Total Hip Arthroplasty (History and Development)

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Abstract

Total hip arthroplasty (THA) is now one of the most common major orthopaedic procedures in the world. The history of hip arthroplasty may be considered in three major steps; osteotomy arthroplasty, interpositional arthroplasty and prosthetic arthroplasty. Prosthetic procedures have proven its value for treating pathologies such as osteoarthritis, hip fractures and occasionally for hip dysplasia,. Another point on the success of these procedures is the biomaterial point of view. In this paper, we aimed a brief look at the history and development of THA.

Key Words: *Total hip arthroplasty, history and development*

Total Kalça Artroplastisi (Tarihçe ve Gelişim)

Özet

Total kalça artroplastisi, günümüz dünyasında en sık uygulanan majör ortopedik girişimler arasındadır. Kalça artroplastisinin tarihçesi üç temel aşamada ele alınabilir, bunlar; osteotomi artroplastisi, interpozisyonel artroplasti ve protez artroplastisidir. Osteoartroz, kalça kırıklarının tedavisinde ve zaman zaman kalça displazilerinde protez uygulamaları yararlarını kanıtlamış bulunmaktadır. Bu girişimlerin başarılı olabilmesinde diğer bir önkoşul ise uygun ve yeterli biyomekanik özelliklere sahip biyomateryallerin kullanımıdır. Bu makalede, total kalça atroplastisinin tarihçe ve gelişiminin özetlenerek sunulması amaçlanmıştır.

Anahtar Kelimeler: *Total kalça artroplastisi, tarihçe ve gelişim*

Definition

We can define total arthroplasty as the replacement of both sides of a diarthrodial joint. If one side of a joint is replaced, it is called hemiarthroplasty and total hip arthroplasty (THA) is the name of the procedure performed on hip joint.

Basic anatomy

The hip joint (articulatio coxafemorale) has a deep stable ball-and-socket configuration allowing considerable range of motion. It is formed by the reception of the head of the femur into the cup-shaped fossa of the acetabulum. The fibrocartilaginous acetabular labrum encircles the outer edge of the femoral head, attaching at the periphery of the acetabulum and inferiorly attaching to the transverse acetabular ligament at the base of the acetabular fossa. The joint capsule envelops the hip joint, attaching to the bony pelvis on the acetabular side and on the femoral side attaching along the intertrochanteric line (1-3).

Evolution of Hip Arthroplasty

Osteoarthritis and rheumatoid diseases have afflicted man since earliest times. For centuries the problem of rendering an ankylosed hip mobile captured the imagination of surgeons. The history of hip arthroplasty may be considered in three major steps; osteotomy arthroplasty, interpositional arthroplasty and prosthetic arthroplasty.

Osteotomy (Resection) arthroplasty

Ambroise Paré, a famous French barber-surgeon of the Renaissance performed the first recorded joint excision in 1536. He excised the elbow joint of a patient with destructive infection (4). Joint excision found a place in the treatment of severely diseased joints. Moreau of France published a volume entitled "The resection of articulations affected by Caries" in 1805 (4). A clearly planned osteotomy of the upper femur with the objective of gaining motion has been credit to John Rhea Barton, a Pennsylvania physician. Barton performed a trochanteric osteotomy that lasted 7 minutes, in 1826 (4,5). James Syme, professor of clinical surgery at the University of Edinburgh, well known with his amputation technique, published his famous book "The excision of diseased joints" in 1831. Between 1921 and 1945, Gaithorne Robert Girdlestone, professor of orthopaedic surgery at Oxford, refined the indications and technique of the resection arthroplasty (6). Still, orthopaedic surgeons sometimes have to perform Girdlestone resection arthroplasty procedure in problematic cases. Although initially it was used to treat septic and tuberculous arthritis of the hip, the procedure worked so well that, prior to development of total hip replacement, it was often used as a primary procedure in the treatment of degenerative and rheumatoid arthritis (6).

Interpositional arthroplasty

A New York general surgeon Carnochan used a wooden block between the surfaces of resected necks of a mandibula in 1840 (5). Louis Ollier wrote his classic work, "On resections and conservative operations on the osseous system" in 1885 (4). Muscle, fibrous tissue, celluloid, silver plates, rubber sheets, magnesium, zinc and decalcified bone were used as interpositioning materials by that time. The interpositioning of these materials between the articulating surfaces helped to maintain motion at the site of the osteotomy and prevent recurrence of bone growth (5). However, continuous motion usually led to ankylosis at the site of arthroplasty. Chromicized submucosa of pig's bladder and tensor fascia lata muscle were tried in early 1900s by some surgeons. Some of the early animal studies were published in 1900, when V. Chlumsky reported his classic experiments on the placement of foreign materials in animal joints. He tested the reaction of animal tissues to magnesium, tin, zinc, silver, celluloid, rubber, colloidon, and even decalcified bone (4). A brief history of interposition is given in Table.

Table. Chronological insight to interposition materials and performing surgeons.

Surgeons	Year	Interposition Material
J. M. Carnochan	1840	Block of wood
A. S. Verneuil	1860	Soft Tissue
L. Ollier	1885	Periarticular Soft Tissue
H. Helferich	1893	Pedicle flap of Muscle
J. E. Pean	1894	Thin Platinum Plate
Foedre	1896	Pig's Bladder
R. Jones	1912	Gold Foil
J. B. Murphy	1902	Fascia Lata
Hofman	1906	Periosteum
Lexer	1908	Fascia
Loewe	1913	Skin
Baer	1919	Chromicized submucosa of pig's bladder
Putti	1920	Fascia Lata

A significant improvement in arthroplasty came in 1923 when a Boston surgeon, Marius Nygaard Smith-Petersen used a glass cup to cover the reshaped head of the femur. Subsequently, he employed Pyrex (1933), Bakelite (1937), and finally by the suggestion of his dentist, John Cooke, Vitallium (a cobalt-chromium alloy) with increasing durability and less tissue reaction (4,5).

Replacement Arthroplasty

In 1891 Gluck from Germany, took a big step forward by replacing the hip joint with ivory components for both the ball and the socket (7). In 1919, Delbet in France used reinforced rubber prosthesis. Hey-Groves in England used ivory in prosthetic replacement arthroplasty (resection of the femoral head) in 1927. However, these early attempts at prosthetic replacement were uniformly unsuccessful (8).

In 1940, Bohlman and Moore removed a giant cell tumor from the upper end of a femur and inserted the first metallic prosthesis. This device was the forerunner of the "self-locking" hemiarthroplasty by Moore, which had a straight stem with fenestrations. During the same time a more curved solid stem; the F. R. Thompson prosthesis was developed serving as the forerunner of McKee, Mueller, Harris, and Aufranc-Turner femoral components in their total hip system (Fig. 1). Judet brothers received much acclaim for their acrylic prosthesis in 1948. However, breakage and loosening of the prosthesis and absorption of the bone often called for secondary interventions. Eventually these components were made of CoCr alloy, but favor swung toward the most predictable fixation achieved with the intramedullary systems (7). During the late 1940s Valls and Townley in the United States each introduced a shortstemmed hemiarthroplasty. Townley's stem was curved, entered the medullary canal and ultimately became the total articular replacement arthroplasty (TARA) with the addition of a thin-walled polyethylene socket (Fig. 2). In 1953, Edward J. Haboush suggested the use of fast-setting methylmethacrylate dental cement, that has been used in dentistry since 1928, as a means of fixing the prosthesis firmly to the femoral shaft (4,8).

In 1958, John Charnley first reported his clinical experiences with the replacement of a human joint using steel femoral components and Teflon. Teflon was chosen as the material for the acetabular component because of its low coefficient of friction. Unfortunately, most of these prostheses failed (6). In 1960, he described fixation of the components with acrylic cement. In November 1962, the acetabular component was replaced by a more wear-resistant plastic, high density polyethylene (5). He chose a small femoral head because he felt that frictional components would be important in the durability of the prosthesis and accordingly named it the "low-friction arthroplasty" (6). Introduction and popularization of acrylic cement for fixation and high-density polyethylene as the bearing material of the socket are major contributions of Sir John Charnley. Charnley's contribution to the understanding of THA is indeed a milestone in orthopaedic surgery. Three significant advances during the 1960s brought THA into the modern era: the introduction of the metal to Ultra High Molecular Weight Polyethylene (UHMWPE) bearing couple, the use of methylmethacrylate for fixation and the reduction of postoperative sepsis. Sir John Charnley played a leading role in each of these areas (Fig 3).

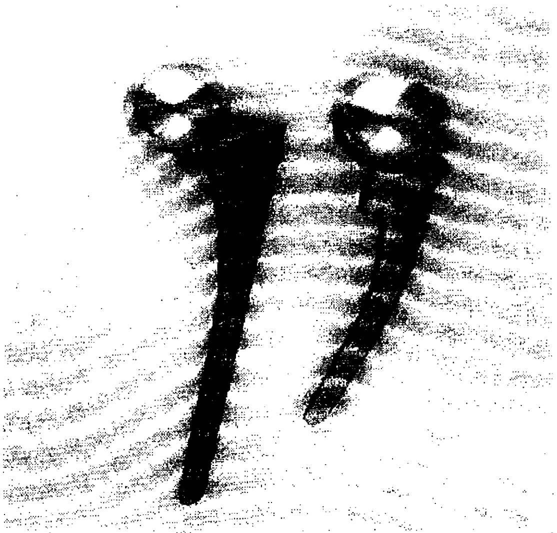
Fig 1. Austin Moore "self-locking" fenestrated hemiarthroplasty component and the more curved generally shorter FR Thompson femoral component, circa 1950s. (Amstutz HC, Hip arthroplasty. New York: Churchill Livingstone, 1991).

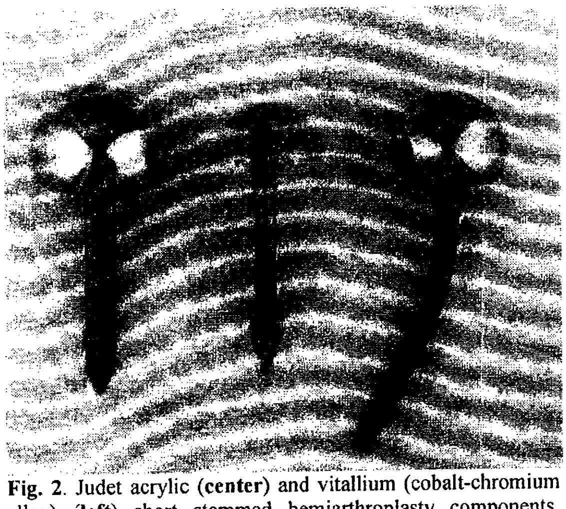
Fig. 2. Judet acrylic (**center**) and vitallium (cobalt-chromium alloy) (**left**) short stemmed hemiarthroplasty components. TARA (**right**) curved intramedullary hemiarthroplasty component. (Amstutz HC, Hip arthroplasty. New York: Churchill Livingstone, 1991).

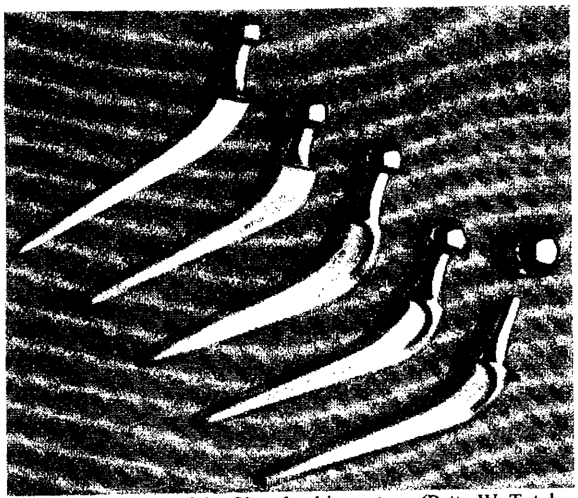
Fig 3. Refinements of the Charnley hip system. (Petty W. Total joint replacement. Philadelphia: Saunders, 1991.)

Biological fixation by porous-surfaced prostheses

The primary advantage of biologic fixation of femoral implants with porous coating is the avoidance of polymethylmethacrylate. The earliest use of porous-coated stainless steel stem was by Tronzo (5). The first porous-coated CoCr stem was inserted in France in 1971 (7). In fully coated prostheses, when fixation became rigid distally, thigh pain and proximal bone atrophy can be seen. In this technique, it is particularly important that the femoral component be as large as possible to prevent subsidence and subsequent loosening (9,10). Pore sizes of 250 μm to 450 are optimal for initial growth, osteonal remodeling and strength of fixation (11). Bony ingrowth can be achieved in a high percentage of cases when criteria have been met; including an extensive area of porous coating, initial stability, adequate bone stock, and intimate contact of prosthesis with endosteal bone. The incidence of thigh pain, radiographic stress shielding, and removal problems must still be solved to prove efficacy (12).

Hydroxyapatite ceramic coating

Hydroxyapatite (HA) may be viewed as bone without the gift of life (13). It encourages the invasion of bone in and around the implanted material. In comparisons of smooth pressfit implants and smooth HA coated implants, a clear increase in fixation strength is noted with HA coatings (11). However, it must be remembered that calcium phosphate ceramics are osteoconductive, not osteoinductive. Their enhanced ossification can be realized only under conditions where there is close proximity to an adequate host bone bed (14).

Biomaterials

Current and future biomaterials are crucial to the long-term success of total joint replacements. The design of surgical procedures has been based on alterations of the biomechanics. When designing or refining hip implants, care must be given to the processing techniques, mechanical properties, and biocompatibility of the material in the physiological environment. Cortical bone is a very complex structure with an irregular shape, blood vessels and osteons arranged in haversian system. The normal intramedullary implant is constructed of materials, which are far stronger than cortical bone. The materials of which implants are made are required to withstand forces that normal bone is never exposed (15).

Research and clinical experience have delineated mainly three groups of materials that perform well mechanically and biologically in the human physiology: metals, polymers and ceramics (9). Composites also are added to this list by some authors. Composites are synthesized in an effort to create materials that combine properties, which no single constituent material has, by itself. In addition, they frequently have properties that exceed the simple addition of the properties of each single component. For femoral stems the future may be away from metal toward composites. Carbon-carbon composites offer a unique ability to lower the modulus of the material while maintaining its strength (16). Ceramic modular femoral heads used with standard metallic stems is another development. Wear rates of ceramic femoral heads against high-density polyethylene are significantly lower than metal heads.

Complications and Problems to be Solved

In the past two decades, significant progress has been made in the surgical treatment of the arthritic disorders. However, surgical procedures are not always without complication. Early complications of total hip replacement are not usually material-related, namely; nerve injury, local vascular complications, deep vein thrombosis, ectopic ossification, femoral fractures, trochanteric non-union, dislocation, leg length inequality, wound healing problems and infection (17,18). Late complication can be defined as one that appears initially more than three months after operation (18).

Osteolysis and aseptic loosening have become the major problems limiting the longevity and clinical success of THA. Aseptic loosening is the prevailing cause of failure that necessitates revision. In 1968, Sir John Charnley described a lytic lesion around a cemented femoral component and attributed this finding to a possible infection (18). Subsequent assessment of cemented components noted periprosthetic radiolucencies and endosteal lytic lesions as a common finding and it became apparent that a process of aseptic loosening was occurring. Comparison of previous radiographs may reveal migration, the most reliable radiographic proof of loosening. Other evidence suggesting loosening is lucency at the cement-bone interface; a bone-cement lucency of at least two mm in the projected circumference of the prosthesis or a prosthesis-cement lucency that is not pres??ent on the immediate post operative film (19). The mechanism of aseptic acetabular loosening is thought to be the biological responses to particulate wear debris in both the cemented and uncemented constructs. Biologically active wear debris may be produced by each component of the prosthesis, including those parts made of metal, polymethylmethacrylate, or polyethylene (18).

Improvement in cementation techniques, have significantly improved the radiographic appearance and performance of the cemented stem. It is now apparent that acetabular loosening is the major long-term problem after THA. Radiographs of cemented prosthesis often show lucencies at the cement-bone interface, but these prostheses are not necessarily loose. However cement fractures reliably indicate loosening and component failure, even in the absence of immediate symptoms.

Partial or complete loss of the proximal support, which leads to medial migration of the proximal stem with adequate fixation of the distal end may lead to fatigue and stem failure. Fractured femoral stems are now more rare with modern prostheses than with implants formerly available (19,20). Dislocation is an uncommon problem in units regularly performing large numbers of hip replacements. It is usually due to malposition of the components.

Late infections, heterotopic ossification, trochanteric problems and femur fractures are other late complications of THA.

The cup

The main long-term complication of THA is aseptic loosening of the cup. Micromotion at the interface subsequently results in ultimate implant failure secondary to aseptic loosening. The rate of loosening for the stem follows a roughly linear course. Aseptic loosening of the cup is relatively rare during the first six-to-eight years and increases exponentially after the tenth postoperative year. Acetabular osteolytic lesions are most frequently noted along the apex of the implant. In 1992, in a review of acetabular fixation, Morscher described risk factors for aseptic loosening of the cup; that is young age, female gender (stem loosening is more frequent among men), and greater body weight. According to Morscher, uncemented porous-coated acetabular components represent "the state of the art" in THA, and hemispheric cups are superior to other designs. Threaded and metal-backed acetabular components have failed to demonstrate any improvement in results (21).

Osteolysis

Osteolysis is a significant cause of failure of THA. Bone loss associated with osteolysis is explained by the generation of wear debris activating macrophagic osteoclastic mechanisms. Presence of various particulate matter including cement, metal and polymer has been cited as the underlying cause for macrophagic activation. Roentgenographically, osteolysis causes a linear pattern of expanding radiolucencies about implants inserted with cement. On the other hand, osteolysis occurring with cementless implants creates local cavitery defects. Because the process is slow and insidious, clinical presentation of osteolysis is delayed. Roentgenographic evidence of osteolysis occurs long before the patient is symptomatic. Therefore, periodic x-ray evaluation is a critical issue in the ongoing management of patients with prosthetic implants. When the classic signs of osteolysis are evident, the patient should undergo x-ray evaluation every six months. If the lesion continues to progress and implant loosening is pending, surgical intervention is recommended.

When literature is reviewed reports on osteolysis could be found for different methods like cemented, cementless, with or without polyethylene applications. It is apparent that osteolysis can be caused by different inciting factors including cement, polyethylene, and metal debris. Nashed et al (22) noted more severe osteolysis with a combination of uncemented metal-backed cups and titanium heads. The authors concluded that uncemented metal-backed cups are the main cause of osteolysis.

Hybrid total hip replacement

A combination of cementless acetabular component and cemented femoral stem is called hybrid total hip replacement. Improved cementing techniques have substantially decreased femoral failure rate in short and intermediate term. According to Harris (23), femoral and acetabular components behave differently and often fail by different mechanisms. Cemented acetabular components commonly fail on a biological basis caused by macrophage induced bone lysis. In contrast, most femoral loosening is mechanical in origin with the dominant short term failure mechanism being related to thin areas in the cement mantle whereas the longer term mechanism involve debonding of the stem from the cement mantle, especially high proximally and near the tip. Including Harris' series, recently good results of hybrid total hip replacement was seen in the literature.

Berger et al (24) reported 150 hybrid THA in 139 patients with an average follow-up of 103 months. An uncemented hemispheric porous coated acetabular component with screws and a precoated femoral component with contemporary cementing techniques were applied. Using revision and radiographic loosening as the end point, the probability of both components surviving 10 years was 96.9%, 98.6% for the acetabular component and 98.4% for the femoral component.

Lewallen and Cabanela (25); from Mayo Clinic, reviewed 152 hips with a minimum follow up of five years. They concluded that, hybrid fixed hip arthroplasties have shown excellent clinical performance and fixation durability.

Callaghan et al (26), reported 131 primary hybrid hips with midterm follow-up. The authors, being not satisfied with the cemented acetabular fixation showing failure after 10 years, have started performing hybrid arthroplasties since 1986. In their series, no acetabular component had been revised for aseptic loosening. Same promising results of hybrid total hip arthroplasty have also been obtained from the series of Goldberg and colleagues (27).

Developments and Future Trends

The most recent advances in diagnosis involve the use of diagnostic imaging. Magnetic Resonance Imaging (MRI), not only shows soft tissue anatomy but also reflects metabolic and biochemical activity. Computed Tomography (CT) improves preoperative planning with the development of enhanced three dimensional reconstruction (16). On follow up, patient-derived data systems allow orthopaedic surgeons to assess the impact of THA on the health status of their patients. Thus, identifying the sociodemographic and lifestyle factors improves the outcome by better patient selection (28,29).

Metals used in THA have emerged from the era of stainless steel and chrome-cobalt alloys to the current use of high strength alloys such as forged chrome-cobalt and titanium-6-per cent aluminium-4-per cent vanadium (Ti-6Al-4V). It is clear, however, that using a lower-modulus material such as titanium for a cemented stem will increase the stress in the cement, and may increase the loosening rate. For femoral stems the future may be away from metal toward composites. Carbon-carbon composites offer a unique ability to lower the modulus of the material while maintaining its strength. The biocompatibility of carbon is excellent. Ceramic modular heads used with standard metallic stems are another development with lower wear rates but they have their own drawbacks. The gold standard for any hip arthroplasty procedure is how it works in the young patient. The goal of the orthopaedic community is to provide a reliable, technically reproducible, cost effective restoration of function for a spectrum of pathology with a low complication rate. These goals will be achieved by material advances in composite engineering, redesign of geometry to reduce stress shielding (30), advances of biodegradable polymers to stimulate and enhance fixation and structural restoration, growth stimulants to accelerate functional rigidity, biodegradable vehicles to carry antibiotics to the local region to treat joint infection and the study of biomechanics and biomaterials (31,32).

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