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Research on the Clinical Advances in Hip Resurfacing Arthroplasty

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Abstract: Hip Resurfacing Arthroplasty (HRA), as a significant advancement in modern arthroplasty, has demonstrated considerable value in treating hip diseases in young and highly active patients due to its unique bone-conserving characteristics. Compared to traditional Total Hip Arthroplasty (THA), HRA offers distinct advantages in preserving femoral bone stock, maintaining physiological biomechanical structure, and facilitating the recovery of high-level physical function postoperatively. However, metal ion release and associated complications caused by metal-on-metal (MoM) bearing surfaces remain major constraints on its clinical application. This article systematically reviews the technical features, evolving indications, clinical outcomes, complication management strategies, and future directions of HRA. It focuses on its clinical value in specific patient populations and emphasizes the critical role of strict adherence to surgical indications, meticulous surgical technique, and systematic postoperative follow-up in ensuring long-term efficacy. By comprehensively analyzing the existing literature evidence, it aims to provide theoretical basis and technical reference for clinical practice.

Keywords: Hip Resurfacing Arthroplasty; Total Hip Arthroplasty; Metal Ions; Prosthesis Design; Revision Surgery.

1. Introduction

With the change of population structure and lifestyle, the incidence of hip joint disease is becoming younger and younger, which puts forward higher requirements for joint replacement. Since its resurgence in the 1990s, hip resurfacing arthroplasty (HRA) has emerged as an innovative joint reconstruction technique, demonstrating unique advantages in treating young, active patients. Its design philosophy centers on maximizing preservation of the patient's own bone tissue, particularly femoral bone stock, thereby restoring joint function closer to physiological conditions. Compared to traditional total hip arthroplasty (THA), HRA not only preserves more bone volume but, more importantly, maintains the hip joint's normal biomechanical properties, enabling patients to regain a higher level of mobility postoperatively.

However, the development of HRA has not been without challenges. Early limitations in prosthesis design and material selection, particularly the use of metal-on-metal (MoM) friction pairs, led to metal ion-related complications. These included periprosthetic osteolysis, soft tissue reactions, and systemic effects. These issues spurred clinicians and researchers to conduct more in-depth studies and improvements on HRA. In recent years, advancements in surgical techniques, optimized patient selection criteria, and improved prosthetic materials have significantly enhanced the clinical outcomes of HRA. This paper aims to provide evidence-based guidance for clinical practice by systematically reviewing recent research advances and comprehensively analyzing the current status and role of HRA in hip reconstruction surgery.

2. The Evolution of Technical Features and Indications for HRA

2.1. The Technical Principles and Design Characteristics

The core technology of HRA lies in its unique conservative design. During the procedure, the surgeon only trims and replaces the damaged articular surface, preserving the patient's native femoral head-neck structure and the majority of the bone stock. This design achieves joint surface reconstruction through precise reshaping of the femoral head and the implantation of a matching metal cap. Unlike THA, which involves complete resection of the femoral head and neck, HRA maximizes the preservation of the patient's anatomy, resulting in postoperative hip biomechanics that more closely resemble the physiological state.

From a biomechanical perspective, HRA offers several advantages. Firstly, preserving the femoral neck structure maintains the normal lever arm and moment of the hip joint, which is beneficial for the maintenance of proprioception and the recovery of gait. Secondly, due to the preservation of femoral bone stock, stress distribution in the proximal femur postoperatively is more rational, reducing the stress shielding effect and contributing to the long-term survival of the bone tissue. Furthermore, the larger femoral head design provides improved joint stability, significantly lowering the risk of postoperative dislocation.

2.2. The Evolution and Optimization of Indications

The selection of indications for HRA has evolved from broad to strict and then to precise. Initially, HRA was primarily applied to young patients (typically <55 years old) with high activity levels who had femoral head necrosis but good bone quality. With accumulated clinical experience, it was observed that surgical outcomes were particularly favorable in specific subgroups, such as male patients, cases with moderate femoral head necrosis (typically <50% involvement), and those with intact acetabular bone.

In recent years, as understanding of HRA has deepened, its indications have been further refined. Currently recognized ideal indications include: 1) Male patients aged <65 years; 2) Femoral head necrosis at Ficat stages II-III; 3) Hip osteoarthritis at Kellgren-Lawrence grade ≤3; 4) Femoral head necrosis area <30%; 5) Patients with high physical activity demands. Relative contraindications include: severe osteoporosis, renal insufficiency, metal allergies, and women of childbearing age.

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3. The Efficacy Comparison Between HRA and THA and Selection Strategies

3.1. The Functional Recovery and Patient Satisfaction

Multiple high-quality studies have systematically compared the efficacy of HRA and THA. A meta-analysis by Fan Zhirong et al.[1], which included 15 studies involving 2,534 patients, showed that the Birmingham Hip Resurfacing (BHR) group had significantly superior outcomes compared to the THA group in both postoperative Harris Hip Score (92.3±3.2 vs. 88.7±4.1) and UCLA Activity Score (7.5±1.2 vs. 6.2±1.4). In patient satisfaction surveys, the HRA group achieved a satisfaction rate of 94.2%, significantly higher than the 86.5% in the THA group. These data indicate that HRA holds distinct advantages in terms of functional recovery and subjective patient perception.

From the perspective of athletic functional recovery, HRA patients postoperatively outperform THA patients in areas such as maximum walking speed, stair-climbing ability, and high-intensity athletic performance. A 5-year follow-up study revealed that 78% of patients in the HRA group were able to return to their pre-injury activity levels, compared to only 52% in the THA group. This difference is particularly pronounced in younger and more active patient populations.

3.2. The Efficacy Differences in Specific Populations

HRA demonstrates differential efficacy characteristics across various age groups. A meta-analysis by Niu Wenjie et al. [2-3] focusing on middle-aged patients (45-60 years) indicated that the advantage in postoperative functional scores for the HRA group was more prominent in this age bracket. This may be related to better bone quality and stronger recovery capabilities in middle-aged patients. Furthermore, HRA shows unique value in treating specific disease types. Research by Zhang Xinxiong demonstrated that in patients with post-traumatic arthritis, HRA was superior to THA in both operative time (125±15 min vs. 145±20 min) and intraoperative blood loss (450±50 ml vs. 550±80 ml).

However, it must be objectively acknowledged that the advantages of HRA exhibit significant "population specificity." In elderly patients, those with osteoporosis, or individuals with lower activity demands, the benefits of HRA are less pronounced. In some cases, its applicability may even be compromised due to concerns about metal ion exposure. Therefore, clinical selection requires precise assessment and individualized decision-making.

4. The Challenges and Concerns Faced By HRA

4.1. Metal Ion-Related Issues

Metal ions generated from the Metal-on-Metal (MoM) bearing surface represent a major challenge for HRA. The research by Liu Xingsheng et al. elaborates on the mechanisms of metal ion production and influencing factors. Microscopic wear at the prosthesis interface can generate approximately 2-5×10^12 wear particles annually, leading to significantly elevated blood cobalt and chromium ion levels. A long-term follow-up study by Wan Yanlin et al. indicated that during the first postoperative year, blood cobalt ion concentrations could reach 1.8±0.6 μg/L, and chromium ion concentrations could reach 2.1±0.8 μg/L. Although these levels tend to stabilize after 2–3 years, approximately 15% of patients maintain persistently elevated concentrations.

The effects of metal ions exhibit dose- and time-dependent characteristics. Short-term impacts primarily manifest as local tissue reactions, including periprosthetic bone resorption and soft tissue mass formation. Long-term effects may involve multiple systemic organs, particularly with potential implications for the nervous, endocrine, and immune systems. Therefore, establishing a comprehensive monitoring system is crucial. Regular postoperative blood metal ion concentration testing, combined with imaging studies for integrated assessment, is recommended.

4.2. Surgical Technical Requirements and Learning Curve

HRA places higher demands on surgical technique and exhibits a significant learning curve effect. Studies indicate that approximately 50 procedures are required for a surgeon to achieve a stable level of technical proficiency. Key factors for surgical success include: precise preparation of the femoral head, appropriate prosthesis positioning (cup abduction angle of 40°±10° and anteversion of 15°±5°), and optimal handling of the bone-prosthesis interface.

The application of intraoperative navigation and robot-assisted technology has significantly improved surgical accuracy. Recent research shows that using navigation systems can control prosthesis placement errors within 2°, which is markedly superior to conventional surgical methods. Furthermore, the development of individualized surgical plans is increasingly important, encompassing preoperative planning based on CT three-dimensional reconstruction and the use of patient-specific instruments.

5. The Revision Strategies Following HRA Failure and Advances in Prosthesis Development

5.1. The Revision Surgery Strategies

The management of failed HRA requires comprehensive consideration of the failure etiology, the extent of bone loss, and the patient's specific condition. Research by Zhang Liqiang et al. confirmed that the Direct Anterior Approach (DAA) offers distinct advantages in HRA revision surgery. This approach utilizes an intermuscular plane, resulting in minimal soft tissue trauma and facilitating rapid postoperative recovery, making it particularly suitable for cases of femoral component failure. Studies demonstrated that revision surgery utilizing the DAA approach significantly shortened both the time to ambulation (1.5±0.5 days vs. 3.2±0.8 days) and the hospital stay (5.2±1.2 days vs. 8.5±2.1 days) compared to other approaches.

Prosthesis selection during revision must be based on the assessment of bone defects. The Paprosky classification is a commonly used assessment tool. For Type I-II bone defects, a standard THA prosthesis may be sufficient; however, for Type III and more severe defects, the use of modular prostheses or bone grafting becomes necessary. It is noteworthy that because HRA preserves more femoral bone stock initially, the complexity of its revision is generally lower compared to revising a conventional THA.

5.2. The innovations in Prosthesis Materials and Design

Significant progress has been made in the development of new prosthetic materials to overcome the limitations of MoM bearings. Research by Yuan Yuzhen, utilizing finite element analysis and optimization algorithms, has proposed improved prosthesis design parameters, including: 1) optimized wall thickness distribution of the femoral cap; 2) enhanced microstructure of the fixation interface; and 3) adjusted material elastic modulus to reduce stress shielding. These improvements have increased the projected lifespan of the prosthesis by over 30%.

In terms of material innovation, the bearing couple of ceramic-on-highly-cross-linked polyethylene shows promising potential. In vitro tests have demonstrated that the wear rate of this combination is merely one-tenth that of traditional MoM interfaces. Furthermore, the application of surface modification technologies, such as titanium nitride coating and porous tantalum interfaces, has shown effects in improving biocompatibility and promoting bone ingrowth. These innovations offer new possibilities for the long-term success of HRA.

6. Summary and Outlook

6.1. Current Consensus and Recommendations

Based on current evidence, HRA holds definite application value in specific patient populations. Its advantages are primarily reflected in: excellent joint functional recovery, high patient satisfaction, good restoration of activity levels, and favorable conditions for potential revision surgery. However, the realization of these advantages largely depends on strict patient selection, precise surgical technique, and systematic postoperative management.

The recommended clinical pathway includes: 1) Comprehensive preoperative evaluation, encompassing assessments of bone quality, anatomical structure, and patient expectations; 2) Individualized surgical planning, incorporating navigation and robotic technology to enhance surgical precision; 3) Systematic postoperative follow-up, including functional assessment and metal ion monitoring; 4) Multidisciplinary collaboration, particularly for the integrated management of patients who develop complications.

6.2. Future Development Directions

The future development of HRA will focus on two core directions. At the technological level, the emphasis lies on innovations in materials science and engineering. This includes: 1) Developing novel wear-resistant materials such as zirconia composite ceramics and ultra-high molecular weight polyethylene; 2) Applying additive manufacturing technologies to achieve personalized customization of prostheses; 3) Exploring bioactive coatings to promote osseointegration.

Clinically, advancing precision medicine principles is essential. This involves: 1) Establishing big data-driven prognostic prediction models; 2) Developing personalized surgical planning systems; 3) Enhancing long-term follow-up databases. Additionally, strengthening patient education and expectation management remains crucial for ensuring treatment outcomes.

With these technological and conceptual advancements, HRA holds promise to overcome current challenges while preserving its unique advantages, offering safer and more effective treatment options for a broader patient population. Future research should prioritize accumulating long-term follow-up data and conducting clinical validation of new technologies to drive the continuous development and optimization of HRA techniques.

References

[1] Fan Zhirong, Huang Yongquan, Peng Jiajie, et al. Efficacy and Metal Ion Levels of Birmingham Hip Surface Replacement Compared with Total Hip Arthroplasty: A Systematic Review and Meta-Analysis [J]. Chinese Journal of Tissue Engineering, 2020, 24 (03): 428-437.

[2] Niu Wenjie, Zhou Xin, Yang Yanfei, et al. Meta-analysis of the Efficacy Differences Between Hip Surface Arthroplasty and Total Hip Arthroplasty in Middle-Aged Patients [J]. Chinese Journal of Geriatric Orthopedics and Rehabilitation (Electronic Edition), 2021, 7 (05): 304-313.

[3] Zhang Xinxiong. Clinical Comparison of Total Hip Arthroplasty and Total Hip Surface Replacement in Patients with Secondary Traumatic Arthritis Following Acetabular Fracture [J]. Journal of Practical Hospital Clinical Medicine, 2019, 16 (03): 171-173.

[4] Liu Xingsheng, Liu Fan. Key Considerations in Hip Surface Replacement Surgery [J]. Jiangsu Medicine, 2019, 45 (05): 510-515.

[5] Wan Yanlin, You Jia, Jiang Wenxue, et al. Follow-up Study on Metal Ion Levels After Hip Surface Arthroplasty [J]. Chinese Journal of Joint Surgery (Electronic Edition), 2021, 15 (06): 660-665.

[6] Zhang Liqiang, Liao Tao, Huang Wei, et al. Outcomes of Direct Anterior Total Hip Arthroplasty in Patients with Failed Hip Surface Arthroplasty [J]. Journal of Practical Orthopaedics, 2019, 25 (02): 163-166.

[7] Yuan Yuzhen. Numerical Analysis and Structural Optimization of Hip Surface Replacement Prostheses [D]. Tianjin University of Technology, 2025.

[8] Ma Tao, Zhang Yumin, Hao Linjie, et al. Advances in Total Hip Arthroplasty Research [J]. Journal of Shaanxi Medicine, 2019, 48 (05): 675-678.

[9] Chen Ning, Li Zhun. Application Value of Total Hip Arthroplasty in the Treatment of Traumatic Osteoarthritis of

the Hip [J]. World Journal of Integrated Medicine, 2020, 6 (05): 32-34.

[10] Peter,Grigoris, Paul,Roberts, et al. The evolution of hip resurfacing arthroplasty. The Orthopedic clinics of North America, 2005,36(2): 125-134.

[11] Amanatullah D F, Cheung Y, Di Cesare P E. Hip resurfacing arthroplasty: a review of the evidence for surgical technique, outcome, and complications[J]. Orthopedic Clinics, 2010, 41(2): 263-272.

[12] McMinn D J W, Daniel J, Ziaee H, et al. Indications and results of hip resurfacing[J]. International orthopaedics, 2011, 35(2): 231-237.

[13] Grigoris, Peter, Roberts, Paul. The evolution of hip resurfacing arthroplasty. The Orthopedic clinics of North America [J] , 2005 (36): 125-134.