater trochanter and ensuring the preservation of the sciatic nerve by adjusting the femur's position. The main goal is to provide effective exposure for the replacement procedure while minimizing the risks associated with nerve damage and postoperative dislocation. The conclusion of the surgery involves precisely reattaching muscle tendons and the hip capsule to promote stability and reduce the likelihood of dislocation [43].

8.1. Preoperative Planning in the Posterior and Posterolateral Approach

In 2016, a study assessed the accuracy and reliability of preoperative digital radiography templates for the posterolateral approach in THR. The retrospective study included 413 patients undergoing primary cementless THR but focused on 200 subjects after excluding certain cases. The calibration of preoperative radiographs involved a radiopaque bar.

The study recommended a 27-inch display monitor for better visibility and comfort. A 10-cm magnification bar was used to ensure accurate image scaling. The templating process was divided into six detailed steps, including adjusting radiograph magnification to 120% and measuring variables like leg length discrepancy and the positioning of prosthetic components.

The study measured the accuracy by comparing predicted and actual implant sizes used during surgery. Reliability was assessed through consistency in size predictions by the same and different observers. Findings showed that digital templating, supported by picture archiving and communication systems (PACS), is an effective shift from traditional radiography, with high prediction accuracy and significant intra- and interobserver reliability [22].

Another retrospective study examined a cohort of 61 patients who received unilateral primary THR via the posterolateral technique using an uncemented anatomical femoral component (SPS®, Symbios). Preoperative 3D planning using CT imaging is used to maximize normal hip anatomy restoration during THR.

To better the fit with each patient's natural hip shape, modular femoral necks were integrated with 3D CT planning. Pre-operative planning was carried out by the HipPLAN software, with the femoral component and neck type selected accordingly. The 10-year survival rate for femoral components was 96%. No thigh pain was noted by any of the re-evaluated subjects. Radiographic examination revealed that the implants were securely fixed, with no signs of stress shielding or cortical thinning. The anatomical SPS® femoral component paired with 3D CT planning showed positive long-term results, according to the study. The combination of 3D CT planning and modular neck implants might have contributed to the favorable outcomes.

However, further studies comparing the effects of 2D and 3D planning would be beneficial [44].

In a 2019 study the precision of preoperative planning through a posterolateral approach in uncemented THR was evaluated. Radiographs of the hip were obtained prior to surgery to facilitate this planning. These radiographs were taken in the AP view, magnified by 20%, showcasing the proximal third of both femurs with the lower limbs internally rotated by 15 degrees. Both AP and lateral views of the hip joint were examined.

The surgical method employed was the posterior-lateral approach, conducted with the patient in lateral decubitus position using pelvic supports.

In the preoperative radiographic planning, prosthetic templates were magnified by 20% to assist in determining the appropriate size and placement of the acetabular components, as well as the horizontal and vertical offsets, dimensions of the femoral component, thickness of the cement mantle and the diameter of the cement restrictor in the medullary cavity.

However, the study did not provide significant insights into the effectiveness of this preoperative planning, aside from underscoring its critical role in enhancing the predictability of surgical outcomes and reducing the risk of various complications in THR. Initial steps in the arthroplasty procedure involve comprehensive planning, which includes a meticulous review of all clinical and radiographic data [45].

2D templates are widely utilized; however, their accuracy is constrained by X-ray magnification and projection positioning. Manual adjustments necessitate that 3D planning software is reserved for particular instances. AI HIP, a tool powered by artificial intelligence, enables rapid, automated detection of bone structure and ensures precise fitting of prosthetic components. Nonetheless, its effectiveness and real-world clinical utility require additional study.

A prospective clinical trial was conducted to evaluate the precision of AI HIP in primary THR using the posterolateral approach, considering variables that might influence its accuracy. Participants underwent preoperative CT scans and X-rays. The planning process incorporated AI HIP, 3D Mimics and 2D digital templates. The study categorized participants into three groups for analysis. The AI Group, which used deep learning models for segmenting bones and detecting anatomical points, alongside automatic prosthesis matching through extensive data and reinforcement learning. Adjustments were made as necessary.

The 3D Group, which focused on creating 3D prosthetics aligned with surgical prototypes. CT data was processed using Mimics software for planning, with specific acetabular cups and femoral stems selected and adjusted for the best fit.

The 2D Group, which depended on standard AP pelvic X-rays and digital templating with Smart Joint software.

Surgical data were then used to determine the actual sizes of the implants. The intended sizes were evaluated against the actual measurements to confirm precision. Expert surgeons reviewed all plans to ensure their reliability. AI HIP demonstrated superior accuracy in prosthetic size determination compared to 2D digital templating (74.58% vs. 40.68% for the cup, 71.19% vs. 49.15% for the stem) and required significantly less time than 3D Mimics planning. Factors potentially affecting AI HIP's accuracy, such as sex and body mass index, showed no significant impact. In individuals with developmental dysplasia of the hip, the accuracy of positioning the acetabular cup was diminished. Preoperative planning has advanced with the introduction of 3D software, though issues with complexity and time consumption persist. AI HIP has shown comparable accuracy to 3D Mimics while demanding significantly less effort in preparation. It outperforms traditional 2D templates by offering more accurate sizing and a 3D perspective. Previous studies have validated the high accuracy of 3D planning. AI HIP's stability was evident from the initial planning stages, even in cases with anatomical variations. Compared to 3D Mimics, AI HIP significantly speeds up the templating process. The study also explored sex, BMI and hip dysplasia as potential factors influencing the accuracy of AI HIP.

As a new tool, AI HIP offers a faster, simpler and more visually intuitive planning process compared to previous methods. Its automatic correction and planning reduce the bias from personal experience. The output encompasses a multi-perspective observation planning approach, supporting ongoing education and reducing the learning curve for surgeons [46].

Another study published in 2023 evaluated the precision of preoperative planning in THA using robotic assistance versus conventional methods. 60 patients undergoing primary THA through the posterolateral approach were divided into two groups: conventional THA (cTHA) and robotic-assisted THA (rTHA). Preoperative planning in cTHA used pelvic digital X-rays and a 2D model, while rTHA used CT imaging and a 3D model guided by robotic navigation for precise implant placement. The study measured the accuracy of preoperative planning with X-ray and CT scans and assessed postoperative leg length disparity. The rTHA group showed higher accuracy in implant sizing and placement compared to the cTHA group, suggesting that robotic systems may offer superior preoperative planning and minimize leg length discrepancies [47].

A 2023 study at Ningxia Medical University General Hospital examined the effectiveness of AI-assisted 3D preoperative planning versus traditional methods in 161 patients undergoing THR via the posterolateral approach. This retrospective analysis compared AI-generated 3D models and automated prosthesis selection to conventional planning with X-ray templates. Outcomes assessed included surgical time, prosthetic model prediction and postoperative implantation accuracy, such as the acetabular abduction angle and leg length discrepancies. The study found that AI-assisted planning generally resulted in quicker surgeries, more accurate prosthesis placement and more consistent correction of leg length discrepancies, despite some limitations in predicting correct prosthetic sizes, especially in patients with developmental dysplasia of the hip. Overall, AI 3D planning was deemed more effective than traditional 2D methods [48].

Another retrospective study was carried out on 204 patients, 220 hips, evaluating the precision of femoral component size templating between two stem designs: a single-wedge metadiaphyseal and a single-wedge mid-short (Biomet Taperloc Microplasty), using three different surgical approaches (Direct Lateral, Posterior and the DAA). The findings demonstrated that the single-wedge mid-short stem design markedly enhanced the accuracy of femoral component size templating. Furthermore, although the surgical approach did not influence the accuracy of cup sizing, the precision was significantly higher in the group that underwent the posterior approach.

The study determines that the highest accuracy in templating is obtained through the use of a calibration marker along with a metaphyseal short femoral stem design and this accuracy does not depend on the patient's BMI or gender [49].

Another study from 2022 comprehensively examined the effectiveness of two ways of placing the acetabular component during THR surgeries: one using functional CT-based 3D templating with patient-specific instruments and the other using traditional 2D templating. Despite employing

advanced technology in the 3D templating group (OPS group), the results showed no statistically significant difference in the primary outcome of mean error in acetabular anteversion compared to the conventional 2D templating group. However, the OPS group displayed a higher precision in achieving target anteversion, with 96% of procedures falling within 10° of planned angles, significantly outperforming the conventional group's 76%.
Both groups underwent the surgeries through a posterior approach, ensuring consistency in surgical technique aside from the planning method. Clinical outcomes such as pain relief and mobility were similar across both groups, highlighting that the increased accuracy in implant positioning did not translate into clinically significant improvements within the study's follow-up period.
The findings suggest that while the use of patient-specific 3D planning can enhance the precision of implant positioning, this does not necessarily correlate with better short-term clinical outcomes. Further research might explore whether these improvements in accuracy have long-term benefits, potentially reducing complications such as implant wear or need for revision surgeries [50].

9. Introduction to the Direct Lateral Approach for Total Hip Replacement

The Direct Lateral Approach for THR is a technique refined over time to minimize incision size and tissue disruption while ensuring comprehensive access to the hip joint. This approach splits the fascia lata and the gluteus medius to expose the hip, strategically avoiding significant nerve damage by respecting anatomical boundaries. This method is particularly noted for its reduced risk of prosthetic dislocations and facilitating quicker patient mobilization post-surgery. Ideal for primary THR and certain revision cases, the approach has evolved to emphasize patient-specific incisions and careful preoperative planning for optimal outcomes [51,52].
A research published in 2009 found that the standard lateral direct Hardinge technique had the shortest surgical time in comparison with other approaches, with a mean of 77 minutes, indicating possibly better efficiency. Complication rates were lower using the standard lateral direct Hardinge technique than in the compared tissue sparing surgery (TSS) groups. Because the method is common, doctors may be more comfortable with it and knowledgeable about the surgical technique, perhaps leading to easier surgeries and fewer problems [26].

9.1. Preoperative Planning in the Direct Lateral Approach

A study examined the radiographic results of THR operating with two techniques: the Direct Lateral Approach (DLA) and the Posterior Lateral Approach (PLA), with a particular focus on the orientation of the prosthesis and how the surgical method influences this aspect. The study used the advanced EOS 2D/3D X-ray imaging system for more precise and detailed imaging results.

From January 2019 to December 2021, the study analyzed 321 patients undergoing primary THR, of whom 120 underwent the DLA and 201 underwent the PLA. The objective was to explore the variances in the placement and alignment of the prosthesis across these approaches and their subsequent effects on postoperative outcomes. The capability of the EOS system to perform 3D reconstructions and provide accurate measurements in a standing position offered a more detailed assessment of prosthesis alignment compared to traditional imaging methods.

The findings revealed notable differences in combined anteversion between the DLA and PLA techniques, indicating that various surgical approaches may necessitate specific prosthesis alignments to reduce the risk of dislocation and enhance clinical results. The study emphasized the need to consider variables such as the inclination of the anterior pelvic plane, patient gender and femoral head diameter when determining the optimal orientation of the prosthesis for THR.

Additionally, the research highlighted the benefits of the EOS imaging system in orthopedic surgery for its precision and 3D reconstruction capabilities, which aid in better evaluating prosthesis alignment and potentially decrease postoperative complications like dislocation.

This comprehensive analysis significantly contributes to the field of orthopedic surgery by suggesting that the choice of surgical approach for THR should take into account its impact on prosthesis orientation and by advocating for the use of sophisticated imaging techniques for enhanced surgical planning and outcomes [53].

The standard lateral direct Hardinge approach resulted in more blood loss during the surgery than certain TSS groups.

Patients had a longer stay in the hospital than other TSS groups. At 6 weeks, the post-operative HHS score was somewhat lower than that of the other TSS groups. At 6 weeks, the post-operative WOMAC score was somewhat greater than that of certain TSS groups.

Complications included one proximal femoral fracture, one cup malposition and one infection, but the overall complication incidence seemed to be lower than in some TSS studies [26].

Another study from 2023 primarily assessed the accuracy of preoperative planning methods in THR revisions, comparing 3D to 2D templating. All surgical procedures in the study were performed using a lateral surgical approach while patients were in a lateral position. It found a significant disparity in the accuracy of predicting the required size of the implant: 3D templating correctly predicted the exact size in 96.3% of cases, whereas 2D templating only managed 55.6% accuracy. This consistency in surgical technique across all cases provides a controlled environment, ensuring that the observed differences in templating accuracy can be attributed to the templating methods themselves, rather than variations in surgical approach [54].

10. Limitations of the Literature Review

The literature review on preoperative planning techniques for THR faced notable limitations due to a lack of studies focused specifically on the topic. Most available research primarily compared surgical approaches, neglecting the differences in preoperative planning. This gap made it challenging to gather comprehensive information on the various planning methods, limiting the review's depth and broadness. The predominance of studies on surgical techniques over detailed preoperative strategies highlights a critical research gap, showing the need for more targeted investigations to enhance understanding and improve THR outcomes.

11. Conclusion

Preoperative planning is essential for the success of THR, employing various methodologies aimed at optimizing surgical outcomes. This discussion synthesizes findings from several studies to assess the efficacy and accuracy of different preoperative planning techniques. It highlights that variations in templating accuracy are primarily due to the methods used rather than differences in surgical approaches.

Evidence consistently shows that 3D templating is more accurate than 2D methods. 3D imaging provides a detailed anatomical view, allowing for precise assessments and implant fittings. For example, studies using 3D planning in the anterolateral approach have demonstrated significantly higher accuracy in predicting implant sizes compared to 2D templating, which often struggles with magnification errors and patient positioning issues.

Transitioning from traditional acetate to digital templating marks a significant advancement in preoperative planning. Digital templates use sophisticated imaging technologies proven to offer higher accuracy in implant sizing and placement. Research shows that digital templating achieves accuracy within one size for both the cup and stem in the majority of cases, surpassing the performance of older acetate methods.

The integration of AI-based tools like AIHIP has transformed preoperative planning by automating bone segmentation and enhancing the predictability of implant sizing. AI combined with 3D imaging not only speeds up the planning process but also improves accuracy, especially in complex cases like developmental dysplasia of the hip.

The choice of templating method significantly affects the accuracy of preoperative planning, while the surgical approach itself, be it direct anterior, posterolateral or others, does not inherently impact the accuracy. This finding is supported by many studies using the same templating techniques across different surgical approaches, which report no significant difference in the accuracy of component placement.

Choosing an effective templating method has profound clinical implications. More accurate preoperative planning can reduce operative time and decrease the likelihood of complications such as dislocations and leg length discrepancies. Although technologies like 3D CT-based planning and AI-assisted templating may involve higher initial costs, they can potentially lower overall expenses by reducing the need for revision surgeries and shortening hospital stays through improved surgical outcomes.

Noted for its tissue-sparing nature, the DAA contributes to improved early functional outcomes and quicker recovery. 3D planning and low-dose CT scans used in DAA show high accuracy in implant placement, which supports superior outcomes in terms of early functional recovery and pain management.

The anterolateral approach emphasizes reducing dislocation rates and involves careful consideration of muscle preservation. Multiple studies suggest lower complication rates and effectiveness in hip replacement surgeries with precise preoperative planning leading to fewer complications and shorter surgery times.

The PA and PLA are characterized by their approach to accessing the hip joint with a focus on preserving the sciatic nerve. The use of robotic-assisted THR and AI-assisted planning in these approaches has demonstrated increased accuracy in preoperative planning, leading to precise implant placement and minimized leg length discrepancies.

Finally, the DLA, known for its reduced risk of prosthetic dislocations and quicker patient mobilization, also benefits from precise preoperative planning. The approach has shown to have a potentially better efficiency in terms of surgical time.

The synthesis of various studies highlights that the accuracy of preoperative planning in THR is predominantly influenced by the templating methods used rather than the surgical approach. The superior precision provided by advanced 3D imaging and AI technologies supports their wider adoption in clinical settings. Future research should focus on directly comparing these advanced technologies to establish standardized protocols that optimize outcomes across all surgical approaches in THR. The ongoing advancements in preoperative planning technologies promise to enhance patient outcomes by ensuring more predictable and refined surgical results.

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