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Review Article

Bearing surfaces in hip replacement – Evolution and likely future

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ABSTRACT

Total hip arthroplasty has evolved from the first total hip arthroplasty in 1938, through the revolutionization of hip arthroplasty by principles of low friction arthroplasty introduced by Sir John Charnley in 1960s to the present state of the art implants and techniques. The main concern regarding failure of total hip arthroplasty has been the biological response to particulate polyethylene debris generated by conventional metal on polyethylene bearing surfaces leading to osteolysis and aseptic loosening of the prosthesis. Therefore, recent research has been focussing on alternative bearing surfaces to reduce the particulate debris generated. These bearing surfaces include ceramic-polyethylene, metal–metal as well as ceramic–ceramic articulations and have demonstrated lesser friction rates as well as significantly lower wear rates as compared to widely used metal on polyethylene surfaces. Clinical experience until now has shown that metal on metal articulations have significant safety concerns whereas metal-on-highly crosslinked polyethylene, ceramic on ceramic and ceramic on highly crosslinked polyethylene articulations have shown encouraging results to hold promise for wider use in younger and more active patients. This review article discusses positives and drawbacks of various bearing surfaces in current clinical use in total hip arthroplasty as well as briefly explores the newer technologies on the horizon which may even further decrease wear and improve total hip arthroplasty survivorship.

Introduction

Total hip replacement has been widely acclaimed as the "Operation of the century".[1,2] Although multiple treatment modalities have been tried for treatment of hip arthritis, surgical treatment has been tried only in last 150 years. Themistocles Gluck probably performed the first hip arthroplasty (a hemiarthroplasty) in 1891 using an ivory femoral head. A wide range of tissues were tried in early twentieth century as an interposition material e.g. fascia lata, skin, pig's bladder etc. Vitallium mould design of Smith-Peterson was the first one to use artificial materials as a bearing surface in hip arthroplasty (Again, a hemiarthroplasty).[3]

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In total hip replacement surgery, both the acetabular and femoral bearing surfaces are replaced with artificial material like metal, ceramic and/or polymeric components. Wiles performed first total hip replacement in 1938 in United Kingdom using a metal on metal combination.[4] This was further developed by surgeons like Ring & McKee during the 1950s & 1960s. During the same period, Dr Ban Saw of erstwhile Burma replaced femoral heads of patients with femoral neck fractures with hand made ivory components achieving excellent results.[5]

The most significant development in evolution of THR bearing surfaces was the introduction of concept of low friction arthroplasty by Sir John Charnley in 1958, using metal on high-density polyethylene as bearing surface.[6] The principles proposed by him remain relatively unchallenged till today despite rapid evolution of multiple facets of hip replacement surgery. In 1970, Boutin introduced the ceramic on ceramic articulation in THR for the first time.[7]

Currently, the bearing surface which has proved to produce most consistent results in THR is the combination of femoral head made of cobalt chrome alloy articulating on an acetabular component made from ultra high molecular weight polyethylene (UHMWPE).[8]

The longevity of a total hip prosthesis is the area of highest concern for arthroplasty practitioners as well as their clientele. Hip replacements are being subjected to higher levels of activity in view of more and more hip replacements being done in relatively younger patients and increasing life expectancy of older population. Wear rates of 75–250 μm/year in polyethylene surfaces lead to periprosthetic osteolysis which is a major concern affecting prosthesis survival, especially in the young.[9,10] Bearing surfaces in THR have undergone a significant evolution from the introduction of low friction arthroplasty by Charnley to currently popular ceramic on ceramic and ceramic on crosslinked polyethylene. This review critically analyses the development of all currently available options and their strengths as well as weaknesses.

Tribology

Although the long-term survival of THR prosthesis is affected by multiple factors, tribology (Friction, lubrication and wear) of the bearing surface is the most important. The aim is to achieve a bearing surface close enough to articular cartilage which has low coefficient of friction, is capable of significant deformation without failure and exhibits no wear in absence of any pathology. In the natural hip joint, the low coefficient of friction is achieved by three lubrication mechanisms – elastohydrodynamic (EHD) lubrication, μEHD, and squeeze-film lubrication. During the stance phase of walking, EHD and μEHD predominate when pressure is generated in the synovial fluid by an entraining motion between the joint surfaces. During the heel strike phase, squeeze-film action predominates as the synovial fluid gets squeezed out with two cartilage surfaces moving toward each other. Synovial fluid film is retained partly due to deformation of the articular cartilage.[11]

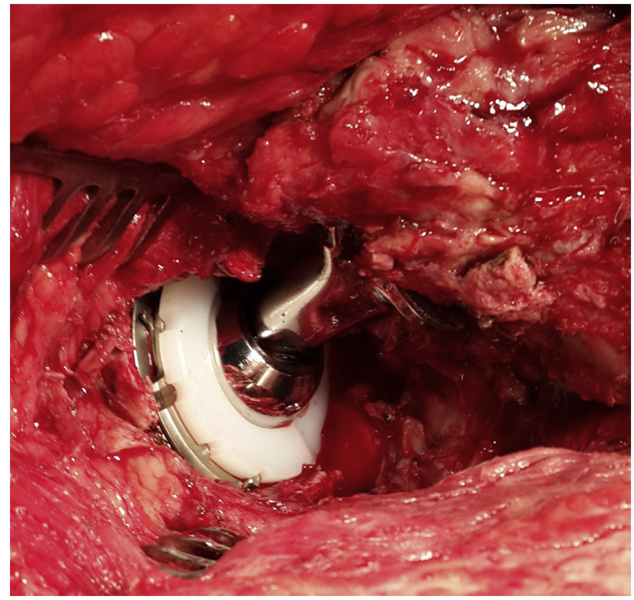

Fig. 1 – Metal on polyethylene – The gold standard.

Ideal bearing surface

Ideal bearing surface in THR prosthesis would have the following features[12]:

1. Low coefficient of friction
2. Small volume of wear particle generation
3. Low tissue reaction to wear particles
4. High resistance to third body wear
5. Enough deformation of articular surfaces to permit adequate fluid film lubrication during the stance phase without increasing wear

The currently used bearing surfaces can be classified into two major classes:

1. Hard-on-soft bearings
2. Hard-on-hard bearings

In this classification, soft bearing is always towards the acetabular side and includes ultra high molecular weight polyethylene (UHMWPE) and highly crosslinked UHMWPE. Hard bearing includes metal alloys (Cobalt chrome) and ceramics (Fig. 1).

Hard-on-soft bearings

Metal-on-highly crosslinked polyethylene

Over the last five decades, the most acceptable bearing surface couple in a prosthetic hip is a cobalt chrome femoral head articulating with a UHMWPE acetabular component in view of the excellent long-term results available. This bearing surface couple remains the standard to which wear testing for other bearing articulations are compared.

Ultra high molecular weight polyethylene (UHMWPE) was first used as a bearing surface on acetabular side in 1958. Several long chains of monomer ethylene constitute UHMWPE.