

BIOTRIBOLOGICAL AND MECHANICAL ANALYSIS OF TOTAL HIP ARTHROPLASTY FAILURE:

How to “break the code”

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Keywords: hip arthroplasty failure, biomechanics, instabilities, vibrations, non linear system.

ABSTRACT:

Total hip arthroplasty (THA) has been a successful intervention for 50 years. In spite of the excellent long term results the challenge remains with failure and revision operations especially with younger and active patients. [3]

The reasons of failure are multi factorial. Today we know of many factors: bad surgical technique (bad positioning of components) poor implant design and industrial process material factors. Biomechanical factors are the third cause of failure and probably the most important to understand. [2]

Aseptic loosening and osteolysis are the limiting factors of lifetime with polyethylene on hard bearing (metal or ceramic head). Metal on metal bearings failure depends on material, size and gender. Ceramic on ceramic hip bearings are a cause of concern because of squeaking and implant breakage but there is not a biological reaction. In almost every failure the mechanochemistries factors of friction, lubrication, and wear are the first step.

We propose an inverse method created by understanding these complicated mechanisms. This method defines a global mechanical system where we include the main bearing as well as connections because they are also cause of friction. We have to associate the biological system with its close environment (bone, fluid, tissues...) and the general body reactions (cells and immunological

system). The most relevant factors are mechanical instabilities and 40-80 higher mechanical stresses than in standard conditions.

INTRODUCTION:

570 000 THA were performed in Europe (population 446 .2 million) for the year 2009 and 500 000 in the U.S. Choice of insert bearings: Polyethylene 48%, Ceramic insert 17% and Metal insert 5% with: Metallic head 68%, Ceramic head 32%.

There is a life time incidence of 18% for revision and is projected to double in the next 10 years.

The causes of revision are aseptic loosening 45%, bone lysis 15%, pain 27%, dislocation/ subluxation 17%, infection 13%. [1]

The reasons of failure are multi factorial. It is by understanding the mechanisms that we can improve our long term THA.

MECHANICAL ANALYSIS:

1/The tribological triplet: mechanism, first bodies, third body (fluid and particles debris) and the tribological flow are the framework of every contact analysis [4].

2/Contact instability and friction: In standard conditions close to equilibrium system there are few problems and wear. But friction of THA is not a long steady state. Fluoroscopy (dynamical X-ray) shows eccentric loading then a new centered position that changes the contact and sliding. Sometimes the mechanical stress is 40 to 80 higher than in standard conditions (contact test with micro- separation 2 mm). The consequences are energy diffusion (thermal energy) with surface transformation and deformation (polyethylene and metal) wear, chemistry change and oscillation-wave diffusion. A stick-slip phenomenon especially occurs with ceramic on ceramic bearing and sometimes associated with squeaking and breakage because toughness is low without deformation except at the nano scale. Instability, oscillation, wave and energy diffusion are fundamental in understanding the sliding of THA [6] [7] [8] [9].

3/ THA is a global system: Main hip bearings are connected with a metal back (insert-metal back). The head is connected to the femoral stem and sometimes to a modular neck [10]. THA itself is linked to the bone. Mechanism of the triplet depends on the THA positioning. Head size, neck and height size can be responsible for contact, impingement and dislocation-subluxation. THA and muscle can create a particular friction between the biological structure and the metal

BIOLOGICAL REACTIONS:

Firstly, the body has to adapt to an arthroplasty and its different mechanical properties compared to natural bone, cartilage, fluid and tissue: The whole triplet changes! We need a primary stability between the bone and the arthroplasty otherwise it is a failure. Secondly, over time wear debris appears and a biological reaction [11]. Our living body can tolerate a huge material like an arthroplasty but tiny particle debris triggers immunologic reactions except ceramic debris (inertness of ceramic). This reaction depends on age, gender, volume and size of debris.

SUMMARY

When we choose a THA we have to define a mechanical threshold and a biological threshold adapted to a patient in their personal and professional life. The most important factor is the mechanical contact instability and energy diffusion in a global system because others factors are a consequence of this one.

References

[1] Pfluger G, Junnk-Jantsch S: Bearing Surface Choice: A European Experience. Seminars in Arthroplasty Vol. 23. 206-210 N°4 Dec. 2012. Elsevier Inc. doi.org/10.1053/j.sart.2013.001.003

[2] Jassim SS, Wanhegan IS, Haddad F.S. The Epidemiology of Total Hip Arthroplasty in England and Wales. Seminars in Arthroplasty Vol. 23. N°4 Dec.2012. pp 197-198. Elsevier Inc. doi.org/10.1053/j.sart.2012.001

- [3] Schmalzried TH, Shepherd EF, Doney FJ, and al: The John Charnley Award. Wear is a function of use, not time. Clin Ortho Relat Res 381: 36-46.2000
- [4] Renouf M, Massi F, Fillot N, Saulot A. Numerical tribology of a dry contact. Tribology International 2011; 44: 834-844
- [5] Dennis DA, Komistek RD, Northcutt EJ et al: In vivo determination of Hip Joint Separation and the forces generated due to impact loading conditions. J Biomech 34:623-629
- [6] Nevelos J, Ingham E, Doyle C, et al: Microseparation of the centers of alumina-alumina artificial hip joints during simulator testing produces clinically relevant wear rates and patterns. J Arthroplasty 15: 793-795, 2000
- [7] Fisher J: Bioengineering reasons for the failure of metal –on-metal hip prostheses: An engineer’s perspective. J Bone Joint Surg Br 93:1001-1004, 2011
- [8] Weiss C, Hothan A, Morlock M and Hoffmann N: Friction- Induced Vibration of Artificial Hip Joints. GAMM-Mitt.32, N°.2, 193-204 (2009) / DOI 10.10.1002/gamm.200910016
- [9] Morlock MM, Bishop N, Zustin J, et al: Modes of implant failure after hip resurfacing, morphological and wear analysis of 267 retrieval specimens. J Bone Joint Surg Am 90:89-95, 2008
- [10] Cooper H, Della Valle CJ, Berger R, et al: Corrosion at the head- neck taper as a cause for adverse local tissue reactions in total hip arthroplasty. J Bone Joint Surg Am 94: 1655-1661, 2012
- [11] Tipper JL, Ingham E, Halley JL, et al: Quantitative analysis of polyethylene wear debris, wear rate and head damage in retrieved Charley hip prostheses. J Mater Sci Mater Med 11:117-124, 2000

