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Enhancing the Longevity of Metal-on-Metal Hip Joint Resurfacing

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Abstract: *Hip replacement is a common orthopaedic procedure that is performed with the intention of alleviating pain and restoring function in patients who are suffering from hip joint disorders, including osteoarthritis, rheumatoid arthritis and avascular necrosis. The procedure entails the replacement of the damaged hip joint with a prosthesis, which is typically composed of metal, ceramic, or plastic components. In recent years, metal-on-metal (MoM) hip resurfacing has emerged as a promising alternative to traditional total hip replacement, particularly among younger, more active patients. In contrast to total hip replacement, hip resurfacing preserves a greater proportion of the patient's bone, which may result in enhanced stability and a reduced risk of dislocation. Nevertheless, MoM hip resurfacing has been linked to specific complications, including the release of metal ions and subsequent local and systemic effects. This has resulted in an ongoing debate regarding the long-term safety and efficacy of the procedure. Notwithstanding these concerns, MoM hip resurfacing remains a preferred option for certain patients due to its bone-preserving benefits and potential for superior postoperative activity levels. This abstract examines the factors that influence the preference for MoM hip resurfacing, including patient demographics, activity levels, and risk factors, while also addressing the challenges posed by metal ion-related complications.*

Keywords:*Hip replacement, Metal-on-metal hip resurfacing, Osteoarthritis, Prosthesis, Bone preservation, Metal ion release, Friction, Lubrication*

1. Introduction

In 1930, the first total hip joint replacement surgery was performed. Over the subsequent 90 years, this rudimentary design underwent significant expansion, alteration and improvement, resulting in a product that would withstand years of use. The techniques employed in hip joint replacement surgery have evolved considerably over time, incorporating advances in polymers, metals, surgical techniques, alterations and patient eligibility criteria. A variety of polymers, metals, and combinations thereof were subjected to rigorous testing, evaluation, and analysis to assess their suitability for use in hip joint replacements. The focus was on determining their longevity and durability. Advances in scientific knowledge facilitated the development of a superior, more durable and safer implant. The recent resurgence of the metal-on-metal hip joint prosthesis has prompted further scrutiny into the potential for improvement of the prosthesis. This demand was primarily driven by the growing number of younger, active patients requiring implants. The needs and activity levels of younger patients demanded a more stable, durable and lasting solution. The key to implant success remains the reduction of friction and wear on the prosthesis itself. The prolongation of prosthesis longevity and the minimisation of complications and side effects remain the primary objectives of hip joint prosthesis research. This not only benefits the prosthesis itself, but also patient revision surgery.

2. LITERATURE REVIEW

Hip resurfacing (Fig. 1) is a conservative surgical procedure that was first performed in the early 1990s. The femoral head and neck are not excised. In this procedure, the femoral head is merely reshaped and resurfaced with a metal cap. Hip resurfacing offers a number of advantages in comparison to the traditional total hip arthroplasty. These advantages include bone conservation, improved function due to the retention of the femoral head and neck, providing better biomechanical restoration, reduced dislocation rates and stress shielding, less infection, a decrease in total time to heal post-operatively and reduced occurrence of thrombo-emboli [Afshinjavid et al.,2009]. Furthermore, hip resurfacing techniques provide a more straightforward approach to revision surgery, should it become necessary [Ma et al., 1983].

Figure1:*Hip joint Resurfacing Implant [Henrik et al., 1996]*

The polyethylene type implant is not sufficiently robust to withstand the demands of hip resurfacing. As a consequence of the aforementioned limitations associated with the polyethylene type implant, metal-on-metal implants are employed as an alternative. This has the advantage of preventing osteolysis and failure of the implant. The metal-on-metal implant has a longer lifespan [Daniel, J, et al. 2014], thereby obviating the necessity for revision surgery. Implants with a larger diameter are constructed with a metal-on-metal prosthesis, which is markedly more stable than its smaller counterparts, thereby eliminating the risk of dislocation. The hip resurfacing prosthesis is bedded with hydroxyapatite (Fig.2) on the porous surface, which encourages early bony in-growth. Once the hydroxyapatite has disappeared, an enduring biological fixation continues within the porous network, allowing stable mechanical fixation. The implementation of rigorous manufacturing controls, encompassing surface roughness, material composition, size and diameter variations, and the incorporation of patient-specific synovial fluid lubrication, facilitates the formation of an elastohydrodynamic film. This thin film lubrication system effectively mitigates the occurrence of wear, osteolysis and metallosis, as evidenced by the findings of [Metcalf et al. 2004].

Figure2*: Metal on Metal(MoM)Smith & Nephew -50mmHip Resurfacing Implant with Hydroxyapatite Surface*

The intra-osseous blood supply is avoided during hip resurfacing surgery, which allows for the treatment of the hip without causing avascular necrosis of the femoral head. As this was a significant concern among surgeons, the avoidance of the blood supply and the potential consequences of necrosis and collapse effectively addressed any apprehensions [Freeman,1994].

As evidenced above, the plethora of advantages inherent to the hip resurfacing technique has supplanted total hip replacement as the surgical procedure of choice and has repositioned metal-on-metal prostheses at the vanguard of implantation.

One of the most significant advantages for the patient is the reduction in the time required for healing following surgery, as well as a diminished risk of the necessity for further surgical intervention.

Metal-on-metal implants are composed of chromium, cobalt, and molybdenum, which are collectively referred to as "metal-on-metal" alloys. These ions are present in the blood at a basic level due to their status as normal dietary constituents and essential dietary elements. It remains uncertain whether these implants result in a notable elevation in the excretion of metal ions in the blood or urine. The use of larger diameter implants is assumed to result in reduced wear due to the formation of a thick fluid film lubrication layer, which in turn leads to a lower rate of ion release. To date, no definitive measure of ions in blood, serum, erythrocytes or urine has been established [Malek, Ibrahim A et al., 2015].Furthermore, the reliability of urine as a measure is questionable due to urinary dilution. The findings of the studies indicate that there is no correlation between the level of activity and the wear of metal ions. In light of the aforementioned evidence, it can be concluded that metal-on-metal implants can be used without undue concern, given the presence of thick fluid film lubrication.

3. MATERIALS &METHOD, RESULTS AND DISCUSSIONS

In light of the current shift in orthopaedic surgery towards hip resurfacing and away from the established technique of total hip replacement, further research is required to investigate the potential benefits of utilising metal-on-metal bearings in hip resurfacing surgery. The use of larger diameter bearings has previously been demonstrated to reduce friction. However, to date, only a limited number of studies have been conducted on metal-on-metal bearings with a diameter of 50-56mm. The friction and wear factors of these implants, as well as the ability to achieve full fluid film lubrication, have yet to be determined. The choice of lubrication will be a crucial factor in determining the most successful replacement regimes and the most effective outcome for the prosthesis.

The present study investigates the effect of various lubricants on friction factors for a large-diameter (50mm) metal-on-metal hip resurfacing bearing (Smith and Nephew BHR) with and without cup deflection (25-35 micron), utilising blood, clotted blood and bovine serum as lubricants. In order to ascertain the degree of friction generated by the 50 mm BHR bearing, a hip joint friction simulator machine was employed. This apparatus imitates the natural movement of the hip joint through the use of a pendulum, enabling the simulation of flexion and extension movements of up to ±25° and the replication of a normal walking gait. The data obtained from the hip joint friction simulator is then transferred to a computer, from which the values of friction factors can be calculated. The objective is to calculate a Z-value known as Sommerfeld number for all lubricants with different viscosities. The Z-value represents the measure of the lubrication regime, and it generates what is known as a Stribeck curve. The load applied with the hip joint friction simulator is equivalent to three times the body weight at 2000 N. Diametral clearances in the range 130-243 microns were employed . In order to achieve a reduction in friction, variable lubrication regimes will be applied in accordance with the aforementioned standards.

The following figures (A and B) show a standard friction torque versus number of cycles for the 50mm diameter BHR with and without cup deflection and stated diametral clearance using blood and serom based lubricants. Figures A and B, therefore, show typical dynamic motion profiles after and before cup deflection of ~25-35 microns using two- point pinching action before friction test and final cup deflection by ~60-70 microns (in total).The frictional torque for the deflected cup is at about 10 Nm as compared to before deflection at about 5Nm for 2000 N applied loads showing an increase of about 5 Nm for the deflected cup. The frictional torques are still within acceptable range without risk of dislocation.

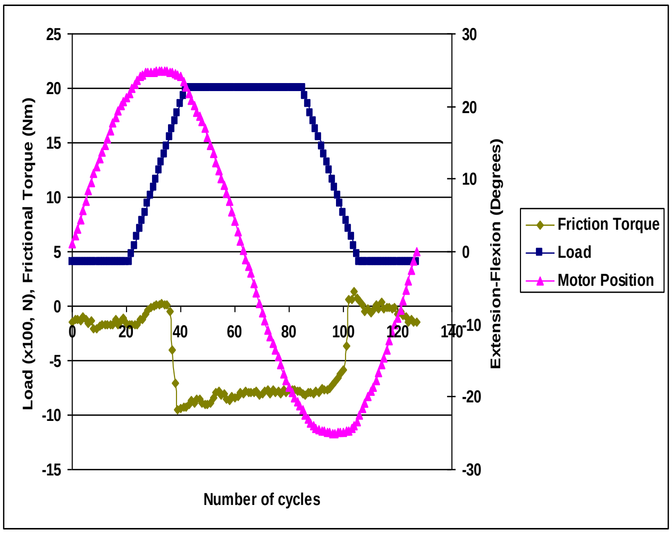


Figure “A” illustrates the friction torque versus number of cycles for the 130 µm diametral clearance, 50mm BHR bearing utilising blood (η=0.0112 Pas) as the lubricant following the cup deflection(25-35 micron).

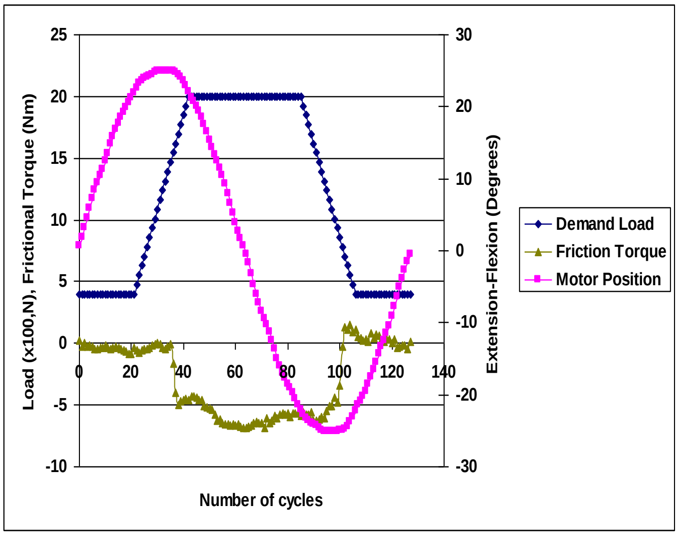


Figure “B” illustrates the friction torque versus number of cycles for the 200 µm diametral clearance, 50mm BHR bearing utilising BS+CMC (η=0.105 Pas) as the lubricant prior to deflection.

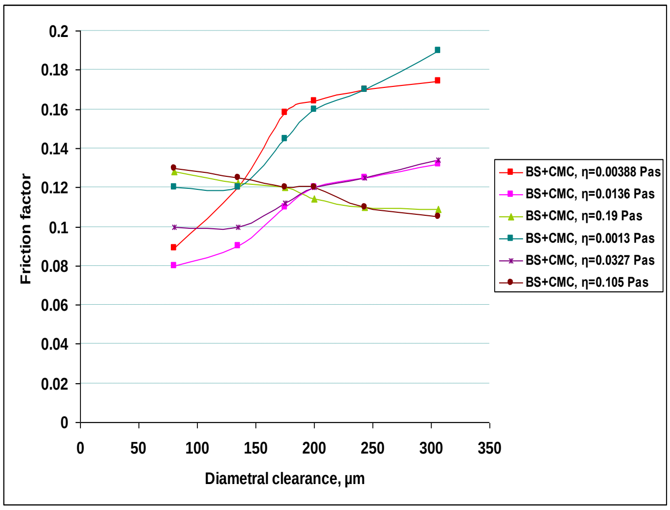
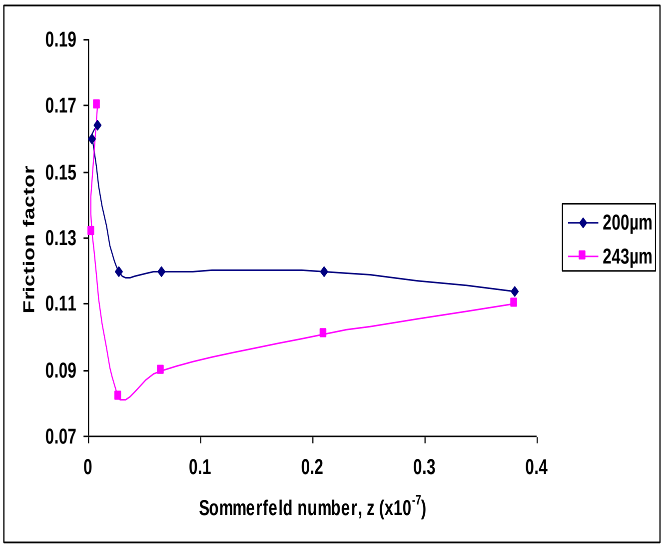


Figure "C" demonstrates the correlation between friction factors and distinct diametral clearances (80-306 µm) in the context of employing a BS+CMC formulation with variable viscosities [Afshinjavid et al., 2010].

Figure "C" clearly demonstrates that as diametral clearances increases for two lubricants (BS+CMC with viscosities of η=0.00388 Pas and η=0.0013 Pas) the friction factor increases which suggests the adverse effect of the lubricant's viscosity on friction factor for these two lubricants, whereas the other lubricants (BS+CMC with viscosities of η=0.0136 Pas and η=0.0327 Pas) show different output, i.e. slight increase in friction factor and the other two (BS+CMC with viscosities of η=0.105 Pas and η=0.19 Pas) showing slight decrease in friction factor as diametral clearances increase again demonstrating the effect of lubricant's viscosity depending on the diametral clearance.



The above figure (Figure D) depicts the results of a Stribeck analysis, which illustrates the relationship between friction factor and Sommerfeld number (Z) for two distinct diametral clearances: of 200 and 243 µm. The analysis was performed utilising a specific lubricant, designated as BS+CMC, prior to deflection. Figure D illustrates that the 243 micron diametral clearance demonstrate a reduction in friction factor (mixed lubrication regime) followed by an increase in friction factor (nearly fluid film lubrication) as the Sommerfeld number "Z" (essentially the lubricant viscosity) increases. Conversely, the 200 micron diametral clearance indicates a mixed lubrication regime, which implies that the 243 micron performs more effectively in terms of a lower friction factor and an enhanced lubrication regime, resulting in reduced wear and tear compared to the 200 micron diametral clearance.

4. CONCLUSION

The field of hip prostheses has undergone significant developments and modifications in design and techniques. A multitude of implants have been subjected to rigorous testing, modification, and reuse. The surgical procedure of choice for the treatment of hip disease is hip resurfacing, rather than total hip replacement. A younger, more active demographic is encountering a greater range of viable implant options without the concern of implant failure. The metal-on-metal implant, previously regarded as outdated and unsuitable for use, is experiencing a resurgence in popularity as the preferred design option. It's capacity to provide a greater range of shapes, sizes, diameters and high-quality implants has resulted in a resurgence in its popularity. The latest research into reducing friction and enhancing lubrication indicates that metal-on-metal implants offer a superior solution when considering surgical procedures. The potential effects of metal ion levels on human health remain unknown, although no definitive evidence has yet been presented. As is always the case, the key to successful implantation is to reduce the forces of friction and wear while increasing lubrication. The optimal objective is to develop an implant that closely resembles the natural hip joint.

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