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## Chronology of Total Hip Joint Replacement and Materials Development

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The development of hip joint materials is one of the most challenging problems to prostheses technology in this millennium. Several types of materials have been developed for this purpose. The materials like glass, polymer (poly-tetra-fluoro-ethylene / PTFE or Teflon and ultra-high-molecular-weight-polyethylene or UHMWPE), metal (stainless steel, CoCr alloy, and CoCrMo alloy), ceramics (alumina, zirconia, Ti-coated ceramic alloys, and high isostatic pressed alumina or HIPed  $Al_2O_3$ ), composite, and apatite materials have been tried with partial success. Currently, Hydroxyapatite (HA) is being used quite frequently all over the world. Hip joint replacement techniques have been discussed under four different classifications i.e. hip arthroplasty, femoral stem, acetabular cup, and finally, total hip arthroplasty (THA). Chronology of technical improvement over first generation alternative joint bearing technologies before 1950s, have been presented by Charnley and other scientists. Before 1960s, there was hardly any technique with predictable results. The modern Charnley's low-friction UHMWPE-on-metal technique was the actual invention of the total hip replacement (THR) technique. The main objective of this paper is to list all the efforts in the direction of total hip replacement technique and material development chronologically. All historical and recent efforts for developing suitable materials and various designs have been covered in detail. Towards the end of the paper, the current trends and direction in material development techniques and the areas of research have also been emphasized.

### Introduction

The hip joint consists of a ball and socket joint. The top of the thighbone (femur) is a largest bone of human body, called femur joins with the horizontal pelvic coxal bone and lower end of that is fixed at the knee. The ball (femoral head) at the top of the thighbone fits into a portion of the pelvic bone forms the cup (acetabulum) or socket as shown in Figure 1(a). Between joining surfaces of the acetabulum and femoral lies a smooth glassy substance called cartilage. It provides frictionless cushion for constrained motion to femoral head within acetabular socket as shown in Figure 1(b).

Any failure emanating from acetabulum to femoral bone produces most common hip joint diseases in human body. Humans suffer from the various hip joint problems namely osteolysis, osteoarthritis, avascular necrosis, rheumatoid arthritis, fracture neck of femur, other inflammatory arthritis, developmental dysplasia, Paget's disease, arthrodesis (fusion) takedown, tumour, road accidents,

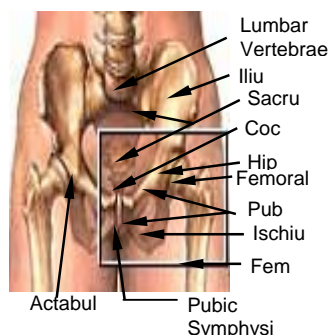


Figure 1(a): Front View of Pelvic Bone

soldier's injuries etc. Meaning of the medical terminology of some of these diseases is discussed below.

**Osteolysis:** It is local loss of bone tissue and appears because of wear. Destruction of bone takes place especially by bone resorption through removal or loss of calcium. Osteolysis may be evident in neoplastic, infectious, metabolic, traumatic, vascular, congenital and articular disorders [1].

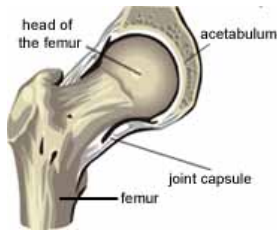


Figure 1(b): Acetabular Cup over Femoral Head

**Osteoarthritis (OA):** It is degenerative arthritis disease because, a "wearing out" involving the breakdown of cartilage in the joints and is one of the oldest and most common types of arthritis. It is characterized by breakdown of the joint's cartilage. Cartilage is part of joint and cushions ends of the mating bones. The bones get deformed, and even small movements will cause friction between the ball and the socket of the hip, causing severe pain.

**Avascular Necrosis:** This is caused by lack of blood supply into bone. This condition may ultimately lead to bone death. Pain usually develops gradually and may be mild initially. If avascular necrosis progresses, bone and the surrounding joint surface may collapse causing increase in pain.

**Rheumatoid Arthritis (RA):** This involves inflammation in the lining of the joints and/or other internal organs. RA produces chemical changes in the synovium that cause it to become thickened and inflamed. In turn, the synovial fluid destroys cartilage. Rheumatoid arthritis typically affects many different joints and it is a chronic inflammatory joint disorder.

**Fracture neck of Femur:** This is simply the fracture of the neck of femur. The structure of the head and neck of femur is developed for the transmission of body weight efficiently, with minimum bone mass, by appropriate distribution of the bony trabeculae in the neck. The incidence of fracture neck of femur is higher in old age.

**Developmental Dysplasia:** Developmental Dysplasia of the hip is a condition in which the femoral head has an abnormal relationship to the acetabulum. It includes frank dislocation (luxation), partial dislocation (subluxation), or instability of the hip, wherein the femoral head comes in and out of the socket. Radiographic abnormalities reflect inadequate formation of

the acetabulum. Since many of these findings may not be present at birth, the term developmental more accurately reflects the biologic features than the term congenital.

**Paget's Disease:** It is a metabolic bone disorder of unknown origin. This normally affects older people. Bone is a living tissue and is constantly being renewed. Paget's disease of bone causes increased and irregular formation of bone. The bone cells, which are responsible for dissolving body's old bones and replacing them with new ones, become out of control.

**Arthrodesis (Fusion) Takedown:** Arthrodesis means surgical fixation of joints by promoting fusion through bone cell proliferation. It provides potential of a painless, stable base of support. Most frequent complication of arthrodesis is non-union. Etiology of non-union includes bone loss, persistent infection, incomplete bone apposition, limb misalignment, and inadequate immobilization.

**Tumour:** The surgical problems encountered with osteoid osteomas of the proximal femur are unique. En bloc surgical excision is often made difficult by problems in defining the tumour boundaries. This can lead to extensive resection requiring internal fixation or bone grafting, and increased risk of complications [2].

The diseases described above lead to severe disability. As a result people are forced to seek surgical and involving bone replacement in order to get rid of their suffering and keep their joints mobile. Sometimes the problem of pain is severe and the condition of the hip joint is very bad, leading to a need for artificial hip joint replacement. Several variations on design, materials, and techniques of this joint replacement are still being experimented with since 1840, across the continents. Some of the pioneering efforts in this direction are presented here in chronological order.

### Chronological Development

According to shape and design constraint, hip joint techniques can be classified mainly into four. These are (i) Hip Arthroplasty, (ii) Femoral Stem, (iii) Cup Arthroplasty, and finally, (iv) Total Hip Arthroplasty (THA). The first generation of alternative joint bearing technology was developed in before 1950s. Surgeries were undertaken for hip joint

replacement in orthopaedics by Charnley's using low-friction UHMWPE-on-metal design. This design suffered from the problems of high wear rates and low useful life of joints. Techniques used before 1960s, gave no more predictable result. After 1960s, the THA technique gave excellence results. This modern technique was the actual invention of the Total Hip Replacement. Metal-on-Metal (MOM) and Ceramic-on-Ceramic (COC) joints were developed to improve wear rates and joint strength. Today, however, MOM and COC joints have received increased attention due to their potential in reducing the wear rate of arthroplasties, especially for young active patients. Nevertheless, the proliferation of current MOM and COC alternative bearing technologies for hip replacement has been limited due, in part, to stringent manufacturing requirements, contributing substantially higher cost relative to designs incorporating UHMWPE. The survivorship of MOM and COC designs is especially sensitive to implantation technique, and thus these alternatives are perceived as "less forgiving" than UHMWPE bearings for an orthopaedic surgeon who may perform only a few THA procedures per year. Widespread clinical adoption of MOM and COC has also been limited due to additional unique risks related to long-term toxicity (in MOM bearings) and implant fracture (in COC bearings). These are not encountered with hip replacements incorporating UHMWPE. Viewed primarily for young and highly active patients, alternative MOM and COC bearings are not expected to replace UHMWPE bearings in the near future.

### Hip Arthroplasty Technique

This is the replacement of only acetabular part over the femoral head. The acetabular part can be fixed and femoral head can move. Shape of this prosthesis is like hollow hemisphere.

Carnochan (1840) was the first surgeon, who thought that hip joint could also be replaced artificially. A wooden block was installed between the damaged ends of a hip joint in New York by Carnochan. Later on, several

other biological and foreign materials were used. These included as skin, fascia, muscle, pig bladder, and gold foil. Unfortunately, all these surgeries led to unpredictable, painful results and failures.



*Figure 2: The Bell Shape of the Mould Arthroplasty Introduced by Marius Smith-Petersen, 1925 [3]*

A surgeon in Boston, Massachusetts, Dr Marius N Smith-Petersen, MD, introduced the mould arthroplasty (1925). He used [3] a reactive synovial like membrane that he found around a piece of glass in a workman's backyard. The original design was ball-shaped hollow hemisphere of glass as shown in Figure 2, which could fit over the ball of the hip joint. The objective was to stimulate cartilage regeneration on both sides of the moulded glass joint. Smith-Peterson intended to remove the glass after the cartilage had been restored. Glass provide new smooth surface for movement. While proving biocompatible, the glass could not withstand the stresses of walking and quickly failed. This led to use of other materials, such as Viscaloid (a celluloid derivative, 1925), Pyrex (1933), Bakelite (1939), and later that year, an alloy of Cobalt-Chromium is called Vitallium (1936). Vitallium turned out to be inert and durable material for this type of surgery. This was a significant of 1936. This Vitallium material was very strong and resistant to corrosion, and continued to be employed in various prostheses since that time. However, surface quality of this alloy was less than adequate, hence, pain relief was not as predictable as expected and hip movement remained limited for several patients.

### Femoral Stem Technique

This is a technique where artificial femoral stem can be inserted into marrow cavity of the femur with / without any cementing. Here only femoral head can be replaced and acetabulum can be moved over the fixed ball. The shape of the prostheses is given in Figure 3 and 4. It is also called

Hemiarthroplasty. Hemiarthroplasty or partial hip replacement is a procedure in which only head of the femur (ball of the ball and socket joint) is changed with a metallic implant. This is still a common surgery for fracture of the neck of femur among elderly people above age of 80 years.



*Figure 3: First Judet Stem Installed in 1946, Failed Due to Wear Debris of the Acrylic [5]*



*Figure 4: Austin-Moore Original Prosthesis, having Long Stemmed Designs [4]*

Gluck introduced femoral stem in 1890, which was experimented with the ivory joint and found that human body could not tolerate large foreign objects. In 1919, Delbet used a rubber femoral head to treat femoral neck fractures. Groves placed an ivory nail to replace the articular surface of the femoral head, in 1926. Later on, this technique became a model for short-stemmed femoral prosthesis. In 1939, Frederick R. Thomson of New York and Austin T. Moore of South Carolina separately developed replacements for the entire ball of the hip. These were used to treat hip fractures and also certain arthritis cases. This type of hemiarthroplasty addressed the problem of arthritic femoral head only. The diseased acetabulum (hip socket) was not replaced. This prosthesis consisted of a metal stem that was placed into the marrow cavity of the femur, connected in one piece with a metal ball fitted into the hip socket. Bohlman and Austin

T. Moore (1939) collaborated for the fabrication and implantation of a custom made 12-inch-long Vitallium femoral head prosthesis for a patient with a recurrent giant cell tumour. This prosthesis functioned well and later on influenced the development of long stem femoral head prosthesis [4].

Dr. Jean Judet and his brother, Dr. Robert Judet (1938) of Paris, attempted to use an acrylic material to replace arthritic hip surfaces. This acrylic provided a smooth surface, but unfortunately became loose after implantation. The Judet brothers developed the first short-stemmed prosthesis in 1946 as shown in Figure 3. Designed on the basis of Groves nail, it was made out of poly-methyl-meth-acrylate (PMMA) with a head that was of a sphere attached to a short stem. Later versions of this design, made of Vitallium were partially successful. The idea of Judet brothers inspired Dr. Edward J. Haboush of The Hospital for Joint Diseases, New York City to utilize a “fast setting dental acrylic” to actually glue the prosthesis to the bone. Short-stemmed prosthesis first introduced by Judet brothers [5] failed subsequently due to acrylic wear debris.

F.R. Thompson and Austin T. Moore developed the most popular long-stemmed prosthesis in 1950s. The Austin-Moore prosthesis had fenestrations for self-locking as shown in Figure 4. This feature later became the impetus for biological fixation. These were used to treat hip fractures and certain arthritis cases. This type of hemiarthroplasty addressed the problem of arthritic femoral head (the ball) only. The diseased acetabulum (hip socket) was not replaced. But this was a highly successful technique, which is used even today because of its cheap cost and higher rate of success.

Austin-Moore Prosthesis was later used in the McKee-Farrar total hip. McKee's first designs of a metal-on-metal joint from the 1950s employed screw fixation. Later versions of McKee's design, referred to as the McKee-Farrar prosthesis, were clinically introduced in the 1960s. The McKee-Farrar

prosthesis [6] employed cement fixation as shown in Figure 5, whereas the McKee's Ring prosthesis [7] developed in the 1960s, employed screw fixation as shown in Figure 6. At that time, there was no effective method of securing the component to the bone. Large number of patients developed pain because of loosening of the implants. The desired results were still not achieved.



Figure 5: McKee-Farrar Prosthesis Employing Cement Fixation [6]



Figure 6: McKee's Ring Prosthesis Employing Screw Fixation [7]

### Cup Arthroplasty Technique

Originally, the mould arthroplasty had a brim around its edges to provide stability. But, this brim encouraged undesirable fibrous tissues and limited motion. Thus high revision rate inspired the development of hemispherical true-arc cup design by Otto E. Aufranc. This design removed the brim and added congruous inner and outer contours. This model was called Cup Arthroplasty. This design was a milestone in hip surgery and its principles inspired later developments. In the cup arthroplasty, it was observed that the cup would occasionally get stuck in the acetabulum and would allow motion only between femoral head and the fixed cup. This led to development of fixed cup in the acetabulum, otherwise known as the hip-socket arthroplasty. Despite good results by Gaenslen (1952), McBride (1955) and Urist

(1957), this procedure failed to become popular.

### Total Hip Arthroplasty Technique

This is the technique where acetabulum cup and femoral head both can be replaced. Femoral arthroplasty's relative failure to address problems on the acetabular side of the joint combined with the problems of cup arthroplasty and the failure of the hip socket arthroplasty, led to the development of the total hip arthroplasty.

Many peoples needed surgery to relieve their suffering due to pain and joints immobility. There were some early surgeries to remove arthritis spur calcium deposits and irregular cartilage in an attempt to smoothen the surfaces of joints. This led to the need to search for some materials, which could be utilized to resurface or even replace the hip. The property of the cartilage in hip joint is not dissimilar to that of cartilage in the lower limb. Their important tribological feature is being high water content. Type II collagen and proteoglycan extra-cellular matrix binds water, and retain it in the tissue over long periods of static loading. The role of chemically bound water, first described by McCutcheon (1959), is critically important in lubrication of the joint, which was first described as a sponge hydrostatic or self-pressurized lubrication [8].

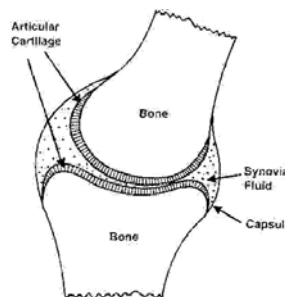


Figure 7: A Schematic Diagram of a Natural Synovial Joint in the Lower Limb [8]

The tribology of the natural joint has been studied extensively over the last 30 years. However, there remains a considerable scientific challenge to fully understand the structure and fundamental relationships in both healthy and diseased natural joints. The



major elements of the natural synovial joint [8] are the underlying bone, articular cartilages (in knee, meniscus), synovial fluid, tissues that constrain and articulate joint, ligaments, and tendons as shown in Figure 7 for lower limb joint.

Phillip Wiles (1938) performed the first hip arthroplasty. It was a MOM total hip made of stainless steel as shown in Figure 8. He performed 6 operations in London with the first MOM total hip arthroplasty. Its failure was due to loosening. The onset of World War II had a big effect in slowing down progress in this area of total hip arthroplasty [3].

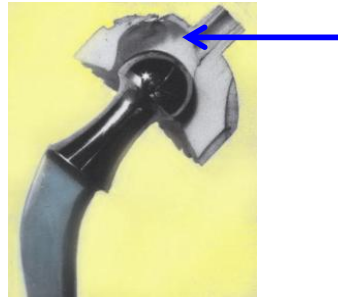


*Figure 8: Phillip Wiles Metal on Metal Total Hip Arthroplasty [3]*

Sven Kiaer (1950) introduced acrylic cement to the orthopaedic profession. The McKee-Farrar total hip arrived on the scene in 1951. Its later versions included modifications that allowed increased range of motions and a fixed stem using acrylic cement [3].

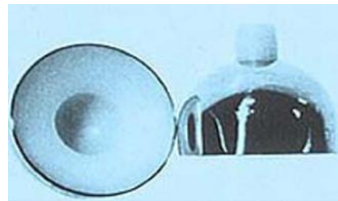
In England, a very innovative surgeon, John Charnley, was on total hip replacement problem. In 1958, Charnley aggressively pursued effective methods of replacing both the femoral head and acetabulum of the hip and he developed a conceptual low friction arthroplasty after analysing animal joint lubrication. He realized that a cartilage substitute was necessary in order to allow artificial joint to function at extremely low friction level as seen in nature. His first attempt was to use Teflon shells on the surface of the femoral head and acetabular components [9]. The rapid failure of Teflon parts led to development of a new design with a small diameter metallic femoral head attached to acrylic-fixed stem, which articulated with a thick walled Teflon shell as shown in Figure 9. This new design failed

quickly due to the poor wear characteristics, and led to generation of huge amount of wear debris. These wear debris promoted massive inflammatory reactions in the joints and travelled to various parts of the body via blood [9, 10].



*Figure 9: Total Wear-Out of a Teflon Socket by After 3 Years use, Charnley [4]*

Due to these difficulties, Charnley wanted an alternative solution. Thus, in order to obtain fixation of polyethylene socket as well as the femoral implant to the bone, he borrowed PMMA from his dentist friend. This substance, known as bone cement, was mixed during the operation and used as a strong grouting agent to firmly secure the artificial joint to the bone. This was really the birth of "Total Hip Replacement (THR)". This led to further development of a socket made of High Molecular Weight Polyethylene (HMWPE) with wear properties that were 500 to 1000 times better than Teflon as shown in Figure 10.



*Figure 10: The UHMWPE Socket Articulated with a Highly Polished Stainless Steel Ball [4]*

Many variations to his original design were developed after 1961. Charnley was performing surgery regularly with good results. Thousands of people were successfully relieved of their hip pain with long term success. The queen of England knighted him for his immense contribution to the humanity.

Muller [5] further developed Charnley joint as shown in Figure 11. This design used a 32 mm head, rather than a 22 mm head and was banana-shaped, allowing easy insertion without having to perform a trochanteric osteotomy.



Figure 11: Banana-Shaped Curved Prosthesis for Easy Insertion [5]

In the late 1970s and early 1980s, there was interest in the “double cup” or surface-replacement arthroplasty. All versions of the technique shared a similar intrinsic defect: a thin shell of polyethylene that wore rapidly, producing large amounts of wear debris, early loosening and massive osteolysis. As a result, most orthopaedic surgeons generally abandoned surface replacement arthroplasty.



Figure 12: The Charnley Flanged Stem introduced in 1975 [11]

The tapered wedge cross section and lateral cement flanges were designed to produce compressive stresses instead of hoop stresses in the cement mantle. The Charnley flanged stem was introduced in 1975 as shown in Figure 12.

Later, cemented MOM made of Co-Cr-Mo McKee-Farrar (1973-1976) total hip arthroplasties (THAs) were clinically and radio graphically evaluated over a long-term follow-up.

During these developments the potential of high density polyethylene was realized in

earlier stages. Its use therefore, induced quantum jump in improving prostheses designs. A historical chronology on this subject is indicated below.

### Chronology of UHMWPE use for Joint Development by Charnley

1958 Charnley develops the technique of Low Friction Arthroplasty (LFA). Using PTFE as the bearing material, Implants were fabricated by Charnley in his home workshop and in the machine shop at Wrightington and chemically sterilized.

1962 Charnley adopts UHMWPE for use in his LFA. Components were chemically sterilized.

1968 Production of the Charnley LFA by Chas F. Thackray Ltd., of Leeds, UK. The UHMWPE was gamma irradiated.

1969 General commercial release of the Charnley LFA by Chas F. Thackray Ltd., of Leeds, UK. UHMWPE were marketed as gamma irradiated (in air) with a minimum dose of 2.5 MRad.

1970 Commercial release of the Poly II-Carbon Fibre Reinforced UHMWPE for THA by Zimmer, Inc.

1972 Use of alumina ceramic heads articulating against UHMWPE in Japan.

1980-84 Development of Silane-Cross-linked HDPE by University of Leeds, Wrightington Hospital, and Thackray.

1980s Commercial release of Hylamer (Extended Chain Re-crystallized UHMWPE) for THA by DePuy Orthopaedics.

During the 1980s and early 1990s, aseptic loosening and osteolysis emerged as major problems in orthopaedics that were perceived to limit the lifespan of joint replacements [12]. The potential for extremely low clinical wear rates, necessary to reduce the risk of osteolysis, has led to renewed interest in developing new COC (alumina and zirconia ceramics) designs for hip arthroplasty during the 1990s.

After widespread introduction of hip and knee prostheses in the 1970s, little attention



was paid to tribological function of these devices till 1980. It was felt that the majority of these would not wear out or fail mechanically. During this period, concern was mainly focussed to causes of loosening, stress shielding or cement failure. Afterwards considerable attention focused on the wear, wear debris, and adverse biological reactions in the artificial hip joints.

Over the last 40 years, several different bearing combinations have been used in joint replacements. Various materials like MOM, COC, PTFE-on-metal, and polyethylene-on-metal have been used in this surgery. However, UHMWPE material was used most frequently on metal or ceramic femoral head in the hip joint beyond 1990s. Alternative bearing materials for the hip, such as alumina ceramic on alumina ceramic and cobalt chrome alloy pairings were also employed [8].

Metals/ alloys with porous coated surface to encourage bone growth infiltration are now being evaluated. Figure 13 shows one such hydroxyapatite coated acetabular cup. CeramTec AG (Plochingen), Germany, which is world's largest supplier of ceramic hip joints has sold 1.3 million BIOLOX® Forte (medical grade alumina ceramic) femoral heads for hip arthroplasty between 1995 and 2002 [13].



Figure 13: A Hydroxyapatite coated acetabular cup [13]

### Direction of Hip Prosthesis Material Development

Various hip prosthesis materials have been developed in the past with partial success but they eventually failed. In the present times, trend in hip prosthesis material research is towards having porous coating surfaces with excellent biocompatibility and good mechanical properties.

Advantage of conventional total hip prosthesis is that it is cheap and technically

very easy to fit into skeletons of different sizes and shapes for immediate weight bearing. Surgeons have had very long experience with this method, and components made from modern cross-linked polyethylene improve the wear-resistance results. However, the cement ages and disintegrates in long term and polyethylene wear debris cause "polyethylene disease", osteolysis.

The large number of materials used in this current research from its birth is discussed below.

**Wood:** Wooden prosthesis produces very large wear particles in the body fluid.

**Glass:** It provides very high surface finish but doesn't withstand a high body load.

**Plastic:** Plastics have superior surface finish and very low co-efficient of friction. But it has low strength, and produces very fine wear debris, which are absorbed by bone and blood, leading to adverse effects in brain.

Wear debris generation is one of the main problems with modern hip replacements. The particles of polyethylene from the cup liner are attacked by body's immune system, destroying the bone in and around the implant, eventually leading to loosening of the implant. Wear debris induced osteolysis is caused by adverse cellular reactions with wear particles in the body. Wear debris's cellular reaction is presented in Figure14.

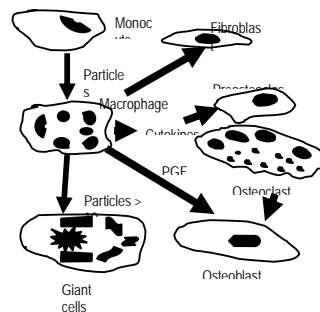


Figure 14: Representation of particle cell interactions [8]

Wear debris are generated in the joint dispersed into surrounding fluids and tissues, where they are phagocytosed by

macrophages. These activated macrophages release cytokines such as tumour necrosis factor (TNF- $\alpha$ ), prostaglandin E<sub>2</sub> (PGE<sub>2</sub>) etc., which act upon osteoblasts and osteoclasts to cause inflammation and osteoclastic bone resorption [8, 15]. It was reported [15] that the macrograph activation is dependent on the volumetric concentration and size of wear particles. The particles in the size range 0.3 to 10  $\mu\text{m}$  are most active biologically.

**Metal-on-Metal:** Metallic prosthesis has high strength and toughness. However, it causes problem in human body due to corrosion, wear and adverse reaction with host tissues. The metallic ions produce soluble metallic salts that enter the body fluids like blood and urine. Nickel is usually eliminated quickly from the body by urine, whereas Cobalt and Chrome stay longer in the body, Chromium is retained even in body's tissues [16, 17].

**Ceramic-on-Ceramic:** The advantages of COC over MOM implants are that COC implants show less wear than MOM implants. The most common ceramics Al<sub>2</sub>O<sub>3</sub> and ZrO<sub>2</sub> exhibit high mechanical strength and good biocompatibility. COC components demonstrate significantly lower wear compared to conventional metal-on-plastic prostheses. Therefore, these improved wear characteristics extend life of the implant. Table 1 shows the comparative wear of different types of implants. However, ceramics implants have very low fracture toughness values compared to metals or polymers, which turn is undesirable for an implant.

*Table 1: Wear volume reducing with using ceramics [18]*

Materials for Cup-on-Head	Wear Volume (mm <sup>3</sup> / year)
UHMWPE-on-Metal	56
Cross linked	2.8
UHMWPE-on-Metal	0.9
MOM	0.004
COC	

**Bioceramic:** More recently, in last two decades, there has been considerable interest in bioceramic materials like hydroxyapatite (HA). Development of this material has stabilized the Femoral Stem Technique [14]. Development of medical

grade hydroxyapatite and various other apatite materials are under research for hip joint prosthesis development.

#### **Porous Coating on Metal or Metal alloy:**

Porous coating surface can provide uncemented joints and tissues can grow into the pores of the implant coatings. It provides stable and strong bonding to the joint. At the same time, fracture toughness of the implant in good because of the metallic joint. Acetabular shell design is important for long-term performance of ceramic coated metallic hip joint implant. This implant is a cementless prosthesis, which is fixed to the bone without using bone cement. Additional technology such as Arc Deposition and Hydroxyapatite (HA) coating are an essential part of the shell design.

Arc Plasma Deposition [19] is a titanium metal coating process, which is applied to the outer surface of the acetabular shell. It provides a roughened, textured surface on the acetabular shell, which help provide initial fixation of the implant onto the bone.

Hydroxylapatite (HA) is a naturally occurring substance that closely resembles natural bone. Bone mineral stores calcium and phosphorous supplied by body, two minerals critical to one's health. HA material is highly biocompatible and it has brought great success in orthopaedic applications for last two decades.

The HA coatings have been applied not only to metals such as Ti alloys or Ca-Cr-Mo alloy, but also to carbon implants, sintered ceramics and even polymers [20]. Strong interface bonding between Si<sub>3</sub>N<sub>4</sub> ceramic and Ti metal has been developed [21]. Fracture toughness is an essential parameter for this type of ceramic coated joint. Gan et al. determined interfacial shear strength ( $t_{\text{max}}$ ) using a simplified equality for a film of thickness ( $d$ ),  $t_{\text{max}} = p d_s / 1.5 >$ , where  $>$  is the average steady-state crack spacing and  $s_f$  is the tensile strength of the film.  $s_f$  was determined experimentally by measuring the strain ( $\mu\text{f}$ ) at which cracks were first detected to form and multiplying by the film modulus [22]. The interface

generated when the patellar tendon was attached to a hydroxyapatite (HA) coated implant was examined by Pendegrass et al. using light microscopy and a quantitative histomorphological in vivo analysis [23].

Chronological of hip joint replacement techniques and materials development have been discussed in detail in this paper and a summary of implant developments presented shortly below.

### **Date      Design and Material Used**

1840    Hip Arthroplasty: Carnochan replaced hip joint by wooden block.  
 1890    Hemiarthroplasty: Gluck introduced ivory joint.  
 1919    Hemiarthroplasty: Deblt used rubber in place of femoral head.  
 1925    Hip Arthroplasty: Smith-Peterson used glass. Another material was viscaloid (celluloid derivative).  
 1926    Hemiarthroplasty: Grooves used in ivory nail to replace articular surface of ball.  
 1933    Hip Arthroplasty: Material used was Pyrex.  
 1936    Hip Arthroplasty: Material used was Vitallium (Co-Cr alloy).  
 1939    Hip Arthroplasty: Material used was Bakelite.  
 Hemiarthroplasty: Bohlman and Austin T. Moore used 12-inch-long Vitallium ball.  
 1938-46      Hemiarthroplasty: Dr. Judet brothers first develop the stemmed prosthesis.  
 1950s    Hemiarthroplasty: F. R. Thompson and Austin T. Moore used long stemmed prosthesis.  
 1950    Total Hip Arthroplasty: Sven Kiaer introduced acrylic cement.  
 1951    Total Hip Arthroplasty: Used by McKee Farrar.  
 1952    Acetabular Cup: Used by Gaenslen.  
 1955    Acetabular Cup: Used by McBride.  
 1957    Acetabular Cup: Used by Urist.  
 1958    Acetabular Cup: John Charnley introduced low-friction arthroplasty by Teflon.

1961    Acetabular Cup: Sir John Charnley introduced low-friction arthroplasty by PMMA.

1970    THA: Pierre Boutin first implanted alumina-on-alumina ceramics.

1973-76      THA: McKee Farrar used CoCrMo alloy.

1977    THA: Willert used Hip and Knee prosthesis.

1980s    THA: Tribological function.

1990s    THA: New COC (alumina and zirconia) Design.

1992    THA: Sedel used COC (Alumina).

1994    THA: Fisher reduced wear, wear debris and typical biological reactions.

1995    THA: Muller used cobalt chrome alloy pairings.

2000s    HAP & THA: People are interested on Hydroxyapatite materials with porous surface to encourage bone in growth and growth of bone.

### **Conclusion**

This study provides the chronology of hip joint prosthesis design and advanced materials development. The main causes for the hip joint diseases are loosening of implant due to wear debris, unstable implant, and adverse reaction of prosthesis with host tissue. Since, all polymer, metal, ceramics and their combination of materials are failed to give a stable long term success in the joint part, porous coating on the high strength and toughened metal/alloys are being used to get a stable joint.

Porous metal surfaces are designed to encourage bone ingrowth and Hydroxyapatite can be used as a suitable material for bone replacement. New century brought in wider recognition to the role of functional biomaterials, biological activities, and tissue engineering in the replacement and repair of diseased tissues. Medical grade advanced materials like porous coated metals/ alloys and polymer ceramic composites are being investigated and considered for stable long term success in hip joint replacement.

## References

- Montecucchi PC. Total Anatomic Hip Prosthesis. Montegen, 540 Beverly Court, Suite 1 - Tallahassee FL 32301 – USA, Via G. Dezza n. 24 - 20144 Milan – Italy; 2002.
- Chaarani MW. Percutaneous extra-articular excision of femoral neck osteoid osteoma: report of a new method. *Surgical Technique*. J. R. Coll. Surg. Edinb 2002; 47 October: 705-708.
- Bierbaum BE, Howe KK. Total hip arthroplasty: learning from both successes, failure - Early improvements involved techniques, materials; current issues focus on wear debris. *Orthopedics Today*, Oct. 1999.
- Charnley J. *Low Friction Arthroplasty of the Hip – Theory and Practice*. Berlin: Springer-Verlag; 1979.
- Muller ME. Total Hip replacement: Planning Technique and Complications In: *Surgical Management of Degenerative arthritis of the Lower Limb*. Heidelberg: Lea and Febiger; 1975, p. 91.
- McKee GK and Watson-Farrar J, Replacement of arthritic hips by the McKee-Farrar prosthesis. *J Bone Joint Surg [Br]* 1966; 48: 245-59.
- Ring PA, Complete replacement arthroplasty of the hip by the ring prosthesis. *J Bone Joint Surg Br* 1968; 50: 720-31.
- Fisher J. Biomedical Applications. *Modern Tribology Handbook*, Vol. Two: Materials, Coating and Industrial Applications, edited by Bharat Bhushan. Florida: CRC Press, Boca Raton; 2001, p1593-1609.
- Collis DK. Long-term (twelve to eighteen-year) follow up of cemented total hip replacements in patients who were less than fifty years old. *J Bone Joint Surg* 1991; 73A: 593-597.
- Cornell CN and Ranawat CS. The impact of modern cement techniques on acetabular fixation in cemented total hip replacement. *J Arthroplasty* 1986; 1 (3): 197-202.
- Mendenhall S. Putting joint replacement in historical perspective - Compared to other surgeries, TJR has remained a successful and cost-effective procedure. *Orthopedics Today* 2000; Jan.
- Higuchi F, Inoue A, and Semlitsch M. Metal-on-metal CoCrMo McKee-Farrar total hip arthroplasty: characteristics from a long-term follow-up study. *Arch Orthop Trauma Surg*. 1997; 116(3): 121-124.
- Willmann G. Fiction and facts concerning the reliability of ceramics in THR. In *Bioceramics in Joint Arthroplasty*. 8th Biolog Symposium Proceedings. Eds. H. Zippel and M. Dietrich. Darmstadt: Steinkopff Verlag; 2003.
- Astion DJ, Saluan P, Stulberg BN, and Rimnac CM. The porous-coated anatomic total hip prosthesis - Failure of the metal-backed acetabular component. *J Bone Joint Surg* 1996; 78A: 755-766.
- Green TR, Fisher J, Stone MH, Wroblewski BM, and Ingham E. Polyethylene particles of a 'critical size' are necessary for the induction of cytokines by macrophages in vitro. *Biomaterials* 1998; 19: 2297-2302.
- Brodner W, Grohs JG and Bitzan P et al. Serum cobalt and serum chromium level in 2 patients with chronic renal failure after total hip prosthesis implantation with metal-metal gliding contact. *Z Orthop Ihre Grenzgeb*, 2000;138(5):425-9.
- Schaffer AW, Pilger A and Engelhardt C et al. Increased blood cobalt and chromium after total hip replacement. *J Toxicol Clin Toxicol*, 1999;37(7):839-44.
- Heisel C, Silva M, and Schmalzried TP. Bearing surface options for total hip replacement in young patients. *J Bone Joint Surg Am* 2003;85A:1366-379.
- Huang N, Yang P, Leng YX, Wang J, Sun H, Chen JY, and Wan GJ. Surface modification of biomaterials by plasma immersion ion implantation. *Surface & Coatings Technology* 2004; 186: 218– 226.
- Suchanek W and Yoshimura M. Processing and properties of hydroxyapatite-based biomaterials for use as hard tissue replacement implants. *J Mater Res* 1998; 13(1): 94-117.
- Maeda M, Oomoto R, Naka M, and Shibayangi T. Interfacial reaction between titanium and silicon nitride during solid state diffusion bonding. *Trans JWRI* 2001; 30(2):59-65.
- Gan L, Wang J, and Pilliar RM. Evaluating interface strength of calcium phosphate sol-gel-derived thin films to Ti6Al4V substrate. *Biomaterials* 2005; 26:189–196.
- Pendegrass CJ, Oddy MJ, Cannon SR, Briggs T, Goodship AE, and Blunn GW. A histomorphological study of tendon reconstruction to a hydroxyapatite-coated implant: regeneration of a neo-enthesis *in vivo*. *Journal of Orthopaedic Research* 2004; in Press.