FAILURE ANALYSIS OF ULTRA-HIGH MOLECULAR WEIGHT POLYETHYELENE ACETABULAR CUPS

by

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THESIS SUMMARY

Failure analysis of ultra-high molecular weight polyethylene acetabular cups

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Owing to the crippling nature of arthritis, surgeons have been trying for well over a century to successfully treat this debilitating disease particularly when attacking the hip joint. In the early 1970s, Sir John Charnley started with total hip replacement as a solution to this ever-increasing problem. Many different designs were developed but all the designs revolved around a femoral stem, femoral head and acetabular component. Independent of the design, longevity of the implant remains a problem. The major cause of replacements, according to various hip registers, is due to aseptic loosening resulting from osteolysis. According to these registers, the average in-vivo life of a hip replacement is approximately 12 years.

The main aim of this study was to determine the root cause of mechanical failure of the acetabular cups and to determine the origin of the excessive amount of ultra-high molecular weight polyethylene (UHMWPE) wear debris floating in the joint resulting in osteolysis.

During the study, various techniques were used to investigate the acetabular components to try to establish the root cause of mechanical failure. These techniques included:

1. Visual inspection
2. Investigation making use of dye penetrant spray
3. Investigation under stereo microscope
4. Investigation making use of a scanning electron microscope
5. Electrophoresis
6. Mass-spectrometric analysis
7. Analysis of the synovial fluid on high-frequency linear-oscillation machine (SRV).

The wear debris retrieved from the scar tissue surrounding the joints of a number of patients was also analysed.

Apart from the obvious defects such as mechanical damage due to impingement, the main defect on which this study focuses is the wear patches found on the inside of the acetabular components.

The wear areas were presented as areas where the surface layer of the UHMWPE was ripped off by adhering to the rotating femoral head. This type of failure is possible if localised overheating takes place resulting in the material either adhering to the rotating femoral head or the material being squeezed out under the prevailing pressure. Both these mechanisms were confirmed by the wear debris retrieved from the scar tissue, being either droplets of UHMWPE or whisker-like wear products.

To confirm the existence of elevated temperatures the brown discolouring on the inside of the acetabular cups was analysed, making use of electrophoresis, mass-spectrometric analysis and scanning electron microscope recordings. In this part of the study, it was confirmed that

localised temperatures on the bearing surface had reached at least 60°C during in-vivo service. This temperature was confirmed by inserting a thermocouple just under the surface of an acetabular cup and then measuring the temperature while in-vitro testing was taking place on a hip simulator.

The wear debris as retrieved was also duplicated in laboratory experiments while the temperature on the surface of an acetabular cup was monitored. It was established that wear particles similar in shape and size were formed at temperatures in excess of 90°C. At temperatures above 50°C the UHMWPE had visually shown extensive increase in creep, indicating that at these temperatures the material softens sufficiently for this type of debris to be generated

The overheating as described can also only occur if there is a lack of lubrication in the bearing couple. The synovial fluid from 12 patients was retrieved during revision surgery. This synovial fluid was then tested on a high-frequency linear-oscillation machine (Optimol SRV test machine) to determine the lubricity characteristics of the synovial fluid as retrieved. It was discovered that the load-carrying capability of the synovial fluid did not comply with the minimum requirements for a fluid to function as a lubricant.

The final conclusion of this study is that excessive amounts of wear debris are generated due to the localised overheating of the bearing couple as a result of insufficient lubrication. The localised heat build-up results in excessive amounts of wear debris being generated and deposited in the joint area resulting in osteolysis.

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σ	Principal stress – either tension or compression
r	Radius
E	Young's modulus of elasticity
H	Hardness of material
v	Poisson's ratio

Glossary

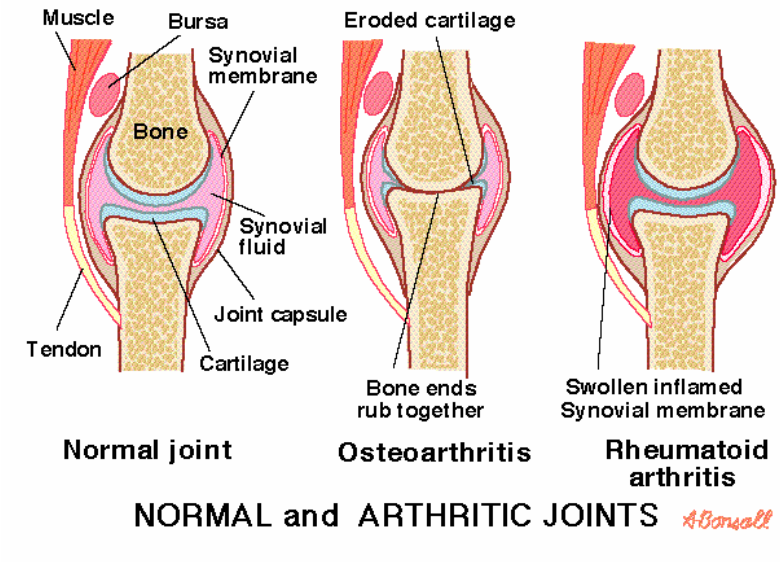
Abduction	Act of turning outward.
Acetal	Acetal, also known as polyacetal, polyoxymethylene (POM), or polyformaldehyde, is a high-performance engineering polymer.
Adduction	Act of turning inward.
Arthritis	Arthritis is inflammation of one or more joints. When joints are inflamed they can develop stiffness, warmth, swelling, redness and pain. There are over 100 types of arthritis, including osteoarthritis, rheumatoid arthritis, ankylosing spondylitis, psoriatic arthritis, lupus, gout, and pseudogout. Earlier and accurate diagnosis can help to prevent irreversible damage and disability.
Arthrodesis	Athrodesis is the surgical fixation of a joint. It is also called artificial ankylosis.
Avascular necrosis	Condition in which poor blood supply to an area of bone leads to bone death. This is called avascular necrosis and osteonecrosis.
Cortical bone	Main construction of the shaft of the femur.
Dislocation, congenital hip	The abnormal formation of the hip joint in which the ball at the top of the thigh bone (the femoral head) is not stable within the socket (the acetabulum). The ligaments of the hip joint may also be loose and stretched.
Dysplasia	Abnormal in form. Dysplasia is derived from the Greek *dys*- (bad, disordered, abnormal) and *plassein* (to form). For example, retinal dysplasia is the abnormal formation of the retina during embryonic development.

Electrophoresis	Gel electrophoresis is a method that separates macromolecules — either nucleic acids or proteins — on the basis of size, electric charge, and other physical properties.
Ethylene oxide	Ethylene oxide is a colourless liquefied gas with a sweet odour used for the sterilisation of implants and equipment within a steriliser/autoclave.
Extension	Movement that increases the angle at a joint.
Fixation, internal	A surgical procedure that stabilises and joins the ends of fractured (broken) bones by mechanical devices, such as metal plates, pins, rods, wires or screws.
Flexion	Movement that decreases the angle at a joint.
Fracture	A fracture is a break in the bone or cartilage. It usually is a result of trauma. A fracture can, however, be the result of an acquired bone disease such as osteoporosis or the result of abnormal formation of bone in a congenital bone disease such as osteogenesis imperfecta ("brittle bone disease").
Hydroxy-apatite	Plasma-sprayed calcium phosphate coating that is bio-active.
Izod impact strength	Material test that provides toughness data under dynamic rather than static conditions (Shigley & Mischke, 2003).
Lateral	Side of the patient.
Lysis	Destruction. Haemolysis (*haemo-lysis*) is the destruction of red blood cells with the release of haemoglobin; bacteriolysis (*bacterio-lysis*) is the destruction of bacteria; and so on. Lysis can also refer to the subsidence of one or

more symptoms of an acute disease as, for example, the fever of pneumonia.

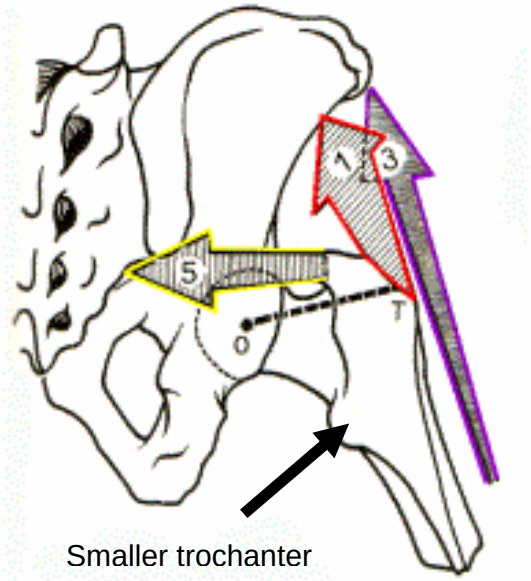
Osteoarthritis

A type of arthritis caused by inflammation, breakdown, and eventual loss of cartilage in the joints. Osteoarthritis is also known as degenerative arthritis. Osteoarthritis can be caused by ageing, heredity, and injury from trauma or disease. The most common symptom of osteoarthritis is pain in the affected joint(s) after repetitive use.



Osteolastic

A pathological condition resulting from accumulation of acid or a loss of base in the body; characterised by an increase in hydrogen ion concentration (decrease in pH). Has various causes including several states that produce excesses in various acids; included are diabetes mellitus (keotone bodies), renal insufficiency (phosphorus, sulfuric and hydrochloric acids), respiratory disease (carbonic acid), and prolonged strenuous exercise (lactic acid).

Osteolysis	Also called particle disease, aggressive granulomatosis. Particulate debris from wear of arthroplasty components, most commonly polyethylene component (Schmalzried et al.,1997). Large pieces sequestered in fibrous tissue.
Osteotomy	Osteotomy is an operation in which a bone is cut, enabling a surgeon to reposition it. An osteotomy may be performed to lengthen or shorten a leg, to correct bowed or bent legs, or to reset a fracture.
PMMA	Polymethyl methacrylate — a thermoplastic polymer synthesised from methyl methacrylate and used as bone cement for the fixation of implant.
Smaller trochanter	 Smaller trochanter
Posterior	Back of the patient.
Rheumatoid arthritis	An auto-immune disease that causes chronic inflammation of the joints, the tissue around

the joints, as well as other organs in the body. Auto-immune diseases occur when the body tissues are mistakenly attacked by its own immune system. The immune system is a complex organisation of cells and antibodies designed normally to "seek and destroy" invaders of the body, particularly infections. Patients with these diseases have antibodies in their blood which target their own body tissues, where they can be associated with inflammation. Because it can affect multiple other organs of the body, rheumatoid arthritis is referred to as a systemic illness and is sometimes called rheumatoid disease. While rheumatoid arthritis is a chronic illness (meaning it can last for years), patients may experience long periods without symptoms.