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A WALK THROUGH TIME: EXPLORING THE HISTORY OF JOINT REPLACEMENTS

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Throughout history there have been attempts to alleviate joint pain by various means. With Industrial Revolution and the development of modern medicine, surgery was seen as a means to relieve joint pain. The first endoprosthetic surgery was performed in Germany in 1890 using ivory. Since then, the materials and manufacturing technologies for joint replacements have evolved drastically, and this advancement continues to accelerate. This paper traces the evolution of endoprosthetic materials, from early 19th-century experiments with ivory and glass to modern orthopedic innovations using stainless steel, titanium, and other advanced materials. The main aim of this paper is to examine the historical development of biomaterials used in endoprosthetic manufacturing and explores emerging trends in this field.

Keywords: Joint Replacements – History – Orthopaedic Surgery – Prosthetics – Arthroplasty

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Introduction

Throughout history there has been a tendency to alleviate pain of a patient by means of surgical interventions. First such attempts consisted of removing the damaged tissue of the patient to alleviate pain. First procedures that could be called arthroplasty were performed at the end of the 19th century. At this time material technology was limited to commonly used materials, either organic (ivory, bone, etc.) or nonferrous materials such as (copper, platinum, silver, gold etc.). With the technological progress of material science, the materials used in orthopaedic operations changed drastically throughout time.[1]

During the 20th century, advances in manufacturing led to the development of chromium steels and titanium alloys well-suited for medical applications. Additionally, this period marked the introduction of new materials in medicine, including polymers like Teflon and polyethylene, as well as various nonferrous materials such as ceramics[2].

Current research in implant technology focuses on improving existing materials, enhancing biocompatibility, and developing personalized implants and prosthetics through advanced manufacturing methods such as 3D printing.

1 Pablo Gomez – Jose Morcuende, *Early Attempts at Hip Arthroplasty*, Iowa Orthopaedic Journal [online], 25/4, 2005, p. 25–29, available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1888777/> [cit. 2024-07-22].

2 Massimiliano Merola – Saverio Affatato, *Materials for Hip Prostheses: A Review of Wear and Loading Considerations*, Materials Multidisciplinary Digital Publishing Institute (MDPI)12/3, 2019, p. 22, [online], available from: <https://www.mdpi.com/1996-1944/12/3/495> [cit. 2024-07-22], available also from: <https://doi.org/10.3390/ma12030495> [cit. 2024-07-30].

Beginnings of Joint Replacement Surgery

First surgical operations that would be considered as an endoprosthesis were performed at the end of 19. century by a German surgeon named Prof. Themistocles Glück (Figure 1).[3]

Fig. 1: Prof. Themistocles Glück[4]

Professor Glück began his surgical trials in the 1880s, first experimenting on animals before proceeding to human patients. He performed multiple joint replacement surgeries, though these were largely unsuccessful as most of his patients suffered from tuberculosis and developed post-operative infections. Joint prostheses were constructed from ivory with nickel-plated components for bone attachment, as illustrated in Figure 2. Glück presented his findings at the Fourth Session of the 19th Congress for the German Society for Surgery in Berlin on April 12, 1890.[5]

3 Philippe Hernigou, *Earliest times before hip arthroplasty: from John Rhea Barton to Themistocles Glück*, International Orthopaedics [online] 37(11), 2013, p. 2313–2318, available from: <doi:10.1007/s00264-013-2004-4> [cit. 2024-07-23].

4 Anonymous, *Themistocles Gluck*, Wikipedia (2011), available at: <http://en.wikipedia.org/wiki/Themistocles_Gluck>.

5 Richard Brand – Michael Mont – M. M. Manring, *Biographical Sketch: Themistocles Gluck (1853–1942)*, in: PubMed Central (PMC) [online] 2011, p. 1525–1527, available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3094624/> [cit. 2024-07-23].

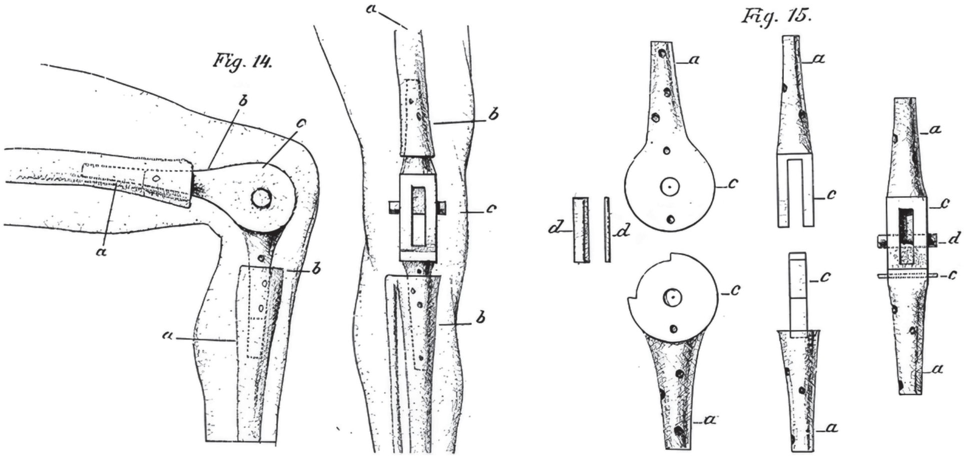

Fig. 2: Implants proposed by prof. Themistocles Glück[6]

Further development in the field of joint replacements was made by Smith-Peterson, who developed a new implant in the early 20th century (1920s). Peterson's method consisted of implanting a cup made of an inert material. The cup was meant to stimulate growth of cartilage on both sides of the implant. This concept arose from the surgical removal of a glass shard embedded within a patient's body, which was found to be coated in mucous membrane. During the development of the method, various materials were tested: glass, Pyrex, Bakelite, and Vitallium. Every material except Vitallium proved to be a failure, glass easily shattered under load. Pyrex and bakelite caused immune response. Only vitallium proved to be a success due to its biocompatibility (vitallium is consider inert). Vitallium is an alloy of 60% cobalt, 20% chromium, 5% molybdenum used at the time in dental implants. Vitallium is still nowadays used in dentures, certain surgical appliances, prostheses, implants, and surgical instruments.[7]

Within the next stage of development, the femoral head was replaced by an implant made of various materials. The femoral head implant made from acrylic by Robert brothers and Jean Judet from Paris were most popular. The implant was introduced in 1948 and one such implant has the distinction of being in vivo for 51 years. This is a unique case, however, as the acrylic was prone to breakage in high loads and its short shank was prone to loosening in the femur.[8]

The next femoral head implant was developed by an American surgeon Frederick Roeck Thompson. Instead of acrylic head used in Judet prosthesis Thompson chose Vitallium or stainless steel combined it with a longer neck cemented in bone and held in place by screws

6 Ibidem.

7 Ph. Hernigou, *Earliest times before hip arthroplasty: from John Rhea Barton* (as note 3).

8 Rihard Trebše – Anže Mihelič, *Joint Replacement: Historical Overview*, in: SpringerLink [online] 2012, available from: <https://link.springer.com/chapter/10.1007/978-1-4471-2482-5_2> [cit. 2024-07-23]; Louis Breck – Leonard Morton – Palafox Marto, *The Frederick* Thompson *Hip Prosthesis*, [online], Clinical Orthopaedics 12, 1958, s. 5, available from: <https://journals.lww.com/clinorthop/fulltext/1958/01230/the_frederick_thompson_hip_prosthesis.17.aspx> [cit. 2024-07-23].

and bolts. This method is still used for treatment of fractured neck of a femur, which are especially common in elderly patients.[9]

The first surgeon to successfully use metal-on-metal interface in arthroplasty was an English surgeon George McKee in 1953. This method used modified Thompson femoral stem with a new one-piece socket (cobalt-chrome alloy) as the new acetabulum. This method proved unpopular by the 1970s due to wear of the head and a socket releasing metal particles into the body. In 1960s surgeon Sir John Charnley from the Manchester Royal Infirmary pioneered a method of "Low friction arthroplasty" which is in principle identical to modern methods used today.[10]

At the same time multiple methods and types of prostheses of hip joint were developed, such as Bohlman femoral head (1940), Jepson hip prosthesis (1948), McBridge Doorknob hip prosthesis (1951), Mcbridge hip socket (1955), Urist Hip socket (1956) and many more. Ultimately all these methods were succeeded by Charnley's low friction arthroplasty.[11]

Modern Method of "Total Hip Arthroplasty"

Modern method of arthroplasty is derived from the method of Sir Charnley who advocated the use of small femoral head, which reduces friction and wear due to smaller surface area of the femoral head. Modern method of total hip arthroplasty (THA) consists of four main parts (Figure 3).[12]

Fig. 3: A titanium hip prosthesis, with a ceramic head and polyethylene acetabular cup[13]

[9] John D'Arcy – Michael Devas, *Treatment of fractures of the femoral neck by replacement with the Thompson prosthesis*, [online], The Journal of Bone & Joint Surgery British Volume 85/3, 1976, s. 8, available from: <https://boneandjoint.org.uk/Article/10.1302/0301-620X.58B3.182698> [cit. 2024-07-26].

[10] Stephen Knight – Randeep Aujla – Satya Biswas, *Total Hip Arthroplasty – over 100 years of operative history*, PubMed Central (PMC). [Online] 2017; available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3257425/> [cit. 2024-07-29].

[11] M. Merola – S. Affatato, *Materials for Hip Prostheses*, s. 24.

[12] John Charnley, *Low Friction Arthroplasty of the Hip*, Berlin 1979.

[13] Nuno Nogueira, *Hip replacement*, Wikipedia, available at: <https://en.wikipedia.org/wiki/Hip_replacement> [cit. 2024-07-29].

Femoral stem used to secure pattoimplant in the femur of the patient held in place by cement or press-fitted into place and held secure by screws. The material chosen for stem is titanium, cobalt-chromium alloy, and stainless steel, chosen for the strength and biocompatibility of the material.[14] The femoral head/ball made of wear-resistant material has different sizes depending on patient's body structure. The materials also vary, with the wear resistance being the key property of the material. The main materials chosen for this purpose are metals (cobalt-chromium alloy) and ceramics (zirconium, aluminium oxide).[15]

Acetabular liner interfaces with the femoral head in a tribological system, its size therefore depends on the size of the femoral ball. The selection of materials used depends on patient's activity levels, age and other factors. Liners are made mainly of plastics (polyethylene, etc.), ceramics (zirconia, alumina), and metals (cobalt-chrome, stainless steel, etc.).[16]

The acetabular cup holds the liner in the pelvis. The cup has multiple mounting options to secure it to the bone by pins and screws. Porous outer surface serves to facilitate growth of the bone to further secure the cup into the pelvis. The cup is made of a high-strength biocompatible material, such as titanium, stainless steel, etc.[17]

There are two major types of bearing systems used in hip joint prosthesis. The first are hard-on-soft bearings such as metal-on-polyethylene (MOP), and ceramic-on-polyethylene (COP). The second system is hard-on-hard bearings, which includes metal-on-metal (MOM), ceramic-on-ceramic (COC), and ceramic-on-metal (COM). Each of the systems has its advantages and disadvantages, and their use depends on variety of factors, such as the age of a patient, load on the parts (activity of patient), availability, cost efficiency etc.[18]

Role of a joint prosthesis is intended to replace a damaged part of the body, so it is given that artificial joint should be able coexist in tissue for long period of time, either by its ability to be inert (best example of this is ceramics), or to be able to grow into the body (such as titanium). There are three main causes of hip prosthesis failure, which include aseptic loosening, infection, and instability. The aseptic loosening is the leading cause, accounting up to 23% of hip prosthesis revisions. The wear resistance of the material is therefore an important factor when considering the type of material used in total hip arthroplasty.[19]

Metal-on-polyethylene systems are more cost-effective than other systems, but are prone to failure (loosening of joint) due to polyethylene wear. Metal-on -metal bearing systems are more durable than systems using polyethylene, but are prone to release of metal particles into the bloodstream causing complications. The ceramic-on-ceramic system is the most resistant to wear, but this comes at a cost of material brittleness of the material, that can lead to chipping.[20]

[14] J. Charnley, *Low Friction Arthroplasty of the Hip*.
[15] Ibidem.
[16] Ibidem.
[17] Ibidem.
[18] Ahmed A. Khalifa – Hatem M. Bakr, *Updates in biomaterials of bearing surfaces in total hip arthroplasty*, Arthroplasty 3/1, 2021, s. 8, available online from: <https://doi.org/10.1186/s42836-021-00092-6> [cit. 2024-07-30].
[19] A. A. Khalifa – H. M. Bakr, *Updates in biomaterials of bearing surfaces*.
[20] S. Knight – R. Aujla – S. Biswas, *Total Hip Arthroplasty*.

Biomaterials

A biomaterial is a material intended to supply or replace all or a part of a deficient organ. For hip replacements main property of materials used in joint replacement should be its biocompatibility.

For the biomaterial to be considered biocompatible, it must have multiple properties required when implanted in the living tissues of a human body. Generally, we can say, that biocompatibility is the ability of the biomaterial to be in contact with the body without causing effects that could compromise the health and function of the tissues. Nevertheless, depending on the use of biomaterials (short-term contact or long-term implant, location of use etc.) the requirements on these materials vary from moderate to high.[21]

Polymers were first used as a material for acetabular liners by Charnley due to their mechanical properties, and wear resistance. The first material used in trials/tests was polytetrafluoroethylene (PTFE), better known as Teflon. Teflon has a low coefficient of friction, is chemically stable and is generally considered inert in a body. Due to the high wear rates leading to extensive tissue reaction, PTFE was replaced by ultra-high molecular weight polyethylene (UHMWPE).

UHMWPE showed a positive behaviour until the late 1980s when problems with osteotomy and aseptic loosening emerged, so highly cross-linked polyethylene (HXLPE) was developed.

At present, experiments with the new polymers for acetabular cup continue, and include mixing UHMWPE or HXLPE with vitamin E and/or introducing new polymers such as polyether-ether-ketone (PEEK), etc.[22]

Metals are one of the most widely used materials in the field of THA, and are used for every part of the hip joint prosthesis. Stainless steel is a carbon-based iron alloy with addition of Cr, Ni, Mo and Mn. For medical purposes, steel 1.4404 (AISI 316L) is used.[23]

Stainless steel is not used to such an extent in in long-term use due to its low biocompatibility compared to other metals (titanium and cobalt-chrome alloy) and the potential for wear, but remains a cost-effective option for femoral stems.[24]

Cobalt-chromium alloys have high biocompatibility, are considered inactive in the body, have good corrosion resistance, strength and favourable wear resistance. These alloys are used extensively as material for implants.[25]

21 Véronique Migonney (ed.), *Biomaterials*, Wiley 2014, available online from: <https://doi.org/10.1002/9781119043553> [cit. 2024-07-30].

22 Saverio Affatato – Alessandro Ruggiero – Massimiliano Merola, *Advanced biomaterials in hip joint arthroplasty. A review on polymer and ceramics composites as alternative bearings*, Composites Part B: Engineering 83/83, 2015, s. 276–283, available online from: <https://doi.org/10.1016/j.compositesb.2015.07.019> [cit. 2024-07-30].

23 *Innovations in 3D printed individualized bone prosthesis materials: revolutionizing orthopedic surgery: a review*. Zhigang Qu etc., 2, 2024, International Journal of Surgery, 2024, p. 44, available from: <https://journals.lww.com/international-journal-of-surgery/fulltext/2024/10000/innovations_in_three_dimensional_printed.68.aspx > [cit. 2024-07-30].

24 Chang Yong Hu – Taek-Rim Yoon, *Recent updates for biomaterials used in total hip arthroplasty*, Biomaterials Research 22/1, 2018, s. 12, available online from: <https://doi.org/10.1186/s40824-018-0144-8> [cit. 2024-07-31].

25 A. A. Khalifa – H. M. Bakr, *Updates in biomaterials of bearing surfaces*.

Titanium alloys have high corrosion resistance, mechanical strength, and biocompatibility, which makes them suitable for use in implants requiring high strength, such as femoral stems. Acetabular cups are not manufactured from titanium alloys due to its low wear resistance.[26]

Ceramic was introduced in the mid-20th century for use as a wear surface in THA. Ceramic has high biocompatibility, wear resistance and chemical stability. The limiting factor of these materials is cost of production and brittleness that causes ceramic cups/femoral ball to chip under load. The first heads were alumina ceramic, which was introduced to THA in 1970s. Alumina ceramic suffered from high brittleness, leading to introduction of zirconia ceramic in 1985. Zirconia ceramic have higher toughness compared to alumina's. Zirconia ceramic was met with concern due to the changes in a patient's body during the monoclinic phase (increased risk of fracture), which has led to a decline in their use.

The later development of alumina-zirconia ceramic combines the hardness of alumina ceramic with the toughness of zirconia ceramic, Since the early 2000s it is manufactured under the name of BIOLOX DELTA.[27]

Conclusion

The history of biomaterials used in total hip arthroplasty is a testament to the remarkable progress of medical science and technology. From the early days when organic materials such as ivory were used, the field has evolved with the introduction of metals, ceramics and polymers.

The latest developments in this field include improvements in manufacturing methods, the use of coatings to improve mechanical properties of a materials, the use of materials that mimic human tissue, the development of personalised implants or self-healing materials etc.[28]

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Procházka časem: Objevování historie kloubních náhrad

RESUMÉ

Článek zkoumá historický vývoj a budoucí směřování materiálů používaných při chirurgických náhradách kloubů, zejména kyčelního kloubu. Začíná prvními známými operacemi v 90. letech 19. století, které prováděl

[26] Madalina Simona Baltatu – Petrica Vizureanu – Andrei Victor Sandu – Iustinian Baltatu – Doru Dumitru Burduhos-Nergis et al., *Prospects on Titanium Biomaterials*, European Journal of Materials Science and Engineering 8/4, 2023, s. 201–212, available online from: <https://doi.org/10.36868/ejmse.2023.08.04.201> [cit. 2024-07-31].

[27] S. Affatato – A. Ruggiero – M. Merola, *Advanced biomaterials in hip joint arthroplasty*; Chang Yong Hu – Taek-Rim Yoon, *Recent updates for biomaterials used*.

[28] Sianne E. T. Toemoe – Victor Lu – Parminder J. Singh – Vikas Khanduja, *The Past, Present and Future of Hip Arthroplasty*, in: Mrinal Sharma (ed.), Hip Arthroplasty, Singapore 2023, s. 825–840, available online from: <https://doi.org/10.1007/978-981-99-5517-6_63> [cit. 2024-07-31]; A. A. Khalifa – H. M. Bakr, *Updates in biomaterials of bearing surfaces*.

Themistocles Glück s použitím slonoviny jako implantátu, až po moderní kloubní náhrady kyčelního kloubu, které jako první zavedl Sir John Charnley. Článek se zaměřuje na konstrukci moderních kloubních náhrad, přičemž klade důraz na biomateriály a detailně rozebírá vlastnosti a využití materiálů, které byly v průběhu historie používány v ortopedii.

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