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Comprehensive Management of Hip Osteoarthritis: A Systematic Review of Biomechanics, Total Hip Arthroplasty, and Rehabilitation Strategies

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Abstract

Background: Hip osteoarthritis (HOA) is a progressive degenerative joint disease that significantly affects mobility, functionality, and quality of life. As global life expectancy increases, the prevalence of HOA is expected to rise, necessitating a comprehensive evaluation of management strategies, including biomechanical adaptations, conservative treatments, total hip arthroplasty (THA), and rehabilitation protocols. This systematic review synthesizes current evidence on the most effective therapeutic approaches for optimizing pain relief, functional mobility, and long-term patient outcomes.

Methods: This study followed PRISMA guidelines for a systematic literature review. Searches were conducted in PubMed, Scopus, Web of Science, and Cochrane Library, selecting peer-reviewed studies published between 2018 and 2024. Inclusion criteria covered clinical trials, cohort studies, systematic reviews, and meta-analyses evaluating HOA management, THA techniques, and post-surgical rehabilitation. Quality assessments were performed using the Cochrane Risk of Bias Tool, Newcastle-Ottawa Scale, and AMSTAR-2 checklist. Data were synthesized using narrative synthesis and meta-analysis, where applicable.

Results: Conservative treatments, particularly exercise therapy, weight management, and NSAID-based pharmacological interventions, demonstrated significant efficacy in delaying disease progression and improving symptoms. Total hip arthroplasty remains the gold standard for end-stage HOA, with robotic-assisted THA, dual-mobility implants, and highly cross-linked polyethylene liners emerging as significant advancements in surgical precision and implant longevity. Postoperative rehabilitation, including proprioceptive training, gait retraining, and balance exercises, is essential for restoring function and minimizing complications. Biomechanical studies revealed that spinopelvic alignment, gait asymmetry, and altered joint offset play crucial roles in disease progression and surgical outcomes.

Conclusion: Managing hip osteoarthritis requires a multimodal and individualized approach, integrating biomechanical assessments, conservative strategies, surgical innovations, and structured rehabilitation programs. Advances in artificial intelligence-driven gait analysis, virtual rehabilitation, and 3D-printed implants offer promising future directions for optimizing treatment. This review highlights the necessity of early diagnosis, biomechanical optimization, and evidence-based rehabilitation protocols to enhance patient mobility, independence, and overall quality of life.

Keywords: Hip Osteoarthritis, Total Hip Arthroplasty, Biomechanics, Rehabilitation, Conservative Treatment

1. Introduction

Hip osteoarthritis (HOA) is a chronic and progressive degenerative disease characterized by the gradual deterioration of articular cartilage, leading to pain, stiffness, and functional impairment. It is one of the leading causes of disability among the elderly population and significantly impacts quality of life (Hall *et al.*, 2022) [14]. As global life expectancy increases, the prevalence of HOA is expected to rise, posing significant challenges to healthcare systems worldwide. The condition is

associated with multiple risk factors, including aging, genetic predisposition, obesity, and mechanical stress, all of which contribute to the disease's progression and severity (Jahn *et al*., 2024) [16].

The pathophysiology of HOA involves complex interactions between mechanical loading, metabolic alterations, and inflammatory processes. Cartilage degradation, subchondral bone remodeling, and synovial inflammation are hallmarks of the disease. Over time, these pathological changes result in joint space narrowing, osteophyte formation, and decreased shock absorption capacity, leading to pain and restricted mobility (Van Buuren *et al*., 2021) [28]. As the disease progresses, patients experience worsening symptoms that affect daily activities such as walking, climbing stairs, and dressing, ultimately leading to loss of independence.

Obesity has been identified as a major modifiable risk factor for HOA, as excess weight increases mechanical stress on the hip joint. Additionally, adipose tissue plays an active role in systemic inflammation, releasing pro-inflammatory cytokines that exacerbate cartilage degradation (Yuan *et al*., 2023) [35]. Weight management through dietary interventions and physical activity is essential in slowing the disease's progression and reducing symptom severity. Studies suggest that even modest weight loss can significantly decrease joint loading and pain intensity in individuals with hip osteoarthritis.

Occupational exposure is another crucial factor influencing the development and progression of HOA. Workers involved in physically demanding jobs, such as construction, agriculture, and manufacturing, are at increased risk due to prolonged mechanical stress and repetitive joint movements (Jahn *et al*., 2024) [16]. Similarly, athletes engaged in high-impact sports, such as long-distance running and soccer, are more likely to develop HOA due to repetitive microtrauma and excessive joint loading.

Socioeconomic disparities in HOA prevalence and treatment outcomes have been widely documented. Individuals from lower socioeconomic backgrounds often experience delayed diagnosis, limited access to conservative treatment options, and higher rates of disability due to inadequate healthcare resources (Callahan *et al*., 2021). Additionally, variations in genetic susceptibility contribute to differences in disease prevalence among different racial and ethnic groups. For example, some studies indicate that Asian populations have a lower incidence of HOA compared to Western populations, potentially due to genetic and lifestyle factors.

The clinical presentation of HOA typically includes chronic pain localized in the groin, morning stiffness, and progressive loss of range of motion. As the disease advances, pain becomes more persistent, affecting sleep quality and overall well-being (Teirlinck *et al*., 2023). Diagnosis is primarily based on clinical assessment and imaging studies, with radiography being the standard method for detecting structural changes such as joint space narrowing, osteophyte formation, and subchondral sclerosis.

Management of HOA involves both conservative and surgical approaches, depending on disease severity and patient-specific factors. Conservative treatments focus on symptom relief and functional preservation through pharmacological and non-pharmacological interventions (Weng *et al*., 2023) [32]. Physical therapy, weight management, and exercise therapy have been shown to be among the most effective strategies for improving joint function and reducing pain. Exercise programs targeting muscle strengthening, flexibility, and neuromuscular control are particularly beneficial in enhancing mobility and preventing disease progression.

Pharmacological management of HOA includes the use of analgesics and nonsteroidal anti-inflammatory drugs (NSAIDs) to control pain and inflammation. However, long-term use of NSAIDs is associated with adverse effects such as gastrointestinal bleeding, cardiovascular complications, and renal dysfunction, necessitating careful risk-benefit assessment (Da Costa *et al*., 2021) [8]. Some studies suggest that exercise therapy provides pain relief comparable to NSAIDs but with fewer side effects, making it a preferred long-term treatment option.

In advanced cases where conservative management fails to provide adequate symptom relief, total hip arthroplasty (THA) is the treatment of choice. THA is one of the most successful orthopedic procedures, offering significant pain relief and functional restoration (Jahn *et al*., 2024) [16]. The procedure involves the replacement of the damaged femoral head and acetabulum with prosthetic components, which can be either cemented or uncemented depending on patient characteristics and surgeon preference.

The longevity of hip implants has improved with advancements in prosthetic materials and surgical techniques. Modern implants, made from highly durable materials such as ceramic and cross-linked polyethylene, exhibit reduced wear rates, leading to extended implant survival (Van Buuren *et al*., 2021) [28]. The introduction of dual-mobility implants has further enhanced joint stability and reduced the risk of dislocation, particularly in high-risk patient populations.

Despite the success of THA, postoperative rehabilitation is critical for optimizing outcomes. Rehabilitation programs focus on early mobilization, muscle strengthening, balance training, and gait retraining to facilitate recovery and prevent complications (Zhang *et al*., 2023) [37]. Studies indicate that structured rehabilitation programs significantly improve functional outcomes and reduce the risk of falls in post-THA patients.

Biomechanical alterations play a crucial role in the pathogenesis and progression of HOA. Changes in hip joint mechanics, such as altered joint offset and compromised abductor muscle function, contribute to disease severity and impact post-surgical outcomes (VIA *et al*., 2024). Biomechanical assessments using motion capture systems and force plate technology provide valuable insights into gait abnormalities and compensatory movement patterns in HOA patients.

Spinopelvic alignment is another key consideration in hip biomechanics. Abnormalities in spinopelvic motion can increase the risk of implant malpositioning and dislocation following THA (Oommen *et al*., 2024) [22]. Preoperative assessment of spinopelvic parameters allows for personalized surgical planning, ensuring optimal implant positioning and joint stability.

Recent advancements in surgical technology, such as robotic-assisted THA, have improved precision in implant placement, leading to better functional outcomes and reduced complication rates (Rice *et al*., 2024) [25]. The integration of artificial intelligence in preoperative planning and intraoperative navigation further enhances surgical accuracy and patient-specific customization of implants.

Despite these advancements, challenges remain in optimizing long-term outcomes for HOA patients. Future

research should focus on developing biologic therapies for cartilage regeneration, improving implant longevity, and refining rehabilitation protocols to enhance post-THA recovery. Emerging technologies, including 3D-printed customized implants and AI-driven gait analysis, hold promise for further advancing hip osteoarthritis treatment.

Given the complexity of HOA and the evolving landscape of treatment strategies, it is essential to synthesize current evidence to guide clinical decision-making. This review aimed to evaluate the latest research on hip osteoarthritis, including its biomechanical implications, conservative treatment options, surgical interventions, and rehabilitation strategies. By analyzing clinical trials, systematic reviews, and meta-analyses, this study sought to provide an updated perspective on optimizing patient outcomes at different stages of disease progression.

This study aimed to systematically review the literature on hip osteoarthritis, focusing on biomechanical changes, conservative management, total hip arthroplasty, and rehabilitation strategies. The objective was to synthesize current evidence to identify the most effective therapeutic approaches for improving pain relief, functional mobility, and long-term patient outcomes. Through a comprehensive evaluation of clinical trials, observational studies, and meta-analyses, this review sought to provide a foundation for future research and clinical practice guidelines in the management of hip osteoarthritis.

2. Methodology

This study employed a systematic literature review (SLR) methodology based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The review aimed to synthesize the existing evidence on hip osteoarthritis (HOA), including biomechanical changes, conservative management, total hip arthroplasty (THA), and rehabilitation strategies. To ensure methodological rigor, this study followed a structured approach that included defining the research question, conducting a comprehensive database search, applying strict inclusion and exclusion criteria, performing quality assessments, and synthesizing data for analysis.

The research question was formulated based on the PICO framework (Population, Intervention, Comparison, and Outcome), which is widely used in systematic reviews to structure clinical inquiries. The study focused on patients with hip osteoarthritis or those undergoing total hip arthroplasty (Population), analyzing conservative treatments, surgical interventions, and rehabilitation protocols (Intervention), comparing different treatment modalities and biomechanical adaptations (Comparison), and evaluating pain relief, functional improvement, and joint stability (Outcome). By structuring the research question in this manner, the study aimed to provide a comprehensive assessment of the most effective therapeutic approaches for managing HOA and optimizing THA recovery.

A comprehensive literature search was conducted across four major databases: PubMed, Scopus, Web of Science, and the Cochrane Library. These databases were selected due to their extensive coverage of medical, orthopedic, and rehabilitation studies. The search terms were carefully chosen to capture relevant studies on hip osteoarthritis, biomechanics, total hip arthroplasty, and rehabilitation. Keywords included “hip osteoarthritis,” “total hip arthroplasty,” “hip biomechanics,” “hip rehabilitation,” “gait analysis,” “exercise therapy for hip OA,” “NSAIDs in hip osteoarthritis,” “balance training after THA,” and “robotic-assisted THA.” Boolean operators (AND, OR) were used to refine searches and increase sensitivity in identifying relevant studies.

The inclusion and exclusion criteria were meticulously applied to ensure that only high-quality, relevant studies were included in the review. Inclusion criteria encompassed peer-reviewed articles published between 2018 and 2024, covering clinical trials, cohort studies, systematic reviews, and meta-analyses that evaluated HOA, THA, and rehabilitation strategies. Studies focusing on biomechanical changes associated with HOA and THA were prioritized, along with research examining conservative treatment approaches such as exercise therapy, pharmacological management, and weight reduction. Additionally, studies that assessed postoperative rehabilitation strategies, including balance training, proprioception exercises, and strength training, were included.

Exclusion criteria were implemented to filter out irrelevant or low-quality studies. These criteria excluded non-English publications, case reports, conference abstracts, and expert opinions due to their lower levels of evidence. Studies focusing exclusively on pediatric or traumatic hip conditions were also excluded, as the review aimed to examine degenerative HOA and post-THA recovery. Articles with small sample sizes ($n < 30$) were not included, as small studies may lack statistical power and generalizability. Finally, studies lacking quantitative outcome measures or failing to use objective biomechanical assessments were excluded to ensure a high level of scientific rigor.

Following the database search, study selection was conducted in two phases: title and abstract screening, followed by full-text review. Two independent reviewers screened the titles and abstracts of all identified studies to assess their relevance based on the inclusion and exclusion criteria. Disagreements between reviewers were resolved through discussion, and in cases where consensus was not reached, a third reviewer was consulted. The full-text review was then performed to confirm study eligibility, ensuring that all included articles provided sufficient data for analysis.

Data extraction was performed using a standardized data collection sheet. Key variables extracted from each study included author, year of publication, study design, sample size, population characteristics (age, sex, disease severity), treatment interventions (exercise therapy, pharmacological treatment, surgical techniques, rehabilitation strategies), and outcome measures (pain reduction, functional mobility, joint stability, biomechanical adaptations, and patient-reported outcomes). Extracting this data systematically allowed for a structured comparison of different treatment modalities and their effectiveness.

To assess the quality of the included studies, two different tools were used based on study design. For randomized controlled trials (RCTs), the Cochrane Risk of Bias Tool was employed to evaluate potential sources of bias, including selection bias, performance bias, detection bias, attrition bias, and reporting bias. For observational studies, the Newcastle-Ottawa Scale (NOS) was utilized to assess study quality based on selection criteria, comparability, and outcome assessment. Systematic reviews and meta-analyses were evaluated using the AMSTAR-2 (A Measurement Tool to Assess Systematic Reviews) checklist, which provides a

comprehensive appraisal of review methodology. Studies were classified as high quality, moderate quality, or low quality based on these assessments.

Data synthesis was performed using narrative synthesis and meta-analysis where applicable. Studies were grouped based on intervention type (biomechanical assessments, conservative management, surgical treatment, rehabilitation strategies) and analyzed qualitatively to identify trends and common findings. Where sufficient quantitative data were available, a meta-analysis was conducted using a random-effects model to account for variations between studies. Heterogeneity was assessed using I^2 statistics, with values above 50% indicating substantial heterogeneity. Forest plots were generated to visually present effect sizes and confidence intervals for key outcomes.

Ethical considerations were also considered. Since this study was based solely on previously published research, no ethical approval was required. However, only studies that had obtained ethical approval and informed consent from participants were included to ensure compliance with research ethics.

3. Results

3.1 Hip Osteartrhosis

Hip osteoarthritis (HOA) is a chronic degenerative disease characterized by the progressive deterioration of articular cartilage and structural changes in the subchondral bone, joint capsule, and surrounding tissues. This condition significantly impacts the quality of life of affected individuals and is one of the leading causes of functional disability in older adults (Hall *et al*., 2022) [14]. With an aging population and increasing life expectancy, the prevalence of osteoarthritis is expected to rise substantially in the coming decades, posing a major challenge to healthcare systems worldwide.

HOA is a multifactorial condition resulting from the interaction of genetic, environmental, biomechanical, and metabolic factors. Among the main risk factors, advanced age, genetic predisposition, excess weight, repetitive mechanical overload, and congenital joint deformities stand out (Jahn *et al*., 2024) [16]. Obesity, for instance, plays a crucial role in the worsening of osteoarthritis, as it not only increases the load imposed on the hip joint but also contributes to a systemic inflammatory state that accelerates cartilage degradation (Yuan *et al*., 2023) [35].

Additionally, occupational exposure and physical activity levels influence the incidence of HOA. Workers engaged in tasks requiring heavy lifting, non-neutral postures, and prolonged exposure to mechanical vibrations have an increased risk of developing the disease (Jahn *et al*., 2024) [16]. Similarly, high-impact sports, such as long-distance running and activities involving repetitive hip movements, may contribute to a higher prevalence of osteoarthritis in this joint.

The epidemiology of HOA also reveals racial, socioeconomic, and geographic disparities. Studies indicate that osteoarthritis prevalence is higher in populations with lower socioeconomic status, which may be associated with limited access to medical care, reduced awareness of preventive measures, and greater exposure to occupational risk factors (Callahan *et al*., 2021). Furthermore, some populations exhibit lower genetic susceptibility to the disease. For example, Asian individuals appear to have a lower incidence of HOA compared to Western populations.

The symptoms of HOA include chronic pain in the groin region, morning stiffness, limited range of motion, and progressive reduction in joint function. In advanced stages, pain may become constant, affecting sleep quality and daily activities such as walking, climbing stairs, and dressing (Van Buuren *et al*., 2021) [28]. Diagnosis is based on clinical criteria and imaging examinations, with radiography being the primary method for identifying structural changes such as joint space narrowing, osteophyte formation, and subchondral sclerosis.

The treatment of HOA involves both conservative and surgical approaches, depending on the severity of the disease and its impact on the patient's functionality. Conservative treatment includes physical therapy, weight management, the use of analgesic and non-steroidal anti-inflammatory drugs (NSAIDs), and lifestyle modifications. Exercise therapy is widely recommended as one of the most effective strategies for reducing pain and improving joint function. Studies demonstrate that physical therapy provides pain relief and improved mobility in HOA patients, with beneficial effects lasting at least six to nine months after the intervention (Teirlinck *et al*., 2023).

Regarding pharmacological treatment, NSAIDs are frequently prescribed for pain and inflammation control. However, prolonged use of these drugs is associated with adverse effects such as gastrointestinal and cardiovascular complications. Studies suggest that diclofenac 150 mg/day and etoricoxib 60 mg/day are the most effective medications for symptom relief in HOA, although their use should be carefully monitored (Da Costa *et al*., 2021) [8]. Comparatively, physical therapy has demonstrated similar efficacy to NSAIDs but with a more favorable safety profile, particularly for elderly patients and those with comorbidities (Weng *et al*., 2023) [32].

In addition to pain and functional limitations, HOA is also associated with an increased risk of falls and fractures due to factors such as joint instability, muscle weakness, and proprioceptive deficits. Patients with hip osteoarthritis are more likely to experience recurrent falls, which can result in severe fractures, such as femoral neck fractures, often requiring surgical intervention and leading to a significant loss of independence (Zhang *et al*., 2023) [37]. Thus, preventive measures such as muscle strengthening and home environment modifications are essential to minimize these risks.

Given the complexity of HOA, adopting a multimodal therapeutic approach is crucial, combining preventive strategies, conservative treatment, and surgical intervention when necessary. Total hip arthroplasty remains the most effective option for advanced cases, providing significant pain relief and restoring joint function. However, this intervention should only be considered when all conservative options have been exhausted.

3.2 Hip Biomechanics

The hip joint plays a fundamental role in human mobility, supporting substantial loads while allowing for a wide range of motion. As a ball-and-socket joint, the hip provides stability and efficient force transmission, making it crucial for weight-bearing activities such as walking, running, and standing. However, when compromised by osteoarthritis (OA), significant biomechanical changes occur, affecting function and increasing joint stress (VIA *et al*., 2024).

Osteoarthritis leads to the progressive degeneration of articular cartilage, resulting in joint space narrowing, increased friction, and subchondral bone remodeling. As the cartilage deteriorates, load distribution across the joint becomes uneven, leading to pain and movement restriction. These changes are further exacerbated by osteophyte formation and capsular stiffness, both of which contribute to mechanical dysfunction (Oommen *et al*., 2024) [22].

One of the key biomechanical alterations in hip OA is the reduction of joint offset. Offset, defined as the perpendicular distance between the femoral head center and the femoral shaft, is critical for maintaining proper abductor muscle function. A decrease in offset results in reduced abductor muscle leverage, leading to gait instability and increased joint reaction forces. These compensatory mechanisms further accelerate joint degeneration and increase energy expenditure during movement (Patil *et al*., 2021) [24].

Another major consequence of OA is altered spinopelvic motion. The interplay between the pelvis and lumbar spine ensures dynamic postural stability, but OA-induced stiffness can cause compensatory changes, such as increased pelvic tilt and lumbar lordosis. These adaptations place additional stress on surrounding structures and complicate surgical interventions such as total hip arthroplasty (THA), where spinopelvic imbalance increases the risk of implant malpositioning and dislocation (Giai Via *et al*., 2024).

Gait analysis in OA patients reveals asymmetrical movement patterns, reduced step length, and slower walking speeds. These adaptations aim to minimize pain but often result in excessive load transfer to the contralateral limb, increasing the risk of secondary joint pathologies. Studies using motion capture systems and force plate assessments have demonstrated that OA patients rely more on their non-affected limb, a phenomenon that persists even after THA if not adequately rehabilitated (Wang *et al*., 2021) [31].

Accurate evaluation of hip biomechanics is crucial for diagnosing OA severity, guiding treatment decisions, and monitoring post-surgical outcomes. Three-dimensional (3D) motion capture technology is widely used to assess hip kinematics and kinetics in real-time. These systems utilize infrared cameras and reflective markers to track movement patterns, identifying deviations from normal biomechanics (Wang *et al*., 2021) [31].

Force plates measure ground reaction forces (GRF) and center of pressure (COP) displacement, providing insight into weight distribution and stability. Patients with hip OA often exhibit asymmetrical GRF patterns, indicative of altered load transfer due to pain and joint stiffness (Lenze *et al*., 2022) [19].

Standard radiographs remain the primary imaging modality for evaluating joint space narrowing, osteophyte formation, and femoral head migration. More advanced techniques, such as CT scans and EOS® imaging, offer 3D reconstructions that allow for more precise measurements of acetabular orientation, femoral offset, and spinopelvic parameters (Junsig *et al*., 2022).

The sit-to-stand (STS) test is commonly used to evaluate lower limb strength and joint stability. Research indicates that OA patients place increased reliance on their non-affected limb during STS transitions, leading to kinetic imbalances. This asymmetry persists even after THA, highlighting the need for targeted rehabilitation to restore symmetrical movement patterns (Wang *et al*., 2021) [31].

THA is considered the gold standard for end-stage hip OA, aiming to restore biomechanics, alleviate pain, and improve function. However, achieving optimal post-operative biomechanics depends on precise implant positioning, restoration of offset, and correction of spinopelvic alignment.

One of the most significant advancements in THA has been the development of dual mobility (DM) implants, which enhance joint stability by increasing the jump distance and reducing impingement risks. These implants have been particularly beneficial for high-risk patients, such as those with neuromuscular disorders or spinopelvic abnormalities. However, concerns remain regarding long-term wear, intra-prosthetic dislocation, and metal ion release (Moghnie *et al*., 2023) [21].

Robotic-assisted THA has further improved surgical precision, allowing for more accurate implant positioning. By incorporating 3D preoperative templating and intraoperative navigation, surgeons can optimize component placement, minimizing complications such as edge-loading and excessive wear. This personalized approach to THA has been associated with superior functional outcomes and improved implant longevity (Rice *et al*., 2024) [25].

Understanding hip biomechanics and the alterations caused by osteoarthritis (OA) is crucial for optimizing treatment strategies. Future research should focus on advancing implant technology, with the continued development of customized implants and 3D-printed prosthetics to enhance biomechanical restoration and improve patient outcomes (Zhang *et al*., 2021). Another key area of innovation is the integration of artificial intelligence (AI) in gait analysis, as AI-driven assessments may help predict OA progression and identify optimal surgical strategies.

Additionally, enhancing rehabilitation protocols through personalized physical therapy programs based on biomechanical analysis will be essential in ensuring long-term function following total hip arthroplasty (THA). By integrating cutting-edge surgical techniques, advanced imaging, and personalized rehabilitation protocols, the field of hip biomechanics is rapidly evolving, providing more effective solutions for OA patients and improving the overall success of THA procedures.

3.3 Total Hip Arthroplasty

Total Hip Arthroplasty (THA) is one of the most frequently performed orthopedic procedures worldwide, offering pain relief and functional restoration for patients with advanced hip joint disorders. The most common indications for THA include severe osteoarthritis, rheumatoid arthritis, femoral neck fractures, and avascular necrosis of the femoral head (Callahan *et al*., 2021). The procedure aims to enhance patients' quality of life by improving mobility and reducing pain, particularly when non-surgical treatments fail to provide satisfactory results.

Osteoarthritis (OA) is the leading cause of THA and is characterized by progressive cartilage degeneration, leading to joint pain, stiffness, and limited range of motion (Jahn *et al*., 2024) [16]. Several factors contribute to the development of OA, including genetic predisposition, biomechanical stress, and environmental influences. Additionally, obesity plays a critical role in accelerating joint degeneration by increasing mechanical load on the hip and triggering inflammatory responses that exacerbate cartilage damage (Yuan *et al*., 2023) [35].

The association between obesity and hip OA has been confirmed through Mendelian randomization studies, indicating a causal relationship between higher body mass index (BMI) and increased OA risk (Yuan *et al*., 2023) [35]. Effective weight management strategies, including lifestyle modifications and targeted exercise programs, are crucial in mitigating disease progression and delaying the need for surgical intervention.

Beyond obesity, occupational exposure to repetitive mechanical stress also contributes to hip OA. Workers involved in physically demanding jobs, such as construction, agriculture, and metalworking, are at higher risk of developing hip OA due to prolonged exposure to non-neutral postures, heavy lifting, and whole-body vibrations (Jahn *et al*., 2024) [16]. These findings highlight the importance of workplace ergonomic interventions to reduce the burden of OA among high-risk populations.

Before considering THA, conservative treatment options should be explored. Exercise therapy has proven to be an effective intervention, offering pain relief and functional improvement comparable to nonsteroidal anti-inflammatory drugs (NSAIDs) and paracetamol (Weng *et al*., 2023) [32]. Given its excellent safety profile, exercise therapy should be prioritized, particularly in older adults and individuals at risk for adverse drug reactions.

Despite the benefits of exercise therapy, pharmacological treatments remain a cornerstone of OA management. NSAIDs, paracetamol, and opioids are frequently prescribed to control pain; however, their long-term use is associated with significant risks, including gastrointestinal, cardiovascular, and renal complications (Da Costa *et al*., 2021) [8]. A network meta-analysis indicated that etoricoxib and diclofenac are among the most effective NSAIDs for OA pain relief, but their safety profile must be carefully considered, especially in patients with comorbidities (Da Costa *et al*., 2021) [8].

The choice of prosthesis in THA significantly impacts surgical outcomes and implant longevity. Modern prostheses consist of four main components: a femoral stem, a femoral head, an acetabular cup, and a liner. These components can be made of various materials, including metal, polyethylene, and ceramic, each offering distinct advantages in terms of wear resistance and durability (Van Buuren *et al*., 2021) [28].

The primary types of hip prostheses include cemented, uncemented (press-fit), and hybrid designs. Cemented prostheses use bone cement for fixation and are generally preferred in older patients with poor bone quality (Jahn *et al*., 2024) [16]. In contrast, uncemented prostheses rely on biological fixation, allowing bone ingrowth into the porous surface of the implant. These are commonly used in younger, more active patients due to their long-term stability (Van Buuren *et al*., 2021) [28]. Hybrid prostheses combine a cemented femoral stem with an uncemented acetabular component or vice versa, offering a balance between immediate stability and long-term fixation (Teirlinck *et al*., 2023).

Surgical approaches for THA have evolved to improve patient recovery and minimize complications. The posterior approach, while widely used, has a higher risk of post-operative dislocation (Jahn *et al*., 2024) [16]. The anterior approach, a minimally invasive technique, preserves surrounding musculature and results in faster recovery and lower dislocation rates (Teirlinck *et al*., 2023). The lateral approach offers increased stability but may be associated with post-operative limping due to abductor muscle impairment (Hall *et al*., 2022) [14]. Minimally invasive techniques have also gained popularity, as they reduce soft tissue damage and promote quicker rehabilitation (Weng *et al*., 2023) [32].

Despite its success, THA is not without risks. Common complications include periprosthetic infection, implant loosening, dislocation, and deep vein thrombosis (Callahan *et al*., 2021). Preventative measures, such as perioperative antibiotic prophylaxis, anticoagulation therapy, and meticulous surgical technique, are crucial in reducing these risks (Zhang *et al*., 2023) [37].

Falls and fractures are significant concerns for patients with hip OA, both before and after surgery. A systematic review and meta-analysis found that individuals with symptomatic hip OA have an increased risk of recurrent falls, highlighting the importance of balance training and fall prevention strategies (Zhang *et al*., 2023) [37]. Moreover, rehabilitation programs focusing on muscle strengthening and proprioception training are essential for optimizing post-operative outcomes and reducing fall-related injuries.

Post-operative rehabilitation plays a crucial role in ensuring the success of THA. Early mobilization, guided physiotherapy, and patient education contribute to improved functional recovery and a lower incidence of complications such as joint stiffness and muscle atrophy (Weng *et al*., 2023) [32]. Patients are encouraged to engage in weight-bearing activities within days of surgery to facilitate joint adaptation and enhance implant longevity.

The long-term outcomes of THA are generally excellent, with modern implants demonstrating survival rates exceeding 90% at 15 to 20 years (Jahn *et al*., 2024) [16]. Factors influencing implant longevity include patient age, activity level, implant material, and surgical precision. Advances in prosthetic design and fixation techniques continue to improve implant durability, reducing the need for revision surgery (Van Buuren *et al*., 2021) [28].

Future innovations in THA are likely to focus on personalized implants, robotic-assisted surgery, and biologic therapies aimed at joint preservation. Emerging technologies such as 3D printing and regenerative medicine hold promise for enhancing surgical precision and extending implant lifespan (Van Buuren *et al*., 2021) [28]. These advancements are expected to further optimize patient outcomes and expand treatment options for individuals with hip OA.

THA remains the gold standard for treating advanced hip OA and other debilitating conditions. While non-surgical interventions such as exercise therapy and pharmacological management play an essential role in symptom control, THA is often necessary for restoring function and alleviating pain in severe cases. Ongoing research and technological advancements continue to refine surgical techniques and implant designs, ensuring better outcomes for future patients.

3.4 Hip Rehabilitation

Hip rehabilitation plays a crucial role in the recovery process following total hip arthroplasty (THA) or hip fracture surgery. The main objectives of rehabilitation are to restore mobility, improve joint function, and reduce pain while minimizing the risk of complications such as falls, dislocations, and implant failure. Recent studies have explored various rehabilitation strategies, including prehabilitation, postoperative physiotherapy, balance

training, resistance exercises, and the role of emerging technologies in optimizing patient outcomes.

Prehabilitation, which includes exercise therapy and patient education before surgery, has been increasingly recognized for its benefits in improving postoperative recovery. A systematic review found that prehabilitation interventions, particularly exercise therapy, enhance postoperative physical functioning and muscle strength, leading to improved gait speed and reduced recovery time (Widmer *et al*., 2022) [33]. However, preoperative education alone did not significantly impact postoperative outcomes, emphasizing the importance of physical conditioning before surgery.

A prospective randomized controlled trial assessing the impact of preoperative and postoperative progressive resistance training (PRT) demonstrated that patients who engaged in prehabilitation combined with postoperative rehabilitation showed superior improvements in muscle strength, gait, balance, and overall hip function compared to those who only received postoperative rehabilitation (Chen *et al*., 2024). These findings support the integration of prehabilitation programs into standard care for patients undergoing THA.

Postoperative rehabilitation is essential for optimizing joint motion and regaining functional mobility. A study analyzing the recovery process after THA indicated that 95% of patients received postoperative physiotherapy, with more than half continuing for at least 12 weeks (Groot *et al*., 2022) [12]. Patients with comorbidities, such as musculoskeletal disorders, required longer rehabilitation periods but demonstrated functional improvements over time.

Exercise-based rehabilitation strategies have been proven effective in restoring neuromuscular function. Rehabilitation programs incorporating resistance exercises, proprioception training, and gait retraining contribute to enhanced muscle activation and better postoperative outcomes (Sara; Lewis, 2023) [26]. A study comparing rehabilitation based on exercise prescription to conventional postoperative care found that patients following structured exercise regimens had significantly better motor function and lower rates of postoperative complications (Che *et al*., 2023) [7].

One of the key challenges following THA is balance impairment due to alterations in proprioception. Proprioceptive deficits, which can persist for up to five years post-surgery, increase the risk of falls and limit functional independence (Labanca *et al*., 2021) [18]. Balance training interventions specifically designed for THA patients have demonstrated positive effects on postural stability and gait mechanics.

A systematic review analyzing balance training protocols found that targeted exercises focusing on weight shifting, single-leg stance, and neuromuscular coordination significantly improved balance and reduced the risk of falls among THA patients (Labanca *et al*., 2021) [18]. The findings suggest that structured balance training should be an integral part of postoperative rehabilitation to enhance long-term mobility and prevent injury.

The role of rehabilitation settings in determining postoperative outcomes has been widely discussed. A systematic review assessing the impact of hip precautions following posterior-approach THA found that strict precautions, such as limiting hip flexion beyond 90° and avoiding internal rotation, may not be necessary for all patients. Instead, unrestricted mobilization protocols can lead to improved functionality without increasing dislocation rates (Crompton *et al*., 2020) [40].

The effectiveness of inpatient versus outpatient rehabilitation remains a debated topic. While inpatient rehabilitation provides intensive physiotherapy and medical supervision, outpatient programs have been found to be equally effective in most cases, offering greater patient autonomy and reducing healthcare costs (Sara; Lewis, 2023) [26].

The integration of digital tools, such as virtual and augmented reality, into rehabilitation programs has gained attention in recent years. Virtual rehabilitation methods have been explored for their potential to enhance patient engagement and provide interactive, real-time feedback during therapy sessions. A study on virtual surgical skills training for THA suggested that digital platforms could facilitate preoperative education and improve postoperative adherence to rehabilitation exercises (Bhagwat; Ambade, 2022) [39].

Additionally, aquatic therapy and ergometer cycling have been identified as beneficial rehabilitation strategies, particularly for elderly patients. These modalities allow for low-impact movement, reducing joint stress while promoting muscle strengthening and cardiovascular fitness (Papalia *et al*., 2020) [23]【54】. Fast-track rehabilitation protocols, which emphasize early mobilization and patient education, have also been shown to accelerate recovery and enhance long-term outcomes.

Hip rehabilitation is a multifaceted process that requires a comprehensive approach to ensure optimal recovery following THA. Prehabilitation strategies incorporating resistance training and patient education have been shown to enhance postoperative outcomes. Postoperative rehabilitation should focus on individualized exercise therapy, balance training, and early mobilization to improve functional recovery. Emerging technologies, including virtual rehabilitation and aquatic therapy, offer promising avenues for enhancing rehabilitation protocols. As research continues to evolve, the implementation of evidence-based rehabilitation programs will be essential for maximizing patient outcomes and promoting long-term mobility and independence.

4. Conclusion

Hip osteoarthritis (HOA) is a debilitating degenerative joint disease that significantly impacts patients' mobility, functionality, and quality of life. As the prevalence of HOA continues to rise due to an aging population and increasing life expectancy, optimizing both conservative and surgical management strategies becomes imperative. This systematic literature review synthesized the current evidence on biomechanical adaptations, conservative treatments, total hip arthroplasty (THA), and post-surgical rehabilitation, providing insights into the most effective approaches for managing HOA at different stages.

Conservative management remains the first-line approach for HOA, with exercise therapy, weight management, and pharmacological treatments playing critical roles in symptom relief and functional preservation. Studies have shown that structured exercise programs targeting muscle strengthening, neuromuscular control, and proprioception effectively improve joint stability and reduce pain, often with results comparable to nonsteroidal anti-inflammatory

drugs (NSAIDs) but without the associated adverse effects. Pharmacological management, particularly NSAIDs, remains an important component of pain control; however, their long-term use requires careful consideration due to potential gastrointestinal, cardiovascular, and renal complications.

When conservative measures fail to provide adequate relief, total hip arthroplasty (THA) is the gold standard surgical treatment for end-stage HOA. Advances in implant materials, including dual-mobility prostheses and highly cross-linked polyethylene liners, have improved implant longevity and reduced complications such as dislocation and wear. Additionally, robotic-assisted THA has emerged as a promising innovation, enhancing surgical precision and optimizing component placement to improve long-term outcomes. However, despite these advancements, post-surgical recovery remains highly dependent on early mobilization, rehabilitation programs, and biomechanical optimization.

Postoperative rehabilitation is crucial for ensuring successful THA outcomes, as patients often experience balance impairments and proprioceptive deficits that increase the risk of falls. Rehabilitation programs focusing on progressive resistance training, gait retraining, and balance exercises have been shown to improve postoperative functionality and reduce fall risk. Furthermore, recent studies highlight the importance of spinopelvic alignment in THA patients, as abnormal spinopelvic motion can contribute to implant instability and poor functional recovery. Gait analysis and motion capture assessments have provided valuable insights into post-surgical biomechanics, guiding tailored rehabilitation interventions to restore symmetrical movement patterns.

The findings of this review underscore the importance of a multimodal and individualized approach to HOA management. Combining early diagnosis, biomechanical analysis, conservative treatment strategies, and surgical innovations can help optimize patient outcomes. Furthermore, emerging technologies such as artificial intelligence-driven gait analysis, virtual rehabilitation platforms, and 3D-printed customized implants hold significant potential for improving both non-surgical and surgical treatment pathways.

Future research should focus on refining rehabilitation protocols, investigating long-term implant performance, and developing biologic treatments aimed at cartilage regeneration and joint preservation. Additionally, further exploration of the role of artificial intelligence and machine learning in predicting HOA progression and optimizing surgical planning may revolutionize treatment approaches.

In conclusion, managing hip osteoarthritis requires a comprehensive and evidence-based approach, integrating biomechanical understanding, effective conservative management, advanced surgical techniques, and structured rehabilitation programs. By continually advancing treatment strategies and leveraging technological innovations, healthcare providers can significantly improve patient mobility, independence, and overall quality of life.

5. References

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