HISTORICAL ARTICLE

Sir John Charnley (1911-1982): Inspiration to Future Generations of Orthopaedic Surgeons

SM Donald

Senior House Officer, Wishaw General Hospital, Wishaw, Lanarkshire, ML2 0DP

Correspondence to:
52 Strathspey Avenue, East Kilbride, Glasgow, G75 8GN

ABSTRACT
For young doctors embarking on a career in medicine, the decision on which path to take is often influenced by their experiences as an undergraduate student and, in particular, by those doctors and teachers who have stimulated and encouraged them. Likewise, inspiration can be derived from studying the life and work of eminent practitioners of the past. A final year elective module provided me with the opportunity to undertake a detailed critique of an aspect of the history of medicine of my choosing, which enabled me to investigate the history of hip replacement. This opened my eyes to the prodigious contribution of Sir John Charnley in the field of orthopaedics. His commitment to the practice and advancement of medical science is indeed an inspiration. This account of John Charnley's work is a testimony to the lifetime achievements of one man, whose hard work and dedication have brought enormous benefit to generations of patients the world over.

Introduction

In 1999, the medical journalist, James Le Fanu, began his third book, 'The Rise and Fall of Modern Medicine' by identifying the most important discoveries of modern medicine – his '*twelve definitive moments*'. Alongside the discovery of penicillin and the birth of the intensive care unit, he recognised the '*singular achievement*' of Sir John Charnley in the development of his total hip replacement.[1] Le Fanu claimed that Charnley's contribution to medicine, more than any of the other definitive moments, '*conformed to the commonly accepted view of how science works*'. He took a problem, namely that of the osteoarthritic hip, focussed on the anatomy, physiology and pathology and through experimentation, hard work and a degree of good fortune, devised a solution which was to stand the test of time. Variations on Charnley's total hip replacement (arthroplasty) are now amongst the commonest operations in orthopaedics with 40,000 hip replacements being conducted every year in the United Kingdom alone.[1] In one recent study of almost 8,000 over-65 year olds, 5.3% had had at least one hip replaced with 1.5% having had bilateral total hip replacements.[2]

The Early Years: The Importance of Joint Lubrication Theory

John Charnley was born in Bury, Lancashire on 29th August 1911. He started his training as a doctor in autumn 1929 when he was accepted by the University of Manchester to study medicine. He was an extremely able student, receiving several prizes during his undergraduate career and even acquiring the Fellowship of the Royal College of Surgeons of England (FRCSEng) in his first year as a doctor - a quite remarkable feat. At the outbreak of war Charnley volunteered for army service, enlisting in the Royal Army Medical Corps. He served in the Middle East and North Africa for much of the war before returning to England shortly after D-Day. It was this war-time experience which, in part, sparked his interest in orthopaedics. In 1947, following the retirement of his mentor, the well known orthopaedist, Sir Harry Platt, Charnley was appointed Consultant Orthopaedic Surgeon at Manchester Royal Infirmary and, shortly thereafter, visiting orthopaedic surgeon to Wrightington Hospital, near Wigan.[3] During the following years he produced his two most well known textbooks, 'Closed Treatment of Common Fractures' in 1950 and 'Compression Arthrodesis' in 1953. It was after these publications, in the late fifties, that his interest in developing a low-friction hip arthroplasty was to gain momentum.

It is possible to speculate that the invention of the successful total hip replacement might have been delayed by many years had it not been for a chance observation by Charnley in the mid-1950s. Whilst conducting a routine outpatient clinic at the Manchester Royal Infirmary, he saw a patient who had had a Judet[1] prosthesis inserted in his osteoarthritic hip two years previously. The patient passed a comment which caught Charnley's attention. He said that his replaced hip squeaked so loudly every time he leant forward, his wife was now avoiding being in the same room as him whenever possible.[4] The squeak of the Judet implant was something with which Charnley became familiar. It seemed to occur in a large number of the patients who received a Judet implant for osteoarthritis, but never in those with femoral neck fractures. Charnley concluded that this was due to the articular cartilage being normal in patients with fractures but worn in those with osteoarthritis, often exposing the bony surface of the acetabulum. This squeak usually disappeared after a short time, which some proposed was due to improved lubrication of the joint, but Charnley was not convinced. He believed that the squeak was due to a high level of friction between the acrylic prosthesis and the acetabulum and that its disappearance was due, not to improved lubrication, but to wear and subsequent loosening of the prosthesis.[5] Charnley realised that one possible solution to developing a successful replacement arthroplasty would be to construct it of a low-friction material. It was this realisation that would eventually lead to the development of Charnley's total hip replacement.[6]

In the 1950s, the recognised theory of joint lubrication was that of hydrodynamic lubrication as proposed by MacConnaill, Professor of Anatomy at University College, Cork in the thirties. In it he inferred from various observations, that a very thin film of synovial fluid separated the two sides of the joint and that the friction present in the joint between the two surfaces was dependent on the viscosity of this film of fluid.[7] Charnley believed this theory was flawed and proposed an alternative theory of boundary lubrication, in which the quality of the substances making up the joint surfaces rather than the fluid was crucial. During the late fifties, much of his work went into proving his theory, through studying the friction developed between various surfaces. His experiments showed that articular cartilage-on-articular cartilage had the lowest co-efficient of friction, that of polished steel against cartilage was twice as great, while that of plastic or steel against bone, as had been used in most of the earlier arthroplasties, was 40 times greater. It was from this he deduced that to construct a successful total hip replacement, a material needed to be found that would give the same low level of friction as cartilage.[8,9] Such a material was identified when Charnley was introduced to polytetrafluoroethylene, or Teflon, during consultation with the plastics division of ICI about a suitable substance.[10] Visually, Teflon is very similar to cartilage, being white, semi-transparent and soft enough to be cut with a knife. Initially, Charnley tried a resurfacing arthroplasty, lining the acetabulum and coating a refashioned femoral head with Teflon. However, whilst the results at 3 months were impressive, with complete pain relief and an excellent range of movement, longer term results were poor due to avascular necrosis and resorption of the femoral head.[5] Not dissuaded by this failure, Charnley persevered with Teflon and built on other contemporaneous work to come up with an improved solution.

Refinement of the Low Friction Total Hip Arthroplasty

Most of the orthopaedic surgeons in the late 1950s who were still doing arthroplasties were replacing the femoral head with a metal hemiarthroplasty prosthesis of the type designed by Moore or Thompson. These had a metal ball of comparable size to the femoral head and a long stem that was driven down the shaft of the femur. This type of operation is still performed today for elderly patients who suffer a fractured neck of femur, but as a technique for arthritis it was poor. The prosthesis still loosened despite the long stem and, due to the weakened nature of bone in arthritis, the head of the prosthesis often eroded through the acetabulum. However, in the early fifties, two surgeons in Norwich, Kenneth McKee and John Watson-Farrar, developed a total hip arthroplasty using a modified Thompson's hemiarthroplasty and a metal cup that screwed into the roof of the acetabulum.[11,12] This metal-on-metal technique had mixed results, but it was a procedure that Charnley drew on with one major alteration. Referring back to his earlier work that identified steel-on-cartilage as having only twice the frictional co-efficient of cartilage-on-cartilage, Charnley used a Moore-type hemiarthroplasty implant similar to the one used in the McKee-Farrar prosthesis, but replacing the metal cup with a Teflon socket fixed into the acetabulum. Charnley described his initial results as '*gratifying*'. However, when discussing the technique with an engineering colleague, it became clear that an improved outcome might be expected if the smallest head possible, that was still able to cope with the load transmitted through it into the Teflon socket, was used. With a smaller head, the frictional torque (the friction developed by the twisting motion of the head in the socket) would be greatly reduced but at the cost of increased wear on the Teflon socket. However, counteracting this, the smaller head would permit the thickness of the Teflon socket to be greatly increased, which would not only protect against the effects of wear but would '*lessen the tendency for the socket to rotate against the bone*'. Accordingly, Charnley almost halved the diameter of the head from 42mm to 22.25mm. Although all these steps to minimise friction in the joint would contribute enormously to reducing the possibility of failure of the prosthesis, Charnley regarded the following final step as the most '*significant breakthrough*'.[5]

One of the key problems with the long-stemmed prostheses was their propensity to loosen due to twisting forces in the shaft of the femur. Most approached this problem by fixing the prosthesis with a variety of bolts, plates or screws, but Charnley took a different approach. In collaboration with D.C. Smith, a lecturer in Material Sciences at the University of Manchester, Charnley had been experimenting with various materials in order to improve the bond between the stem of the prosthesis and the bone of the femur. Eventually, they settled on polymethylmethacrylate cement, a compound very similar to the acrylic used by the Judet brothers to construct their prosthesis. He trialled it in Thompson and Moore hemiarthroplasties and in the few patients whose prostheses had failed for mechanical reasons, it was seen at revision that the stem was still firmly fixed in the femur. Charnley adopted this bone cement or '*grouting*' as he called it and later wrote at length about it in his third book, 'Acrylic Cement in Orthopaedic Surgery'. By 1961, after almost a decade of experimenting in the field of hip arthroplasty, Charnley felt confident enough to publish his work. He had performed 97 small head diameter, low-friction total hip arthroplasties since their invention in January 1960. The results were impressive with negligible wear of the prosthesis after 10 months, almost every patient totally pain-free and most able to '*walk the length of the ward without sticks and with only a slight limp*' by the time they were discharged eight weeks post-operatively.[5,13,14,15] Unfortunately, disaster soon struck.

Further Work Required: Discovery of High Molecular Weight Polyethylene

During 1962, after a further 200 operations had been done, it emerged that Teflon's initial promising results were short-lived. Not only was there considerable wear of the Teflon socket in a large number of patients but, more seriously, the particles of Teflon which had worn off the prosthesis caused a severe inflammatory reaction leading to loosening of the prosthesis and renewed pain in the hip. A disaster on the scale of the Judet prosthesis was only avoided through poor uptake of the procedure by other surgeons wary of yet another arthroplasty technique. Unsurprisingly, Charnley was badly affected by this. Feeling responsible, he personally performed all the difficult, time-consuming revision operations. At home, his wife described his mood as if '*everything was grey and there was an all-pervading gloom*.'[16] However, his patients did not share his sense of despair, many being delighted to have had two or more years of pain-free mobility. Charnley, heartened by this and believing the theory behind his technique to be sound, did not give up on hip arthroplasty, and in the following months experimented with new arthroplasty methods. However, just like the squeaky Judet hip ten years previously, the spark which led to ultimate success was a chance occurrence. During May 1962, Charnley's technician, Harry Craven, was contacted by the representative of a little-known German plastics manufacturer. The representative had a sample of a new plastic, High Molecular Weight Polyethylene (HMWP), that caught Craven's attention. As he was investigating the wear rates of different materials at this time, Craven took a sample to test. Charnley thought little of it on first inspection, but Craven's persistence with it was worthwhile.

'My office door opened to reveal Craven… After running [wear rate tests] day and night for three weeks [with] this new material…[it] had not worn as much as PTFE [Teflon] would have worn in 24 hours under the same conditions. There was no doubt about it: we were on.' [17]

Charnley, not wanting to expose patients to the potential of a repeat of the Teflon reaction, implanted a sample of both Teflon and HMWP under his own skin. Not only was there an initial systemic reaction to the Teflon implant, but after several months a firm, tender nodule had formed around it. In contrast, the HMWP was not painful and no nodule had formed. In fact, it could not even be definitely felt beneath the skin. This was all the proof Charnley needed.[18]

Between November 1962 and December 1965, he personally conducted 773 HMWP total hip arthroplasties, 582 in 'new' patients and 140 of them in his 'old' Teflon patients. Not wanting to risk a repeat of the failure of the Teflon arthroplasty, Charnley waited until 1972 to publish his results. They were worth the wait: 90 per cent of the patients, many of whom were previously crippled with pain, reported no pain whatsoever and the rest had only slight or intermittent pain. In addition, over 80 per cent, most of whom were capable of walking only a limited distance with sticks pre-operatively, were able to walk an unlimited distance without the aid of sticks. Charnley calculated a success rate of 92.7 per cent. Even in the more difficult revision operations, the outcomes were outstanding.[19,20] Furthermore, these results lasted. A 20-year follow-up study of 93 of these 'original' patients published in 1986 showed that over 85 per cent were still pain-free, a further 11 per cent had only occasional discomfort and nearly 80 per cent had near-normal ranges of movement.[21]

Tackling the Problem of Post-Operative Joint Infection

Charnley did not stop here. In his early work, he had identified a joint infection rate of approximately four per cent. Joint infections are a disaster in joint replacement of all types and often require the removal of all of the prosthesis. Any attempt at subsequent revision is much more time consuming than the primary operation. Surgeons had for many years made attempts to prevent bacteria getting to the surgical wound, but Charnley's aim was to eliminate all bacteria from the surgical environment instead. Charnley had started work on this even during the Teflon era. He felt the best method would be for the surgeons, dressed in full body suits, to operate in a filtered clean air enclosure. With a few modifications this "*greenhouse*", as it was dubbed, was used from 1962 to 1966. Again his results were impressive. The hourly bacterial culture count was cut spectacularly from 90 to 1.8 and the infection rate dropped to one per cent.[22,23] Further modifications reduced the infection rate further and evolutions of Charnley's design combined with the use of antibiotics have now allowed the infection rate to be reduced to 0.2 per cent.[24,25]

Conclusion

Even after he officially retired in 1975, John Charnley was still active in research into low-friction total hip arthroplasty. His devotion to work can be seen from his entry under recreation in Who's Who, which in an early edition read '*skiing two weeks per year – otherwise none*.'[26] Later, this became '*other than surgery, none*.'[27] He was in much demand to speak about his work and conducted several intensive lecture tours worldwide. Honorary degrees, prizes and fellowships poured in, but the one which meant the most to Charnley was the freedom of Bury, his hometown, which he received in 1974. Sir John Charnley, knighted in 1977, died on 5th August 1982 at the age of seventy. He left behind a legacy – the most successful operation for osteoarthritis of the hip. Needless to say, research into improving the prosthesis has continued unabated. Notable advances include the use of hydroxyapatite-coated femoral stems, which induces bone growth and provides an improved method of securing the stem,[28] and the use of a ceramic head, which has been found to have a wear rate superior to that of the metal head.[29] Notwithstanding these more recent advances, an end-result study published in 2004[30] has demonstrated the remarkable durability of cemented Charnley total hip replacements over a span of three decades, with 88 per cent of the original prostheses intact at the time of the final follow up. This is indeed a fitting tribute to the man who should surely be acknowledged as the 'father of modern total hip replacement'.[31]

REFERENCES

1.Le Fanu J. The Rise and Fall of Modern Medicine. London: Little, Brown and Company; 1999. p. 104–113.

2.Williams MH, Newton JN, Frankel SJ, et al. Prevalence of total hip replacement: how much demand has been met? J Epidemiol Community Health. 1994; 48: 188–191.

3.Wroblewski BM. Professor Sir John Charnley (1911–1982). Rheumatology (Oxford) 2002; 41: 824–825.

4.Hardinge K. The development of the Charnley low friction arthroplasty. In: Galasko CSB, Noble J, editors. Current Trends in Orthopaedic Surgery. Manchester: Manchester University Press; 1988. p. 242–245.

5.Charnley J. Arthroplasty of the hip: a new operation. Lancet. 1961; 1: 1129–1132.

6.Waugh W. John Charnley: the Man and the Hip. Berlin: Springer–Verlag; 1990. p. 101.

7.MacConnaill MA. The function of intra–articular cartilages. J Anat. 1932; 66: 210–227.

8.Charnley J. The lubrication of animal joints. New Scientist. 1960; 9 June: 60–61.

9.Charnley J. The lubrication of animal joints in relation to surgical reconstruction by arthroplasty. Ann Rheum Dis. 1960; 19: 10–18.

10. Waugh W. John Charnley: the Man and the Hip. Berlin: Springer–Verlag; 1990. p. 105.

11.McKee GK. Artificial hip joint. J Bone Joint Surg Br. 1951; 33: 465.

12.McKee GK, Watson–Farrar J. Replacement of arthritic hips by the McKee–Farrar prosthesis. J Bone Joint Surg Br. 1966; 48: 245–59.

13.Eftekhar NS. The life and work of John Charnley (August 29,1911 – August 5,1982). Clin Orthop Relat Res. 1986; 211: 10–22.

14.Waugh W. John Charnley: the Man and the Hip. Berlin: Springer–Verlag; 1990. p. 99–112.

15.Klenerman L. Arthroplasty of the Hip. In: Klenerman L, editor. The Evolution of Orthopaedic Surgery. London: Royal Society of Medicine Press; 2002. p. 16–17.

16.Waugh W. John Charnley: the Man and the Hip. Berlin: Springer–Verlag; 1990. p. 122.

17.Charnley J. Low Friction Arthroplasty of the Hip: Theory and Practice. Berlin: Springer–Verlag. 1979. p. 376.

18.Charnley J. Tissue reactions to polytetra–fluoroethylene. Lancet. 1963; 2: 1379.

19.Charnley J. The long–term results of low–friction arthroplasty of the hip performed as a primary intervention. J Bone Joint Surg Br. 1972; 54: 61–76.

20.Dupont JA, Charnley J. Low–friction arthroplasty of the hip for the failures of previous operations. J Bone Joint Surg Br. 1972; 54: 77–87.

21.Wroblewski BM. 15–21 year results of the Charnley low–friction arthroplasty. Clin Orthop Rel Res. 1986; 211: 30–35.

22.Charnley J. A clean–air operating enclosure. Br J Surg. 1964; 51: 202–205.

23.Charnley J, Eftekhar N. Postoperative infection in total prosthetic replacement arthroplasty of the hip–joint. With special reference to the bacterial content of the air of the operating room. Br J Surg. 1969; 56: 641–649.

24.Lidwell OM, Elson RA, Lowbury EJ et al. Ultraclean air and antibiotics for the prevention of postoperative infection. A multicenter study of 8,052 joint replacement operations. Acta Orthop Scand. 1987; 58: 4–13.

25.Lidgren L. Joint prosthetic infections: a success story. Acta Orthop Scand. 2001; 72: 553–556.

26.Sir John Charnley. The Times. 1982 Aug 7; Obituaries: 10.

27.Charnley, Sir John. In: Who's Who 1981. London: A&C Black; 1981. p. 462.

28.McNally SA, Shepperd JA, Mann CV et al. The results at nine to twelve years of the use of a hydroxyapatite–coated femoral stem. J Bone Joint Surg Br. 2000; 82: 378–382.

29.Wroblewski BM, Siney PD, Fleming PA. Low–friction arthroplasty of the hip using alumina ceramic and cross–linked polyethylene. A ten–year follow–up report. J Bone Joint Surg Br. 1999; 81: 54–45.

30.Callaghan JJ, Templeton JE, Liu SS et al. Results of Charnley total hip arthroplasty at a minimum of thirty years. A concise follow–up of a previous report. J Bone Joint Surg Am. 2004;86: 690–695.

31.Toledo–Pererya LH. John Charnley – father of modern total hip replacement. J Invest Surg. 2004; 17: 299–301.