# Enhancing Hip Joint Health: Prehabilitation, Rehabilitation and Biomechanics

[1]Vinod Kumar Mahor, [2]Aditya Kumar Litoria, [3]Girish Kumar Khare

[1]Mtech Scholar, Department of Mechanical Engineering, Oriental Institute of Science & Technology, Bhopal India,

[2]Assistant Professor, Department of Mechanical Engineering, Oriental Institute of Science & Technology, Bhopal India.

[3]Associate Professor, Mechanical Engineering, Oriental Institute of Science & Technology, Bhopal India.

[1]vinodmahor53@gmail.com, [2]adityalitoriya@oriental.ac.in, [3]girishkhare@oriental.ac.in

* Corresponding Author: Aditya Kumar Litoria

***Abstract:*** *The hip joint is pivotal in human mobility, supporting multi-axial movement and substantial loads during daily activities. Osteoarthritis, particularly coxarthrosis, poses a significant health burden globally, necessitating total hip arthroplasty (THA) as a common treatment. This review explores the efficacy of prehabilitation in optimizing outcomes before hip surgery, highlighting its potential benefits in enhancing patient education, muscle strength, and proprioception. We discuss rehabilitation strategies post-THA and assess various outcome measures such as the Postel Merle D'Aubigne score and HOOS for functional evaluation. Additionally, we delve into biomechanical considerations using finite element analysis (FEA) in the context of cervical spine mechanics and THA implant design, emphasizing the role of computational modeling in enhancing surgical outcomes and implant durability.*

,

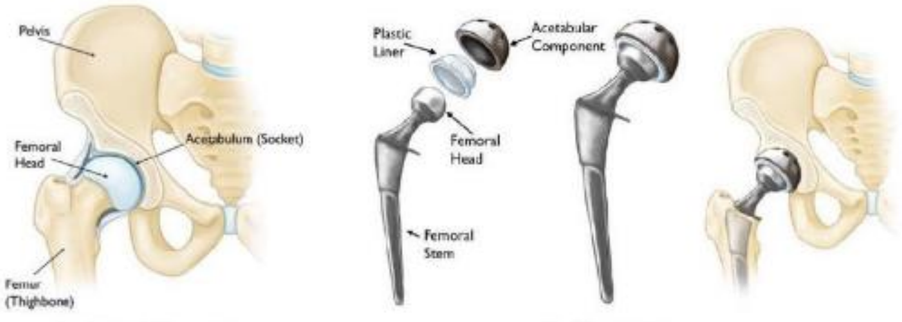
***Keywords:*** *Hip joint, osteoarthritis, total hip arthroplasty, prehabilitation, rehabilitation, patient outcomes, biomechanics, finite element analysis, cervical spine, cervical disc herniation, anterior cervical discectomy and fusion (ACDF), joint instability.*

## I.INTRODUCTION

The axial skeleton and lower extremities are joined at the hip joint. Three major axes of movement are possible in the hip joint, and they are all perpendicular to one another. The femoral head is where the entire axis' center is located. Flexion and extension movements are possible along the transverse axis. Osteoarthritis of the hip joint—coxarthrosis is one of the most common causes of sickness absence among men in Poland [1].Osteoarthritis of the hip joint is recognized as the second most common location of degenerative changes in the joints of the limbs (it is most often diagnosed in the knee joint) and is the most common reason for total joint replacement both in Poland and worldwide [2]. Even though more than 130 years have passed since the first arthroplasty [3], the effects of this form of treatment are not satisfactory. Rehabilitation is one of the basic methods of treating early coxarthrosis [4] physical therapy is also widely used to improve the functional status after hip arthroplasty [5].

The use of prehabilitation rehabilitation preceding treatment—has features that make this form of influence potentially attractive: ensuring patient education [6] increasing muscle strength and range of motion [7] and improving proprioception [8].The prehabilitation efficacy evaluation has major importance considering coxartrhosis prevalence. Recently, prehabilitation is becoming increasingly popular as a method that potentially supports broadly understood oncological treatment [9]. However, prehabilitation only makes sense when it significantly improves the patient's functional status and has a positive impact on the result of the final treatment. Moreover, prehabilitation generates costs both for the health care system and the patient [10]. Medical and cost effectiveness are therefore of key importance if prehabilitation is to become a separate service included in health insurance [11]. Currently, rehabilitation before surgical treatment in Poland is not a routine procedure, although some orthopaedists, rehabilitation specialists, and physiotherapists consider it justified to recommend it to patients.

The assessment of the effectiveness of prehabilitation in patients using self-therapy, postulated already before the pandemic, became more important in 2020 [12]. A rather conservative form of communication—a paper brochure with an outline of exercises (see Supplementary Material)—has been replaced by therapy conducted via electronic media, including smartphones commonly available in developed countries. However, the paper form has the advantage of accessibility and ease of use; after all, having a smartphone and the ability to use the application fluently is not obvious, especially among the elderly. It is postulated to standardize the methodology for creating medical applications used by patients [13]. Certainly, applications enable their creators to automatically remind patients about the need to perform a given activity, a functionality that paper instructions do not have.




(a). Normal hip anatomy (b). Hip prostheses

**Figure 1: Total hip joint replacement [14].**

The Postel Merle D'Aubigne score (PMA) requires the assessment of the range of abduction and flexion of the hip joints, i.e., the critical range of motion for efficient movement up stairs and restoring an energy-efficient gait stereotype without excessive, harmful movement of the center of gravity in the frontal plane [15]. It is a reliable, repetitive tool in clinical practice.The HOOS Hip Disability and Osteoarthritis Outcome Score (HOOS) score allows for a comprehensive assessment of the patient's condition, from pain to sports activities. The Polish version of HOOS has been positively evaluated for use in evaluating the results of hip arthroplasty [16]. The Laitinen scale is applied to assess the severity of pain in the context of intensity, frequency, need to use analgesics and impact on physical activity. A visual analogue scale (VAS) is used to assess the subjective intensity of pain. The variant of 100 mm was chosen, where 0 means no pain at all, and 100 mm—the strongest pain experienced or imaginable to the patient.

The tools are based on the patient's self-evaluation and functional status. The study group consisted mostly of elderly patients, for whom independent movement is one of the key conditions for maintaining independence in basic areas of functioning and playing social roles. Scales based on self-evaluation also allow for the assessment of the patient's risk of kinesiophobia (fear of physical activity), which in the geriatric population leads to a secondary disability and reduced quality of life [17].

## II. Finite Element Analysis (FEA) Basics :

Structural Finite-element analysis (FEA) has been widely used to perform stress and deformation analysis of complex structures, for which an analytical solution might be infeasible. In the biomedical domain, FEA has been applied to study the mechanics of human tissues and organs, tissue-medical device interactions, diagnostic and treatment strategies at a patient-specific level [18].which may need to solve forward and inverse mechanics problems.

The finite element is important for predicting spine mechanics in situations where in vivo and in vitro models prove insufficient. In the determination of internal loads, stresses, and strains in spinal tissue, numerical models have been used [19]. Simulation results from numerical spine models can be employed to gain insight into the inner workings of the cervical spine. Moreover, virtual models can display information previously unobtainable via physical models, such as stress distribution in the intervertebral disc. Gradually, more accurate cervical spine modeling has increased the accuracy of the guidance of spine surgery and the new design of cages. The only notable drawback is that greater computing power is needed. This is controlled by converting models into somewhat less computationally intensive versions. The findings they offer will still be quite accurate if they pass convergence tests and are validated against data that is known to be accurate. Cervical spine modeling has been the subject of multiple reviews of the literature, but there have not been any that contrast cervical spine models with material models. The limitations of the material models and cervical models were not compared and discussed. We will therefore focus on reviewing the material property models and cervical models for potential interest to the surgeons and biomechanical engineers [20].

The cervical spine is one of the smallest and most intricate joints in the human body [21]. Cervical disc herniations are a problem caused by repetitive cervical spine loading [22]. The severity of loading needed also decreases as the age of involved patients increases [23]. This is due to a lack of nutrient supply to the intervertebral disc; resulting in natural wear and decreased performance with age, a phenomenon known as cervical spondylosis [24]. If the disc degenerates, the cervical spine's stability will be compromised, and the intravertebral disc height will change [25]. The decrease in foraminal spacing can result in cervical radiculopathy and the compression of nerves causes great discomfort and reduced quality of life for the affected individual [26].

The first attempts made at addressing this were through the fusion of the adjacent vertebra in a technique known as anterior cervical discectomy and fusion (ACDF) established in the 1950s [27]. The intervertebral disc and osteophytes are removed during this treatment, and the area of the spine is decompressed. Then, to maintain foraminal spacing and to encourage a stable site for osseointegration, an adequately sized cage and bone graft are implanted [28]. Shortly after, plate instrumentation was introduced to help regulate the stresses of the cervical spine. A variety of surgical techniques and hardware have been developed in addition to the standard anterior plating, to improve the biomechanical postoperative state. Some adjunct structures that have been applied include lateral mass and pedicle screw systems, facet replacement devices, and cervical disc replacements for multilevel procedures. For the treatment of cervical disc problems, the golden standard has not yet been discovered. To better meet the needs of the system, more information on the generalities and mechanics of the cervical spine is required. Many techniques have been used to learn more about the cervical spine [29].

**III. Review of Hip Joint Implant Designs :**

The hip joint is among the most essential load-bearing joint surfaces, enabling both strength and multiaxial movement while transferring multiple times body weight (BW) during daily activities like walking, standing, bending and sprinting [30]. The human body is composed of roughly 270 bones at the moment of birth, and this number will be lowered to 206 bones by the time of maturity when some of the bones are merged together [31]. When it comes to the significance of the hip, it may be characterised by the fact that it allows human mobility and sustains the full body weight without causing distress. The inability of the artificial joint to function properly is among the most prevalent reasons for complete joint revision. Any severe relative movement involving joint partners is classified as joint instability, which is often characterised by harm to implant components or adjacent soft tissue[32]. However, because of the joint's load-carrying capabilities in six degrees of freedom (flexion, extension, abduction, adduction, internal rotation, and external rotation), it is susceptible to degeneration and local loading, resulting in discomfort. Artificial joints are frequently used to replace degraded hip joints, also known as total hip arthroplasty to avoid such outcomes. Total hip joint replacement implant consists of stem, femoral head, acetabular cup and backing cup.the components associated in THR. Total hip replacements are often patient-specific and reliant on the requirements of the individual patient in terms of shape and sizes. The range of motion and physical function are critical considerations, particularly in younger patients who have high expectations for their life quality after THA surgery [33]. When a wide-ranging series of patients from various experimental studies were analysed, the findings revealed that younger individuals are more prevalent among older patients undergoing THR to restore function to a clinically relevant level. Furthermore, a substantial reduction in the average age of patients who need hip implants has prompted studies to prolong the durability of THRs in attempt to improve quality of life for active younger patients [34].

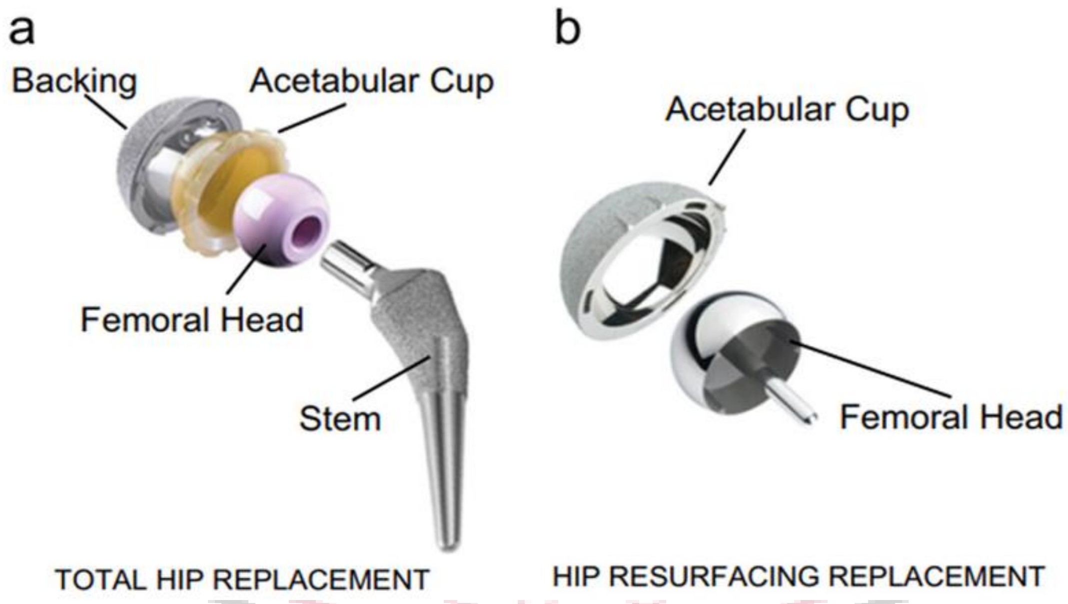



**Figure 3. Components used in hip implants[35].**

Implants were traditionally held in place by pressure, friction or screws. Due to the insufficiency of these methods, new and improved methods have been developed. Now, there are two common types of femoral stem fixation: cemented femoral fixation and cementless femoral fixation [36]. Designing an Optimized Novel Femoral Stem. A femoral head is attached by press fitting, then an acetabular cup and backing cup are attached [37]. Although a press-fit fixation approach eliminates the need for screws or cups with screw holes, it can result in acetabular fractures or incompetence.

**Comparison of Different Types of Hip Joint Implants.**

| Type of Hip Implant | Description | Advantages | Disadvantages |
|---|---|---|---|
| Cemented | Uses bone cement (polymethylmethacrylate) for fixation, providing immediate stability. | Immediate fixation, initial stability | Risk of cement loosening, long-term wear |

| | | | |
|---|---|---|---|
| Uncemented | Relies on bone growth into the implant surface (osseointegration) for long-term stability. | Bone preservation, potential longevity. | Longer initial recovery, initial instability |
| Hybrid | Combines cemented and uncemented components (e.g., uncemented stem with cemented cup). | Flexibility in component selection | Potential for mismatched wear patterns |
| Ceramic-on-Ceramic | Uses ceramic materials for both femoral head and acetabular cup, known for low wear rates. | Low wear rates. | Risk of ceramic fracture |
| Metal-on-Metal | Utilizes metal components for both femoral head and acetabular cup, initially durable. | Low wear rates. | Concerns over metal ion release, tissue reactions |

## 1V. CONCLUSION

In conclusion, while THA remains a cornerstone in managing hip osteoarthritis, the integration of prehabilitation shows promise in improving patient preparation and postoperative recovery. Biomechanical insights from FEA offer valuable perspectives on implant design and surgical techniques, aiming to optimize functional outcomes and longevity of THA. Future research should focus on standardizing prehabilitation protocols, validating computational models, and advancing surgical techniques to further enhance patient care and treatment efficacy.Finite element analysis (FEA) has significantly contributed to understanding the biomechanics of the hip joint and the cervical spine. In the context of THA, FEA aids in the design and optimization of implants, ensuring they can withstand the complex loads and movements experienced by the hip joint. By simulating different scenarios and analyzing stress distributions, FEA helps improve implant durability and performance, ultimately enhancing patient outcomes.Overall, integrating prehabilitation, effective postoperative rehabilitation, and advanced biomechanical modeling provides a comprehensive approach to managing hip osteoarthritis and improving THA outcomes. Continued research and clinical validation are necessary to refine these strategies, ensuring they deliver maximal benefits to patients and healthcare systems alike.

## REFERENCES:

1. Karczewicz, E., Sikora, A., &Zalewska, H. (2019). Absencjachorobowa w 2018 roku.
2. Cross, M., Smith, E., Hoy, D., Nolte, S., Ackerman, I., Fransen, M., ...& March, L. (2014). The global burden of hip and knee osteoarthritis: estimates from the global burden of disease 2010 study. Annals of the rheumatic diseases, 73(7), 1323-1330.
3. Ciećkiewicz, A., &Cwanek, J. (2014). Historiaendoprotezstawubiodrowego do roku 1962. Problemynaukstosowanych, 2.
4. Hochberg, K. S. N. T. (2020). Oatis C Guyatt G Block J, et al.. 2019 American College of Rheumatology/Arthritis Foundation Guideline for the management of osteoarthritis of the hand, hip, and knee. Arthritis Care Res (Hoboken), 72, 149-162.
5. van Doormaal, M. C., Meerhoff, G. A., VlietVlieland, T. P., & Peter, W. F. (2020). A clinical practice guideline for physical therapy in patients with hip or knee osteoarthritis. Musculoskeletal care, 18(4), 575-595.
6. Widmer, P., Oesch, P., & Bachmann, S. (2022). Effect of prehabilitation in form of exercise and/or education in patients undergoing total hip arthroplasty on postoperative outcomes—a systematic review. Medicina, 58(6), 742.
7. Punnoose, A., Claydon-Mueller, L. S., Weiss, O., Zhang, J., Rushton, A., &Khanduja, V. (2023). Prehabilitation for patients undergoing orthopedic surgery: a systematic review and meta-analysis. JAMA Network Open, 6(4), e238050-e238050.
8. Pohl, T., Brauner, T., Wearing, S., Stamer, K., &Horstmann, T. (2015). Effects of sensorimotor training volume on recovery of sensorimotor function in patients following lower limb arthroplasty. BMC musculoskeletal disorders, 16, 1-9.
9. Wade-Mcbane, K., King, A., Urch, C., Jeyasingh-Jacob, J., Milne, A., &Boutillier, C. L. (2023). Prehabilitation in the lung cancer pathway: a scoping review. BMC cancer, 23(1), 747.
10. Rombey, T., Eckhardt, H., Kiselev, J., Silzle, J., Mathes, T., & Quentin, W. (2023). Cost-effectiveness of prehabilitation prior to elective surgery: a systematic review of economic evaluations. BMC medicine, 21(1), 265.
11. Konnyu, K.J.; Thoma, L.M.; Bhuma, M.R.; Cao, W.; Adam, G.P.; Mehta, S.; Aaron, R.K.; Racine-Avila, J.; Panagiotou, O.A.; Pinto, D.; et al. Prehabilitation and Rehabilitation for Major Joint Replacement; Comparative Effectiveness Review, No. 248; Agency for Healthcare Research and Quality: Rockville, MD, USA, 2021
12. Garfan, S., Alamoodi, A. H., Zaidan, B. B., Al-Zobbi, M., Hamid, R. A., Alwan, J. K., ...&Momani, F. (2021). Telehealth utilization during the Covid-19 pandemic: A systematic review. Computers in biology and medicine, 138, 104878.

13. Bokolo, A. J. (2021). Exploring the adoption of telemedicine and virtual software for care of outpatients during and after COVID-19 pandemic. Irish Journal of Medical Science (1971-), 190(1), 1-10.
14. Van Drongelen, S., Braun, S., Stief, F., &Meurer, A. (2021). Comparison of gait symmetry and joint moments in unilateral and bilateral hip osteoarthritis patients and healthy controls. Frontiers in Bioengineering and Biotechnology, 9, 756460.
15. Gojło, M. K., &Paradowski, P. T. (2020). Polish adaptation and validation of the hip disability and osteoarthritis outcome score (HOOS) in osteoarthritis patients undergoing total hip replacement. Health and Quality of Life Outcomes, 18, 1-13.
16. Hidaka, R., Tanaka, T., Hashikura, K., Oka, H., Matsudaira, K., Moro, T., ...& Tanaka, S. (2023). Association of high kinesiophobia and pain catastrophizing with quality of life in severe hip osteoarthritis: a cross-sectional study. BMC Musculoskeletal Disorders, 24(1), 388.\
17. Farras, Adzkia. (2020). A Review Model of Existing Hip Prosthesis Austin-Moore Prosthesis, Mckee-Farrar Prosthesis, And Mckee's Ring Prosthesis Employing Screw Fixation.
18. Liang, L., Liu, M., Elefteriades, J., & Sun, W. (2023). PyTorch-FEA: Autograd-enabled finite element analysis methods with applications for biomechanical analysis of human aorta. Computer Methods and Programs in Biomedicine, 238, 107616.
19. Panjabi, M. M., Cholewicki, J., Nibu, K., Grauer, J., Babat, L. B., & Dvorak, J. (1998). Critical load of the human cervical spine: an in vitro experimental study. Clinical biomechanics, 13(1), 11-17.
20. Yoganandan, N., Kumaresan, S., Voo, L., &Pintar, F. A. (1996). Finite element applications in human cervical spine modeling. Spine, 21(15), 1824-1834.
21. Berthoz, A., Graf, W., & Vidal, P. P. (Eds.). (1992). The head-neck sensory motor system. Oxford University Press.
22. Belavy, D. L., Adams, M., Brisby, H., Cagnie, B., Danneels, L., Fairbank, J., ...&Wilke, H. J. (2016). Disc herniations in astronauts: What causes them, and what does it tell us about herniation on earth?. European Spine Journal, 25, 144-154.
23. Coakwell, M. R., Bloswick, D. S., & Moser, R. (2004). High-risk head and neck movements at high G and interventions to reduce associated neck injury. Aviation, space, and environmental medicine, 75(1), 68-80.
24. Nouri, A., Tetreault, L., Singh, A., Karadimas, S. K., &Fehlings, M. G. (2015). Degenerative cervical myelopathy: epidemiology, genetics, and pathogenesis. Spine, 40(12), E675-E693.
25. Kim, S. W., Limson, M. A., Kim, S. B., Arbatin, J. J. F., Chang, K. Y., Park, M. S., ... &Ju, Y. S. (2009). Comparison of radiographic changes after ACDF versus Bryan disc arthroplasty in single and bi-level cases. European spine journal, 18, 218-231.
26. Patwardhan, A. G., Khayatzadeh, S., Havey, R. M., Voronov, L. I., Smith, Z. A., Kalmanson, O., ...& Sears, W. (2018). Cervical sagittal balance: a biomechanical perspective can help clinical practice. European Spine Journal, 27, 25-38.
27. Grauvogel, J., Scheiwe, C., &Kaminsky, J. (2014). Use of Piezosurgery for removal of retrovertebral body osteophytes in anterior cervical discectomy. The Spine Journal, 14(4), 628-636.
28. Oppenheimer, J. H., DeCastro, I., & McDonnell, D. E. (2009). Minimally invasive spine technology and minimally invasive spine surgery: a historical review. Neurosurgical focus, 27(3), E9.
29. Jacobs, W., Willems, P. C., Kruyt, M., Van Limbeek, J., Anderson, P. G., Pavlov, P., ...&Oner, C. (2011). Systematic review of anterior interbody fusion techniques for single-and double-level cervical degenerative disc disease. Spine, 36(14), E950-E960.
30. Kim, Seokpum&Nasirov, Aslan&Pokkalla, Deepak Kumar & Kishore, Vidya& Smith, Tyler & Duty, Chad &Kunc, Vlastimil. (2023). Compression and energy absorption characteristics of short fiber-reinforced 2D composite lattices made by material extrusion. Engineering Reports. 5. 10.1002/eng2.12701.
31. Hua, X., Li, J., De Pieri, E., & Ferguson, S. J. (2022). Multiscale biomechanics of the biphasic articular cartilage in the natural hip joint during routine activities. Computer Methods and Programs in Biomedicine, 215, 106606.
32. Clarke, B. (2008). Normal bone anatomy and physiology. Clinical journal of the American Society of Nephrology, 3(Supplement_3), S131-S139.
33. Hampton, S. J., Andriacchi, T. P., &Galante, J. O. (1980). Three dimensional stress analysis of the femoral stem of a total hip prosthesis. Journal of biomechanics, 13(5), 443-448.
34. Madeti, B. K., Rao, C. S., & Rao, B. S. S. (2014). Biomechanics of hip joint: a review. International Journal of Biomedical Engineering and Technology, 15(4), 341-359.
35. Morlock, M. M., Bishop, N., & Huber, G. (2011). Biomechanics of hip arthroplasty. Tribology in total hip arthroplasty, 11-24.
36. Bhawe, A. K., Shah, K. M., Somani, S., Shenoy B, S., Bhat N, S., Zuber, M., & K N, C. (2022).
37. Babaniamansour, P., Ebrahimian-Hosseinabadi, M., &Zargar-Kharazi, A. (2017). Designing an optimized novel femoral stem. Journal of Medical Signals & Sensors, 7(3), 170-177.