

Chapter 2

Arthroplasty of the Hip: A New Operation

From Low Friction to Low Frictional Torque

“In a design of a load bearing joint I have rather lost interest in the coefficient of friction between the materials of the rubbing surfaces as a guiding factor in design. It is possible to circumvent the coefficient of friction by concentrating on low-frictional torque in the assembled unit by reducing the diameter of the ball” ... “It was pointed out to me that the best engineering practice would be to use the smallest diameter ball which could cope with the expected load. Resistance to movement of the head in the socket is greatly reduced by reducing the radius of the ball and therefore reducing the “moment” of the frictional force. If, at the same time, the radius of the exterior of the PTFE socket is made as large as possible, the “moment” of the frictional force between the socket and the bone will be increased and this will lessen the tendency for the socket to rotate against bone. The result of reducing the size of the femoral head was to prolong the period during which the success was absolute.”... “Since there was no way of estimating rigours of service in the human hip joint over a period of years, we had to proceed by trial and error ... from the starting size of 41.5 mm diameter ... this was first reduced to 28.5 mm then 25.25 mm and finally to 22 mm” (actually 22.225 mm or 7/8 in.) (1966) (Fig. 2.1). Charnley worked with the then standard Imperial System. The first recorded LFA using 7/8 in. (22.225 mm) head diameter in the Charnley Hip Register is dated 29.09.1960. “Fluon socket arthroplasty – left hip – using 7/8 in. prosthesis long neck.

It is this change of concept from “low-friction” the property of the materials to “low-frictional torque” the principle of the design, that marks the fundamental turning point in the evolution of the low-frictional torque arthroplasty; henceforth referred to as the Charnley LFA (Fig. 2.2).



Fig. 2.1 Reducing the diameter of the head of the femoral component from 41.5 down to 22.225 mm

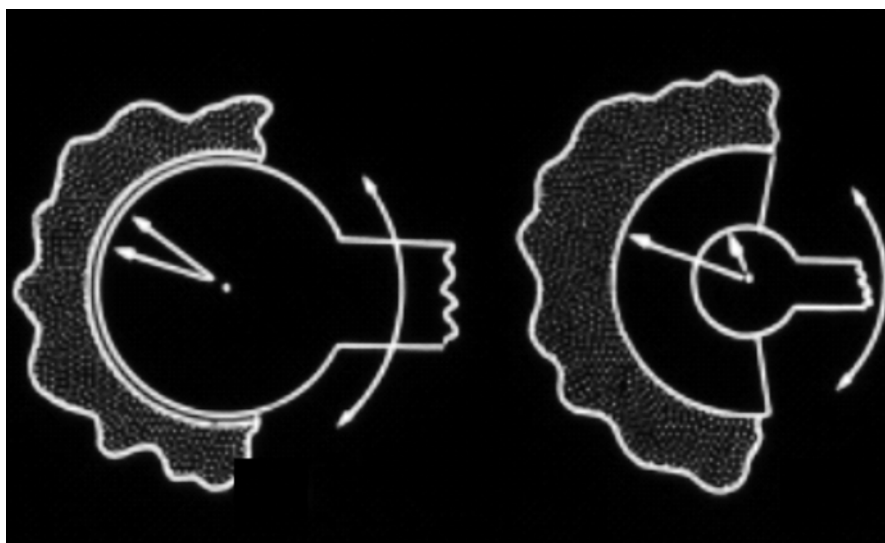


Fig. 2.2 Low frictional torque principle. Difference in the radii of small femoral head with socket of maximum external diameter

Charnley, however, continued using PTFE as the material for the cup. Charnley discussed “*low frictional arthroplasty*” and its application in rheumatoid arthritis, geriatrics and as a primary procedure in fractures of the neck of the femur. Detailing the operative technique Charnley states “*a low-friction socket in Teflon ... cemented in position using cold-curing acrylic cement*”. (1965) [1].

The “Teflon Era”

Charnley’s experience with Teflon is, unfortunately, better known for the failures than the contributions made to the development of hip replacement. It was during that period that the design of the components, *“the mechanical details of the technique became stabilised in the period 1959–1962 in the Teflon era ...”* (1971) wear characteristics and tissue reaction to PTFE wear particles, histology of bone-cement interface were established. Material suitable for the cup was the one missing link.

Kamangar et al. [2] studied 100 PTFE “pressfit” cups in an attempt to find information supporting the low-frictional torque principle. Majority of the cups, 72, were articulating with the 22.225 mm diameter head, 12 with 25.25 mm, 12 with 28.5 mm and 4 with 41.5 mm diameter heads. Of the 100 cups 58 were not completely worn through; 39 were articulating with 22.225 mm, 11 with 25.25 mm, 6 with 28.5 mm and 2 with 41.5 mm diameter heads. Charnley could not have hoped to find the information he was seeking: Long term successful results would not have been possible, all cups were taken from revisions, they were worn and loose, numbers were small and follow-up short to allow comparison of results with various head sizes. Yet, even when examining failures, Charnley did find very valuable information.

“The most serious aspect of the failure of PTFE was the production of tissue reaction by wear debris”

“wear of the PTFE socket seemed to be more dependent on the activity of the patient than the weight ...”

“... the wear of the plastic sockets took place by the steel ball boring into the substance of the plastic to make a cylindrical pathway of the same diameter as the steel head ...”

“the rate of volumetric wear found must be directly proportional to the diameter of the sphere...”

“It is concluded that, from consideration of the geometry and the wear characteristics of metal spheres in plastic sockets, the sphere should have a diameter not greater than half that of the external convex diameter of the socket.” (1969); the fundamental basis of the Charnley concept.

The most important, and probably the least known observation, was that the operation was immediately successful – freedom from pain was complete. Patients were prepared to accept further surgery even if the freedom from pain was no more than several years.

The operation had to be abandoned because of rapid wear of the PTFE cups and gross destruction of bone. During this period of despondency cemented Thompson hemi-arthroplasty was used in some cases where the relatively well preserved acetabulum permitted. Such cases were relatively few.

It must be appreciated that by the time PTFE was abandoned the concept of the low-frictional torque arthroplasty was fully established. Not only that – the design and methods of manufacture of the components, including the lapping and polishing

of the 22.225 mm diameter head in EN58J stainless steel, but also a full range of instruments and the details of surgical technique were in place. Documentation of clinical assessment, operative details and the study of results of this type of surgery and the Hip Register were also fully established. The one missing link was suitable material for the cup.

Statements, Comments and Lessons from the Past: Extracts from Charnley's Hip Register 1959–1961

31.03.60	Revision of double cup left hip arthroplasty. <i>"This confirms the impression that the second operation is, by and large, disappointing"</i> .
29.09.60	<i>"Fluon socket arthroplasty left hip using 7/8 in. prosthesis long neck"</i> . (First recorded case using 7/8 in. (22.225 mm) diameter stainless steel head).
15.06.61	Disarticulation left hip: <i>"This case demonstrates the disastrous effects of sepsis in implant prosthetic surgery."</i> (The only such case).
22.11.62	<i>Low friction arthroplasty Cup: NEW 1 7/8 in..</i> (First documented UHMWPE Cup).

Ultra High Molecular Weight Polyethylene as the Material for the Cup

"I was not interested and said so in no uncertain terms. But my technician (Harry Craven) hating to see the apparatus idle, and unknown to me, loaded the apparatus with four specimens of the new material. After three weeks of day to day running, the test had not worn as much as we would have expected in one day using polytetrafluoroethylene. From that moment the game was on."

"I am rather optimistic about the properties of the new plastic High Molecular Weight Polyethylene. The coefficient of friction is not particularly low but by mechanical design, the frictional resistance of the unit can be made very low." (Charnley recalling events in 1974) (Fig. 2.3)

Information gathered from various sources, including a representative of the distributor, would suggest that ultra high molecular weight polyethylene was introduced, into the UK from Germany, sometime in 1960. It was the result of a combination of factors: the protection of buffalo in the United States and the advent of man-made fibre. Buffalo hide was hitherto used in industry for the manufacture of conveyor belts and washers; the animal was now being protected. Fine, regular texture of man-made fibre was readily spoiled by inclusion of hide shards; High molecular weight polyethylene was the alternative and also very suitable for the manufacture of gears. Charnley "... was assured by the manufacturers of RCH1000 that this product contains no more than 100 ppm of impurities comprising retained

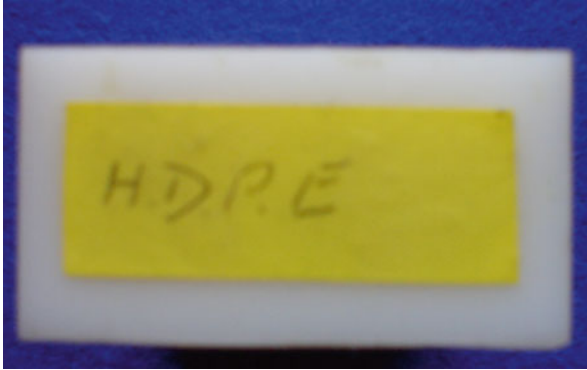


Fig. 2.3 Specimen of high density polyethylene from 1962

catalyst of metallic chlorides (aluminium, titanium, sodium and potassium). The anti-oxidant has not been divulged by the manufacturer." (1974) There is no record detailing the quality of UHMWPE as used in clinical practice from the time of its introduction in November 1962. The first HDP cup was implanted on 22/11/1962. What is documented is the source of the material: "*The high molecular weight polyethylene came from the same source as the early series.*" (1978): there was continuity of the supplier and with it, presumably, of the manufacturing process and, therefore, consistency of the quality of the material.

During the period November 1962–March 1967, the cups were machined by Harry Craven in Charnley's workshop. The machined cups were washed, soaked in formaldehyde overnight, and washed again before implantation. Whether this process had any effect on the wear rate of the UHMWPE is not known. (In the 135 hips replaced between 1962 and 1965, the mean penetration rate was 0.15 mm/year at a follow-up of 9–10 years. Comparable results have been obtained in subsequent series).

From March 1967 the production of UHMWPE cups was taken over by Charles F Thackray, Leeds, U.K. and from then on the cups were sterilised by gamma irradiation, in air.

From 1998 UHMWPE cups had been gamma irradiated in nitrogen. If some confusion occurred in the early stage it is probably because the product material was labelled, for a short period of time, incorrectly, as PTFE although it was in fact RCH1000.

Acutely aware of problems with PTFE, Charnley continued detailed studies of UHMWPE wear. In the 1967–1968 series, 547 LFAs were included with a mean follow-up of 8.3 years (range 7–9 years) "*the average wear (total penetration) was 0.59 mm representing an annual average rate of 0.07 mm/year*" (1978).

The information obtained from the study led to the following conclusions:

Gender: "*males appear to be more likely to show greater wear than females*"

Age: "...there were no significant differences in the age group of patients showing mild to intermediate wear...the incidence of heavy wear was more directly related to the age of the patients."

Weight: "There was ... no direct correlation between the weight of the patient and the amount of wear."

Function: "... there is evidence that physical activity in young male patients is associated with high wear rates ... it appears that unless the function is grade 6 (normal) for several years heavy wear does not occur." These findings confirmed the information previously gathered with PTFE.

Surface finish of the head of the femoral component: "*The arthroplasties ... performed in 1966 were excluded (from the 1978 study) because during 1966 the source of femoral prostheses has changed from those where the head had been finished in our experimental laboratories to those finished professionally.*"

Sphericity and Surface Finish of the 22.225 mm Diameter Stainless Steel Head

There is documented evidence that both sphericity and surface finish of the metal head were of special interest to Charnley; comparisons with other designs were frequently made in the Biomechanical Laboratory at Wrightington Hospital. Once the manufacture was taken over by Charles F Thackray, Leeds, U.K. in 1967 it became their responsibility to comply with the set standards. It is not clear what, if any, standards were laid down at that stage. What is clear, however, that the British and International Standards, established later, were not only achieved but also maintained in clinical practice, when stems taken from revisions, were examined.

Compared with rapidly wearing PTFE, UHMWPE did not appear to pose any foreseeable problems, certainly not observed in the early results. There were other issues to be addressed – fractured stem presenting as a sudden failure. It was those cases that demanded immediate attention. Questions concerning materials, design and surgical technique of stem fixation had to be addressed urgently. With increasing follow-up it became clear that wear and loosening of the UHMWPE was the most likely long-term problem – as predicted by Charnley: "...*The late failure, if it does eventually supervene, is to be expected from one, or both, of the two possible causes: Tissue reaction to particles abraded from the bearing surfaces; and mechanical loosening of the cement bond in the bone.*" (1961).

Acrylic Cement

"The crux of this operation ... lies in the use of cement. By means of cement the load of the body weight is distributed over a large area of bone"

“Acrylic cement does not adhere to bone like glue it merely forms an accurate cast of the interior of the bone so that the load is transmitted evenly over all parts of the interface between cement and cancellous bone.”

“I was not the first to use acrylic cement in attempting to bond orthopaedic implants to bone, but I was the first to use it successfully.” (1963)

These statements summarize succinctly all the aspects of the technique of component fixation using acrylic cement. The challenge now was to translate the concept into practical solutions through the study of materials and designs, but above all, the surgical technique based on the initial premise.

Bone Cement

Bone cements are based on methylmethacrylate (MMA), an ester of methacrylic acid. The original work of Otto Rohm led to the development of MMA dentures. The first “clinical” application of polymethylmethacrylate (PMMA) was an attempt to close experimentally produced cranial defects in monkeys, followed by its use in humans.

Degussa and Kulzer (1943) quoted by Kuhn [3] established a protocol for the chemical production of PMMA. Kiaer [4] and Haboush [5] are reputed to have been the first to use acrylic cement for component fixation. In both these attempts the acrylic cement was confined to the cancellous bone of the proximal femur.

Tissue reaction to PMMA was studied by Henrichsen and colleagues [6] and Wiltse and colleagues [7].

The Femur

In the 3 years following the original report Charnley had inserted 455 prostheses using acrylic cement. Six necropsy specimens were available. The histological appearances on the femoral side were encouraging “... *no sclerosis of cancellous bone ... cancellous bone repaired ... normal appearance of the cellular content of narrow spaces ... no fibrosis.*” (1964)

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