

Historical overview of hip arthroplasty: From humble beginnings to a high-tech future

Nicolae Ciprian Bota, Dan-Viorel Nistor, Sergiu Caterev, Adrian Todor

Department of Orthopedics, Traumatology and Pediatric Orthopedics, "Iuliu Hațieganu" University of Medicine and Pharmacy, Cluj-Napoca, Romania

Abstract

Surgery of the arthritic hip was not an easy task in the previous centuries, lots of operations being followed very closely by complications and failures. Nowadays, hip arthroplasty is considered "the operation of the century". This review follows the evolution of surgery on the arthritic hip, with emphasis on arthroplasty. Acknowledging the history of this operation, one can better prepare its evolution and future directions of research. The final chapter briefly describes the current trends and future perspectives.

Introduction

Throughout history, patients with orthopedic disorders were called "cripples" since this kind of pathology, which concerned the musculoskeletal anatomy and function, was poorly understood. This meant that conditions like trauma, degenerative joint disease and infection had poor outcomes, usually putting the patient at risk for death, major handicap and crippling deformity.

During its evolution, hip surgery focused on three major aspects: approach and anatomy, trauma and joint replacement. Often, hip trauma that required surgical treatment needed proper surgical approaches and implants, which led to the continuous need of research and innovation.

The purpose of this paper is to describe the evolution of hip surgery and hip arthroplasty by understanding the key moments in their history.

Early aspects of hip surgery

The earliest data regarding degenerative hip disease came from paleontologists and

archeologists who found signs of this pathology in *Homo Neanderthalensis* skeletons.^{1,2} Also, skeletons from ancient Britain and medieval times^{3,4} were found with signs of hip arthritis. In those times, the orthopedic treatment was the only one available, surgery for arthritis being yet to be developed. Naturally, patients could ambulate with the use of a cane and crutches, eventually becoming permanently immobilized in bed. No more innovations in degenerative hip disease were developed until modern times. More recently, at the beginning of the 18th century, surgeons used to excise the femoral head, basically performing the excision hip arthroplasty. At the time, this was groundbreaking surgery, especially in an age when limb amputation was common. The first surgeon to report such an operation was Henry Park (1744-1831) in Liverpool, United Kingdom. He told to his mentor Percival Pott (1717-1788) that after "*total extirpation of articulation*" he hoped to obtain a cure by "*callus*" formation.² In that period, the "*callus*" term was a general concept which referred either to a proper bony callus or a fibrous nonunion.

Across Europe, the 18th century was very violent, many wars and conflicts ranging from Ireland and Scotland all the way to the Black Sea and Caucasus. The introduction of military conscription and the spreading of firearms meant that more people were subjected to high energy trauma and many surgeons who practiced alongside an army were very fond of amputations and limb disarticulations. But some surgeons, who were horrified by the idea of invalidity and life-threatening surgery in a time when procedures were performed without anesthesia or any regard to asepsis and antisepsis, were happy to adopt the principle of limb conservation. Among those, the Prussian surgeon Johann Ulrich Bilguer (1720-1796) who wrote in 1761 "*De membrorum amputatione rarissime administranda*" advocating for limb sparing procedures, with minimum tissue excision and lower amputation rates amongst surgeons. Unfortunately, due to the speed of an amputation and its lower technical demand, Park's operation and Bilguer's principles failed to echo into the surgical world.

The breakthrough was in 1821, when Anthony White from London (1782-1849) was credited with the first excision arthroplasty on a 9-year-old patient with hip tuberculosis, according to The Lancet journal.⁵ Lewis Sayre, later in 1854, was a great promoter of hip resection for infection and tuberculosis ("*morbus coxarius*" as he called it). Subsequently, he operated up to

Correspondence: Dan-Viorel Nistor, "Iuliu Hațieganu" University of Medicine and Pharmacy, Calea Manastur Street, nr. 38-40, sc.2, ap.20, Cluj Napoca, Romania. Tel.: +40.752171202. E-mail: dan88nistor@yahoo.com

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59 patients, in which only 39 survived. He presented his results in 1876 at the International Medical Congress in Philadelphia and then across Europe on different occasions during lectures.⁶ Although in the United States this technique was well received, the European surgeons, like Volkmann and Calot kept a conservative approach. Later, in the 1940's, excision of the femoral head was popularized by Gathorne Robert Girdlestone (1881-1950) from Oxford in patients suffering from tuberculosis and joint infection. Girdlestone was a man of deep religious beliefs and his approach to this operation was somewhat biblical, as in his own words "*If thine femoral head offend thee, pluck it out and cast it from thee*". Even today, some surgeons use this procedure as a final resort in a failed total hip arthroplasty.

Osteotomy, interposition and fusion: early techniques for joint salvage

In 1826, John Rhea Barton from Philadelphia (1794-1871) performed the first osteotomy on an ankylosed hip.⁷ He performed an intertrochanteric osteotomy without anesthesia in seven minutes. Twenty days later, he mobilized the limb in order to create a pseudarthrosis. Three months later, the patient was walking using a cane. Through this operation, Barton also provided the first evidence that motion could prevent fracture healing and bone formation. At the time, this kind of treatment had a mortality rate of about 50%, unacceptable by today's standards. Although popularized by McMurray in the 1930's, and later by the biomechanical studies of Pauwels in the 50's and Bombelli in 1983, the indications for proximal femur osteotomy shifted from adult degenerative conditions to young and adolescent septic hip sequelae. In adults, the operation failed to properly address the hip joint and the afflicted joint surfaces, but rather to merely change the loading biomechanics and slow down the degenerative processes, with only slight alleviation of pain and other symptoms.

Later, surgeons began to consider treating the joint surfaces, by using different types of materials or biologic interposition tissues, developing the interposition arthroplasty. Carnochan from New York introduced wood blocks between joint surfaces in 1840.⁷ In 1860, Auguste Stanislas Verneuil from Paris (1823-1895) performed the first soft tissue interposition arthroplasty. In 1885, Leopold Ollier (1830-1900) from Lyon described the interposition of adipose tissue in aseptic joints. Because this material was not fixed to adjacent tissues, his procedures were generally ineffective.^{2,7}

Czech surgeon Viteslav Chlumsky (1867-1943), while working in Breslau (modern day Wroclaw, Poland) experimented in 1896 with a wide variety of interposition materials, such as muscle, celluloid, silver plates, rubber struts, magnesium, zinc, glass, pyres, decalcified bones and wax. Prior to Chlumsky, Themistocles Gluck from Berlin developed in 1891 a ball and socket joint made from ivory that was fixed to the bone with nickel plated screws. Subsequently he used plaster of Paris and powdered pumice with resin to provide fixation.^{2,7-9} Gluck was born in 1853 in Principality of Moldavia's capital, Iasi (modern day Romania). His father later became the personal physician of King Charles I of Romania. Between 1873-1876

he graduated medicine from Leipzig and Berlin. Later he took part as a military physician in Romanian War of Independence (1877-1878) and Serbian-Bulgarian War of 1885-1886 where he saw different kinds of bone trauma. In this period Gluck used screws and steel plates to provide an early form of ORIF (open reduction and internal fixation) on a fractured femur and replaced the malignant bit of a mandible with a steel plate. Although he's usage of artificial joints spanned not only to hip, but also shoulder, knee and ankle, his results were darkened on a long term by infection. Most of his work was not published due to a conflict with his chief surgeon, Proff. Von Bergmann.

At the beginning of 20th century, the road to modern arthroplasty was paved by John Benjamin Murphy from Chicago (1857-1916) who studied the anatomy and evolution of the disease and named it "*malum coxae senilis*". He noticed the presence of osteophytes around the joint and advocated for their removal only, without addressing the joint surfaces of the femur and acetabulum. He described this procedure as "hip cheilectomy". In his patients, Murphy noticed that after the removal of the osteophytes, their range of motion and pain somewhat improved, but in the end, the degenerative process continued to progress.¹⁰

In 1893, a German surgeon, named Heinrich Helferich (1851-1945) developed a procedure for temporomandibular joint arthritis which implied the usage of a fascia lata interposition between the joint surfaces. He advocated this principle long before, in 1882 at the German Surgical Congress. Following his findings, Murphy and his colleague Erich Lexer from Munchen, Germany (1867-1937) also used interposition arthroplasty with fascia lata graft. Others that used biological interposition arthroplasty, at that time were French surgeon Foedre (b. 1860) and William Steven Baer from John Hopkins Hospital in Baltimore (1872-1931) who in 1918 used pig bladder as an interposition material. In those times, informed consent was almost nonexistent, so most surgeons did as they pleased regarding the choosing of their surgical approach and material usage.

In the same period, Sir Robert Jones (1855-1933) used a gold foil to cover the reconstructed femoral heads. Twenty-one years later, he made a follow-up report stating that the patient retained good range of motion with very little pain. This was also the longest follow-up recorded to that point in the history of arthroplasty. In 1924, Royal Whitman from New York (1857-1946) published the first description of hip

osteoarthritis surgery, that was not referring to hip fusion. He described his operation as a "*mechanical adaptation of a hip joint disabled by injury or disease to the essential requirements of locomotion...*". In this type of surgery, the patient needs to sacrifice either stability or mobility for the sake of a pain free limb.

A major breakthrough in hip arthroplasty was made by Marius Smith-Petersen (1886-1953) from Boston who in 1923 described the mold interposition arthroplasty with a synthetic material (glass). He noticed that glass was a material that was very well tolerated by the human body and while he was operating on a patient who had a piece of glass in his back, Petersen noticed that a fibrous membrane was present around it. Therefore, he concluded that glass, molded on the femoral head could stimulate the formation of that fibrous membrane and alleviate pain, thus improving mobility and range of motion. In his own words, it will "*guide nature's repair*" of the joint. During surgery, the mold was inserted through an anterior approach, developed by Smith-Petersen in 1917. First glass implants were used in 1932 and although promising at first, they soon started to shatter. During revision surgeries, Smith-Petersen was excited about the presence of the fibrous membrane and felt encouraged to experiment with other materials, such as celluloid, Bakelite and Pyrex. In 1937, his dentist suggested Vitallium. Following this, he implanted almost 500 hip molds with good clinical results. This device provided the first predictable clinical results in interpositional hip arthroplasty.^{2,8-11}

Early attempts at arthroplasty

The first attempt for replacing the joint surfaces was made by a French surgeon, Pierre Delbet (1861-1925) who used rubber prosthesis for replacing the femoral head in 1919. In 1927, the British surgeon Ernest W. Hey-Groves (1872-1944) used ivory. In 1933 he described that in order to better accommodate the femoral implant, one must cut away the anterior and inferior margins of the "socket" (acetabulum). In 1948, the Judet brothers, Robert (1901-1980) and Jean (1905-1995) used an acrylic prosthesis. However, this implant was very susceptible to wear and was not very acclaimed on the long run.

Based on Judet's concept, in 1950, Frederick Roeck Thompson (1907-1983) developed a Vitallium based prostheses which featured a flared collar below the head and a vertically intramedullary stem.

Harold R. Bohlman (1893-1979) from Nebraska and Austin Moore (1899-1963) were two surgeons who further developed joint arthroplasty by creating a femoral sided implant made of Vitallium and implanting it in 1940 in a patient with a giant cell tumor of the proximal femur. By 1952, they refined their implant into a model that featured a fenestrated stem which allowed bony ingrowth. The Moore stem, as it is known today, is the first arthroplasty product that was widely distributed and still in use when treating femoral neck fractures in the elderly.¹²

In 1938, Philip Wiles (1899-1966) from London described the first THA using stainless steel components fitted to the bone with bolts and screws, but with unsatisfactory results. Edward J. Haboush (1904-1973) from New York and Kenneth McKee (1905-1991) from Norwich experimented in 1940's with dental acrylic cement for fixation. McKee, Farrar and Ring further developed metal on metal prostheses with different designs.¹³ In 1953, George McKee used a Thompson femoral stem and for the acetabular side, a combination of cobalt-chrome as a single piece. These were abandoned when Sir John Charnley defined the modern hip arthroplasty.

The road to modern arthroplasty

John Charnley developed the concept of low friction arthroplasty with regards to 3 distinct ideas⁸: 1) the idea of low friction torque arthroplasty; 2) use of acrylic cement to fix components to bone; 3) introduction of high-density polyethylene as a bearing material. Charnley's low friction arthroplasty had a 77-81% survivorship at 25 years follow-up.¹⁴ Until Charnley, hip components were supposed to mimic the native joint anatomy by having the same size and configuration as the patient's femoral head and acetabulum. He noticed that this configuration was prone to failure, so he developed a system based on a steel ball who was rolling on a polytetrafluoroethylene (PTFE/Teflon) acetabular cup. The ball had a size of 22,225 mm. This meant that the surface bearings were close to native joint friction torque and by decreasing the size of the femoral head from 40 mm to 22 mm, he ensured a greater range of motion, up to 90°. Following this, Muller increased the size of the femoral head up to 32 mm, thus increasing the range of motion up to 106°. In the beginning, Teflon experience wasn't a good one, most of the hips developing aseptic loosening and osteolysis. So, Charnley required a new bearing material and found

it in the shape of ultrahigh molecular weight polyethylene (UHMWPE).

In the 1950s' he introduced the PMMA (poly methyl methacrylate) bone cement. Although he accredited the first use of bone cement to Kiaer of Copenhagen and Haboush of New York in 1951, Charnley's article "*Anchorage of the femoral head Prosthesis to the Shaft of the Femur*" from 1960 stated some of the basic principles, such as medullary reaming of the femur prior to cement and stem fixation.¹⁵ Cemented fixation includes fixation both at the bone-cement interface and implant-cement interface. The main problem with cement fixation is that it is a surgeon dependent technique, the mix being prepared at the site (in the operating room) and at the time with a deficitary technique. In this aspect, early cementation techniques did not imply any preparation of the bone bed, the cement was introduced antegrade and the only pressurization made was a finger-packing method. This means that cement had a poor penetration in the cancellous bone, allowing for the cement mantles and interface tissue to form. In 1982, Krause *et al.*¹⁶ emphasized the importance of bone cement interface and bone bed preparation. Askew *et al.* in 1984 proved that cement pressurization increased its penetration into bone and related this fact with increased tensile and shear forces at the bone cement interface. This cementing techniques are also applicable when one is cementing the acetabular cup.¹⁷

Charnley's legacy

After Charnley introduced his bearing solutions and designs to the market, surgeons started to use different combinations of materials mixed with cemented or uncemented designs. Such, in the 60's Peter Ring used a cementless metal on metal (MoM) arthroplasty,¹⁸ opposed to McKee and Farrar who promoted the first cemented MoM designs using a cobalt-chromium alloy.¹⁹ French surgeon Boutin developed the alumina ceramic on ceramic (CoC) bearing⁹, developing later in 1977 the modular ceramic bearing. As a trend, in the 70's the uncemented bearings were increasingly popular, part due to the concept of "cement disease" and in part due to ease of reproducibility of the surgical technique. As such, surgeons like Lord, Judet, Mittlemeier and Zweymuller promoted this technique. In the 80's, CoC bearings were increasing in popularity after the "particle disease"; a new "complication" of cemented prostheses was defined. Due to a series of complica-

tions, such as ceramic shattering and squeaking, the evolution and research in this domain increased after the development in 1990 of ultra-high cross-linked polyethylene (UHXLPE) and in 1995 and 2003 of BIOLOX® forte and delta respectively. The "forte" implant used ultra-pure alumina ceramic with magnesium oxide. On the other hand, the "delta" implant includes zirconia toughened alumina ceramic with strontium and yttrium. In 1999, Trabecular Metal® implants were developed based on a tantalum structure, useful especially in revision arthroplasty. One of the latest technologies in bearing surfaces is the development of Vitamin E enriched poly in 2010. Now days this implant is useful in young and active patients who seek to maintain their lifestyle.

Modern problems, modern solutions

The 70's were a decade of innovation in stem technology. Great designs like Exeter®, Stanmore®, Lord® and Muller® straight stem were developed. Regarding stem design, two types became popular: the taper-slip (Exeter®) stem and the composite-beam (Stanmore®, Charnley) stem. The taper-slip proved to be slightly superior, mainly because it managed to transfer the shear loading stress forces from the bone-cement interface to radial forces at implant-cement interface. In this setting, in 1970's France, surgeons began using the fixation of a femoral stem with 2 points for support (from cortex to cortex) with a thin cement mantle and the intensive broaching of the femoral canal. This came as a surprise in the age because it contradicts the common belief that the femoral stem should be surrounded by a thick cement mantle and enough cancellous bone for support. This concept was capitalized by Kerboul, which led to the development of Charnley-Kerboul® stem.²⁰ Langlais *et al.* defined these opposite views in 2003 with the term of "French paradox": a phenomenon of two seemingly contradictory cementing concepts leading to good outcomes.²¹

In the 1970's, researchers described the so called "cement disease".²² They noticed microscopic particles of PMMA cement in the macrophages and giant cell population at the level of bone-cement interface and concluded that aseptic loosening was due to improper cement fixation of the components.²² Following this observation, the uncemented total hip was developed. The pioneer of this technique was Ring,¹⁸ in the 60's who used screws on the acetabular

component and a valgus placement of the implant in order to achieve fixation. The porous coated stem was developed in order to allow bony ingrowth and successful integration of the implant. Among the first who published on this matter were Galante and Rostoker in 1971.²³ At first, the stems were coated on all sides, all around, but this led to a rigid implant and high levels of thigh pain. As a result, the stems were coated only on the metaphyseal region, insuring a more stable construct. This led to the modern uncemented stem implants: anatomical, tapered and cylindrical.

In the 80's, a new concept developed, called "particle disease". The term was coined by Harris and was used to define a host inflammatory response as a reaction to particle debris of the implanted components.^{24,25} This gave a "boost" in the development of uncemented prosthetic components such as stems with circumferential coating, different cup designs, some threaded, other coated.

Multiple cemented and uncemented stems were developed in the following years, based on the lessons learned from the French paradox, cement disease and particle disease: Taperloc® in 1983 (which came with a titanium plasma sprayed metaphyseal coating), Wagner long revision stem in 1987, Exeter® modular stem in 1988, CPT® by Zimmer in 1990 and many others.

Hip resurfacing and current state of affairs in arthroplasty

In parallel with the evolution of THR, hip resurfacing continued the work of Smith-Petersen and in 1970 Gerard developed the cemented MoM (matching cup arthroplasty²⁶) and later in 1972 the MoP hip resurfacing. In 1971 and 1972, Furuya in Japan and Freeman²⁷ in UK developed the cemented double cup resurfacing with PoM components. Furthermore, in 1978, Wagner reported the metal on polly resurfacing experience with his central aperture femoral component. In 1990, Corin from Birmingham and later McMinn in 1998 laid the foundations for modern hip resurfacing.

Nowadays, most of the data existing in literature is collected from national arthroplasty registries. Basically, these are huge databases which collect anthropometric data from the patient (such as bodyweight, height, etc), manufacturer of the implant and the type of implant. The oldest national registry is the Swedish Hip Arthroplasty Register, established in 1979. Shortly, he was followed in 1980 by the Finnish one, in 1987 the Norwegian Arthroplasty Register,

the Danish one in 1995, Australian in 1999 and British in 2002. Data collected from these registries not only helped manufacturers in developing better and safer products, but also led to the development of clinical and surgical recommendations who were summarized as diagnostic and treatment protocols, the most famous of which is NICE (National Institute for Health and Care Excellence) protocol and guideline, established in UK in 2002.

The future of hip arthroplasty is going to be intertwined with the development of technology and Artificial Intelligence (AI). However, the way we understand working with AI is dependent of Gartner's Hype Cycle and surgeon's learning curve.²⁸ Cemented hip arthroplasty is more likely to be limited to revision arthroplasty in the future, as their number (cemented) is decreasing yearly. Supporting this statement, based on a retrospective study on the German population, Klug et. al discovered that 50% of arthroplasties between 2007-2016 were cementless and 18% were hybrid. More likely, as the number of hip arthroplasties is going to increase, the components will be more patient specific and personalized.²⁹ Pilz *et al.* concluded that until 2040, the number of hip arthroplasties in Germany will increase due to population ageing and increase in life expectancy.³⁰ Also, hip designs and manufacturers should acknowledge that certain populations and cultures may need a more personalized implant, accustomed with their life-style, especially in Asia.³¹

In the last years, hip arthroplasty became less invasive, with better materials, more resistant to wear and more biocompatible and the prevention of complications and perioperative management is greatly improving together with advances in pain control, anesthesia and rehabilitation. Quoting Prof. Luigi Zagra,³² advances in hip arthroplasty "should be based on changes which are safe with well proven advantages for the patient, with a wise progressive introduction of the novelties in the clinical trials."

Conclusions

Total hip arthroplasty is one of the most reproducible and frequently performed orthopedic surgical procedure. The hip is a complex joint with particular anatomy and biomechanics, thus hip surgery is very challenging when one is poised to recreate the native hip range of motion and mechanics, especially after arthroplasty.

The first steps in hip surgery were due

to trauma and tuberculosis, surgery that was performed in precarious conditions, without any regard to infection and anesthesia. Therefore, complications were often and severe, sometimes resulting in the patient's death.

The final goals of the hip surgeon were to alleviate the pain and regain the patient's mobility. At first, resection and anatomical reconstruction were the treatment of choice, but, as time passed, surgeons realized the difficulties of reconstructing a joint by natural causes (*e.g.* soft tissue interposition) and turned towards different implants in order to replace the diseased joint surfaces and replace them all together.

The future of hip arthroplasty resides in patient specific implants and AI assisted surgery, as well as robotics.

References

1. Trinkaus E. Pathology and the posture of the La Chapelle-aux-Saints Neandertal. *Am J Phys Anthropol* 1985;67:19-41.
2. Gomez P, Morcuende JA. Early attempts at hip arthroplasty-1700s to 1950s. *Iowa Orthop J* 2005;25:25-9.
3. Thould AK, Thould BT. Arthritis in Roman Britain. *Br Med J (Clin Res Ed)* 1983; 287:1909-11.
4. Rogers J, Watt I, Dieppe P. Arthritis in Saxon and mediaeval skeletons. *Br Med J (Clin Res Ed)* 1981;283:1668-70.
5. Anthony White (Obituary). *Lancet*. 1849;1:324.
6. Zampini JM, Sherk HH, Lewis A. Sayre: the first Professor of Orthopaedic Surgery in America. *Clin Orthop Relat Res* 2008;466:2263-7.
7. Hernigou P. Earliest times before hip arthroplasty: from John Rhea Barton to Themistocles Glück. *Int Orthop* 2013;37:2313-8.
8. Learmonth ID, Young C, Rorabeck C. The operation of the century: total hip replacement. *Lancet* 2007;370:1508-19.
9. Knight SR, Aujla R, Biswas SP. Total Hip Arthroplasty - over 100 years of operative history. *Orthop Rev (Pavia)* 2011;3:e16.
10. Murphy JB. *Cheilotomy. Surgical Clinics of Jhon B. Murphy. Vol IV. Philadelphia: Sanders: 1915.*
11. Smith-Petersen MN. The classic: evolution of mould arthroplasty of the hip joint. *J Bone Joint Surg* 1948;30B:L59.
12. Moore AT, Böhlman HR. The classic. Metal hip joint. A case report. By Austin T. Moore and Harold R. Bohlman. *Clin Orthop* 1983:3-6.

13. Houcke JV, Khanduja V, Pattyn C, Audenaert E. The History of Biomechanics in Total Hip Arthroplasty published correction appears in Indian J Orthop 2017;51:629. Indian J Orthop 2017;51:359-67.
14. Paul Fenton MRCS, Ashok Rampurada MRCS Ed, Ford Qureshi FRCS. Bone cement, its history, its properties and developments in its use. 2009. Available from: <http://usmorthopaedic.wordpress.com/2009/08/24/bone-cement-its-history-its-properties-and-developments-in-its-use>
15. Charnley J. Anchorage of the femoral head prosthesis to the shaft of the femur. J Bone Joint Surg Br 1960;42B:28-30
16. Krause WR, Krug W, Miller J. Strength of the cement-bone interface. Clin Orthop Relat Res 1982;290-9.
17. Niculescu M, Solomon BL, Viscopoleanu G, Antoniac IV. Chapter 29: Evolution of Cementation Techniques and Bone Cements in Hip Arthroplasty. In: Antoniac IV, eds. Handbook of bioceramics and biocomposites. 1st ed. Germany: Springer; 2016
18. Ring PA. Total replacement of the hip. Clin Orthop Relat Res 1970;72:161-8.
19. McKee GK, Watson-Farrar J. Replacement of arthritic hips by the McKee-Farrar prosthesis. J Bone Joint Surg Br 1966;48:245-59.
20. Kerboull L, Hamadouche M, Courpied JP, Kerboull M. Long-term results of Charnley-Kerboull hip arthroplasty in patients younger than 50 years. Clin Orthop Relat Res 2004;418:112-8.
21. Langlais F, Kerboull M, Sedel L, Ling RS. The 'French paradox.'. J Bone Joint Surg Br 2003;85:17-20.
22. Harris WH, Schiller AL, Scholler JM, et al. Extensive localized bone resorption in the femur following total hip replacement. J Bone Joint Surg Am 1976;58:612-8.
23. Galante J, Rostoker W, Lueck R, Ray RD. Sintered fiber metal composites as a basis for attachment of implants to bone. J Bone Joint Surg Am 1971;53:101-14.
24. Harris WH. Osteolysis and particle disease in hip replacement. A review. Acta Orthop Scand 1994;65:113-23.
25. Sukur E, Akman YE, Ozturkmen Y, Kucukdurmaz F. Particle Disease: A Current Review of the Biological Mechanisms in Periprosthetic Osteolysis After Hip Arthroplasty. Open Orthop J 2016;10:241-51.
26. Gerard Y. Hip arthroplasty by matching cups. Clin Orthop Relat Res 1978;134:25-35.
27. Freeman MA, Cameron HU, Brown GC. Cemented double cup arthroplasty of the hip: a 5 year experience with the ICLH prosthesis. Clin Orthop Relat Res 1978:45-52.
28. EFORT open reviews. (2020, October 26). Bone & Joint Publishing. Available from: <https://online.boneandjoint.org.uk/doi/abs/10.1302/2058-5241.5.190092>
29. Klug A, Gramlich Y, Hoffmann R, et al. Trends in Total Hip Arthroplasty in Germany from 2007 to 2016: What Has Changed and Where Are We Now? Z Orthop Unfall 2019 Nov 11. doi: 10.1055/a-1028-7822. Epub ahead of print. Erratum in: Z Orthop Unfall. 2019 Dec 03; PMID: 31711254.
30. Pilz V, Hanstein T, Skripitz R. Projections of primary hip arthroplasty in Germany until 2040. Acta Orthop 2018;89:308-13.
31. Shon WY, Park BY, R RN, et al. Total Hip Arthroplasty: Past, Present, and Future. What Has Been Achieved? Hip Pelvis 2019;31:179-89.
32. Zagra L. Advances in hip arthroplasty surgery: what is justified? EFORT Open Rev 2017;2:171-8.