The Relative Merits of Cemented and Uncemented Prostheses in Total Hip Arthroplasty

Abstract

The results of modern cemented and uncemented total hip arthroplasties are outstanding and both systems have their advantages and disadvantages. This paper aims to examine the designs of different types of prostheses, some history behind their development and the reported results. Particular emphasis is placed on cemented stem design and the details of cementing technique.

Keywords: *Cemented stem, prostheses, total hip arthroplasty, uncemented stem*
MeSH terms: *Arthroplasty, replacement, hip, joint, prosthesis, bone cements*

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Introduction

Total hip arthroplasty (THA) can be broadly divided into those hips fixed with cement and those fixed without. Cemented THA use polymethylmethacrylate (PMMA) to function as a grout, producing an interlocking fit between cancellous bone and prosthesis. Uncemented hips rely on biological fixation of bone to a surface coating on the prosthesis. Initial fixation is achieved by inserting a prosthesis slightly larger than the prepared bone-bed, generating compression hoop stresses, and obtaining a so-called "press-fit."

Debate regarding the relative merits of cemented versus uncemented hips continues today as vehemently as it has done since their introduction. Modern fixation techniques and implants using cement have resulted in better outcome than older cemented and historical uncemented series.[1] However, uncemented devices over the past 30 years have shown improved stability equal, in many cases, to cemented fixation. In spite of this, the authors' preference is to use a fully cemented hip replacement in the majority of cases and a cemented femoral stem in all cases. Our these reasons form the substance of the following review article.

Features of Cemented and Uncemented Arthroplasty Designs

Cemented stems fall into two broad categories: taper-slip or "force-closed" and composite beam or "shape-closed." Taper-slip stems, such as the Exeter stem, are collarless and have a highly polished surface finish. They achieve stability through micromotion at the prosthesis-cement interface promoting slight subsidence of the stem within the cement mantle, the generation of radial stresses, and ultimately compression at the bone-cement and prosthesis-cement interfaces.[2] Composite beam stems, such as the later versions of the Charnley Stem, aim to achieve stability through a solid bond between stem, cement and bone, maintaining the position of the stem within the mantle. Design features including rough surface finish and the presence of a collar are intended to improve stability at the prosthesis-cement interface.[2]

Cemented sockets tend to be thick-walled polyethylene cups. They usually have grooves in the outer surface to increase stability within the cement mantle, and an embedded wire marker to allow the assessment of position on postoperative X-rays. Modern designs such as the Exeter Contemporary flanged acetabular cup have PMMA spacer beads to ensure a uniform cement mantle and avoid "bottoming out" which results in a thin discontinuous cement mantle. A flange at the rim of the component aids in cement pressurization during cup insertion.

Uncemented stems exhibit a large range of designs, employing wedged, tapered, cylindrical, modular and anatomic shapes,

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and with the addition of proximal fins and ribs for added stability, and splines, flutes, and slots to reduce modulus of elasticity.[3] [Figure 1] More recently, shorter stem designs have been introduced with the aim of creating a more "physiological" loading of the proximal femur and reducing the problems of stress shielding.[4] Whatever the stem design, the aims are the same: To maximize initial stability and osseous contact, to hold the prosthesis steady while the surrounding bone adheres onto or into it, over subsequent weeks, months, or years.[5,6] Initial stability is crucial because the degree of micromotion at this stage influences the tissue that forms at the bone prosthesis interface. Micromotion of greater than 150 μm leads to the formation of fibrous tissue, between 40 and 150 μm results in a mixture of bone and fibrous tissue and below 20 μm results predominantly in bone formation.[7-9]

Uncemented prostheses are surface-engineered in one of two ways, encouraging bony interlock either by on- or in-growth. On-growth surfaces are created by grit blasting or plasma spraying hydroxyapatite (HA) onto the component to create a textured surfaced, with multiple indentations onto which bone can grow.[3,10] In-growth surfaces are created using sintered beads, fiber mesh and porous metals, which create microscopic pores into which bone can grow. Optimum pore size for bony in-growth is 50–400 μm.[11-13] Optimum percentage of voids within the coating should be 30%–50% to maintain mechanical strength.[13-15]

The potential for improved bonding, and thus stability, through coating prostheses with bioactive materials such as HA and tricalcium phosphate, has attracted increasing interest. These compounds actively stimulate osteoblasts, rather than just providing a scaffold for adherence. Some studies have shown improved weight transfer and radiographic appearance in the short term[1,16-19] while others have found no advantages.[20] No improvement has been demonstrated with regard to revision rate or long-term outcomes.[21,22]

Component coating can be complete or partial. Complete coating presents a large surface area for rigid fixation, but this may reduce loading of the proximal bone, leading to stress-shielding. Proximal coating only, channels the forces of weight bearing through the femoral metaphysis, but provides a smaller area for stable fixation. In either case, circumferential coating provides a barrier to the ingress of joint fluid and particulate debris and thus to the development of osteolysis.[18,23-25]

Uncemented sockets have porous coating over their whole circumference, with fixation using screws, pegs, or spikes to achieve initial stability. Most systems use a metal shell with a polyethylene liner fastened securely inside it. Various locking mechanisms have been designed to facilitate this. Motion between the shell and liner can be a source of particle debris, so-called "backside wear".

A Brief History of Cementing

German surgeon Themistocles Gluck (1891) who, proposed the use of bone-cement in arthroplasty. The previous year in Berlin, he had performed the first total joint replacement using a hinged, ivory prosthetic knee. He had also developed models for shoulder, elbow, and wrist arthroplasties. To secure these to bone, he experimented with a variety of materials including copper amalgam, plaster of Paris, and stone putty.[26] Although his efforts were remarkably successful in the short-term, they invariably failed due to infection or loosening, and ultimately he gave up his work on prosthetics to pursue other areas of medical research.

Pioneering work in the field of PMMA technology is credited to German Chemist Otto Röhm, who patented "Plexiglas" in 1933. In the lead up to World War One, interest in this material and its use in submarine periscopes, gun turrets, and aeroplane canopies grew significantly.[27] In 1936, the German Kultzer Company found that a mixture of methyl methacrylate monomer and ground polymer produced a dough that could be molded and polymerized to a solid mass by heating in the presence of benzoyl peroxide.[28,29] They went on to develop cold-cured PMMA, which hardens at room temperature. Following this, the use of acrylic resins for dentures and cranioplasty prostheses developed during the 1940s.[29]

During the 1950s, the use of cement in joint arthroplasty became a viable possibility. In 1951 Sven Kiaer and Knud Jansen of Copenhagen attached plastic cups to the femoral

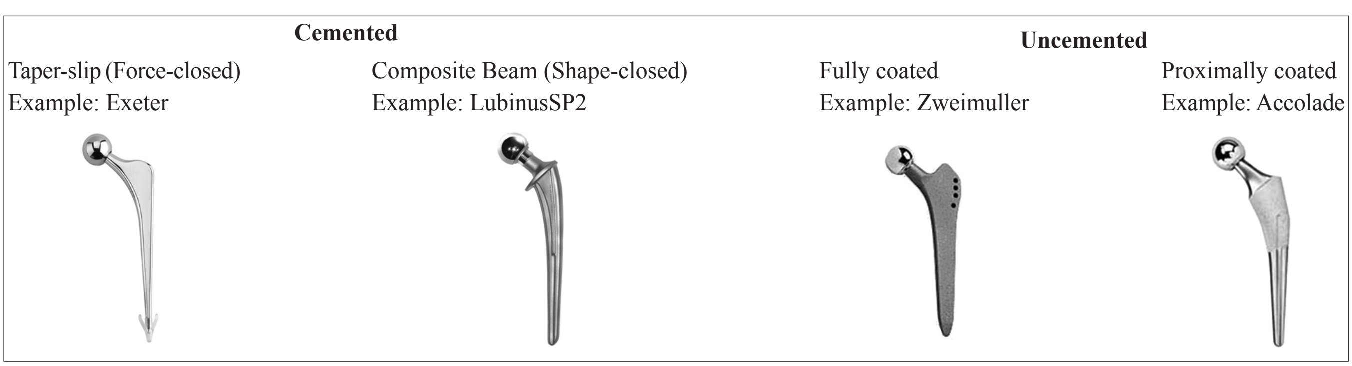

Figure 1: Examples of different cemented and uncemented femoral stem designs

head using acrylic cement. They reported their technique at an international orthopedics meeting, attended by Sir John Charnley, whose work in the area of cemented hip arthroplasty is well known.[30] In 1953, Edward Haboush, working at the Hospital for Joint Disease in New York, published a report of his work with a hip prosthesis and acetabular cup both held in place with dental acrylic.[31] It was Charnley, though, who is credited with popularizing the use of PMMA bone-cement in arthroplasty.[32] He had meticulously studied the properties of PMMA outside the body and in 1958, he performed his first arthroplasty in Manchester. In his pivotal report of his first six cases in the Journal of Bone and Joint Surgery in 1960,[33] he emphasized that the cement dough acted as a grout rather than a glue, achieving its fixation by interlock rather than adhesion, and that the cement should be forced into every crevice in the interior of the femur so that the weight of the body was dispersed over a large area of bone.[30,34]

Although Charnley's hip arthroplasties did well, with an incidence of mechanical failure at the cement-bone interface of only 2.2% at 8 years,[35] other surgeons had less successful outcomes. Unfortunately, the failure of many early, cemented, THAs was attributed to the cement itself, rather than cementing technique or implant design. Space was therefore created for the development of uncemented alternatives.

McKee and Watson-Farrar documented an early model of an uncemented artificial hip joint between 1956 and 1960. They trialed it in 40 patients and reported 51% "good" or "fair" clinical results.[36] Despite the outcomes of early uncemented THA being poor, uncemented prostheses gained favor and their use, particularly in the United States of America, increased.

In 1981, on the basis of human retrieval studies, Albrektsson *et al*. described "osseointegration" as "the attachment of lamellar bone to implants without intervening fibrous tissue."[14] It became understood that the amplitude of micromotion was directly related to the type of tissue that adhered to the prosthesis; where micromotion was very low bone would form, and where higher, it would be fibrous tissue.[7-9] It was also established that micromotion could be minimized with adequate osseous contact and firm fixation of the implant.[5] The first uncemented implant, the anatomic medullary locking implant, was approved by the American Food and Drug Administration in 1983. In 2012, 93% of THA in the US were uncemented. Despite an increasing trend toward the use of uncemented fixation, evidence is still weighted in favor of cement.[36]

First generation cementing techniques were fairly crude and involved antegrade filling of an unplugged femoral canal. The second generation introduced the use of a femoral restrictor to improve cementing pressures. Retrograde filling of the femoral canal marked the third generation of cementation. Modern, fourth generation cementation with canal plug, serial high-pressure pulse lavage, retrograde filling of the femoral canal followed by proximal pressurization and late insertion of an implant into viscous cement is widely practiced and can be considered the gold standard in modern cemented arthroplasty practice.

Properties of Acrylic Cement

Bone-cement is supplied as a powder and a liquid. The powder includes the cement (acrylic) polymer along with an initiator (di-benzoyl peroxide), a radio-opacifier (zirconium oxide or barium sulfate) and often an antibiotic. The liquid contains the monomer along with a stabilizer (hydroquinone) to prevent premature polymerization, and an activator or accelerator (dimethyl-para-toluidine) to encourage polymerization at room temperature.[37,38] As the powdered polymer and liquid monomer are mixed, polymerization occurs, and a viscous dough is formed. It is the viscosity of cement that determines its handling and working properties.

The term "bone-cement" is something of a misnomer. Bone-cement has no adhesive properties, rather, it acts as grout, forming a close mechanical interlock between the bone interstices and the prosthesis, such that physiological loads can be evenly distributed through it and transmitted to the bone.[37,39] The creation of a strong and extensive micro-interlock is the key to success with cemented prostheses. Such interlock optimizes load-carriage to the bone and reduces the amplitude of repeated cycles of loading and unloading. This, in turn, minimizes the formation of a cellular layer and subsequent fibrous tissue at the bone-cement interface, and thus the risk of loosening.[39] Clearly the success of a cemented stem depends on good surgical technique, and hence, it is perhaps reasonable to provide a brief summary of the key points.

Optimum Cementing Technique

The excellent survival rates seen with modern cemented THA are due to rigorous implementation of modern cementing techniques. Optimizing the mechanical interlock at the bone-cement interface can be achieved by ensuring good cement penetration secondary to good pressurization.[40-44] Experiments in Exeter[45] and elsewhere,[46,47] confirmed that improved cementing is associated with better postoperative radiographs.

In the early days of hip replacement, little significance was attributed to the technique of cementation. Work from Robin Ling in Exeter and John Charnley in Wrightington furthered understanding of the mechanical properties of bone-cement and the importance of surgical technique in improving outcomes in THA. It became clear that to deeply and densely interdigitate cement into trabecular bone, and to form a strong mechanical interlock, effort had to be made to first clear the bone interstices of fat and blood. Viscous cement could then be inserted into dry, clean bone and pressurized, maintaining the pressure, before, during and after the insertion of the prosthesis. The key stages are as follows: Before cementation and indeed after each instrumentation of the femur, the femoral canal is cleaned with pulse lavage and suctioned, to remove fat, blood, and other debris. Brushes are not used as this risks damaging the strong cancellous bone into which cement is inserted. Lavage is also important to reduce the pulmonary physiological disturbance and embolic load, and it should be carried out before any instrumentation of the medullary cavity.[48-52] Following lavage, the femoral canal is plugged at an appropriate depth using a well-fitting cement restrictor. This ensures good filling and pressurization and reduces physiological disturbance during cement and prosthesis insertion.[53,54] Gauze soaked in saline or hydrogen peroxide is then packed into the femoral canal while the cement is being prepared.

Cement is mixed in a vacuum for the purpose of fume extraction.[37] Vacuum mixing also serves to reduce cement porosity, but, although reference is often made to this fact in the literature, it has little effect on fixation (porosity predominantly affects the tensile strength of cement while the main force to which cement is subjected in THA is compression, in which it is strongest). Cement is introduced into the femoral canal in a retrograde manner using a cement gun with a proximal seal to maintain pressure in the femoral canal. The pressure applied to the cement has to exceed blood pressure to prevent the cement from being pushed back out of the cancellous bone by bleeding. This pressure needs to be maintained until the viscosity is sufficient to resist extrusion.

At the optimum time, usually 4–5 min into polymerization, the stem is inserted in the desired anteversion and to the preplanned depth as judged by preoperative templating. The taper design of many successful polished cemented stems came about because Clive Lee and Robin Ling, inventors of the Exeter Hip, recognized that a taper was the ideal shape to pressurize cement during stem insertion. This pressure (and also the alignment of the stem in the femoral canal), can be improved by placing a thumb over the calcar during insertion. A proximal seal is then held around the neck of the stem to maintain pressure until cement polymerization is complete.

Acetabular cementing follows the same principles. The labrum and surrounding osteophytes are removed and the acetabulum is decorticated, along with any cysts, to reveal trabecular bone. Milled bone graft is placed in cysts and on the medial wall in order to enhance fixation and to prevent cement extrusion under the transverse acetabular ligament.[55] Multiple drill holes are made to maximize macro-interlock. The bone of the acetabulum is then washed with pulse lavage and packed with a swab soaked in saline or hydrogen peroxide to create a dry surface for cementing. Cement is introduced and pressurized until it is optimal for component implantation.

Benefits of Cemented Total Hip Arthroplasty

There are a number of ways in which cemented THAs outperform their uncemented relatives:

Survivorship

At The Princess Elizabeth Orthopaedic Centre (PEOC), Exeter, we have reported excellent survivorship of cemented components in THA. Kaplan–Meier survivorship of the Exeter contemporary flanged cemented acetabular component, at 12.5 years with aseptic loosening as the end point was 100%,[56] as was survivorship of the cemented Exeter Universal femoral stem at 17 years.[57] Similar results have been reported by other units, both in the UK and internationally.[58,59]

The 2014 report from the National Joint Registry of England and Wales found Kaplan–Meier estimates of cumulative percentage probability of revision 10 years following primary operation to be 3.13 (3.00–3.26) for cemented hips, compared to 7.60 (7.35–7.85) for uncemented hips.[60] The Swedish Hip Arthroplasty Register also demonstrates superior survivorship of cemented over uncemented THAs with revision free component survival at 10 years of 94% versus 85% ($P < 0.001$).[61] No age or diagnosis group was found to benefit from the use of uncemented THA.[61]

The New Zealand Joint Registry reports that the overall all-cause revision rate is lower in cemented than uncemented THA, although, in contrast to the larger registries above, they found uncemented acetabular components performed better in the medium term (9 years) across all age groups.[62] The combined Nordic Arthroplasty Database found that in patients aged 65–74 and 75 or older, the 10-year survival of cemented implants was higher than that of uncemented, hybrid and reverse-hybrid implants. In patients aged 55–64, survivorship of cemented and uncemented implants was found to be similar.[63]

An alternative way of looking at data from arthroplasty registers is to consider the revision burden; the proportion of THAs that are revisions as opposed to primary procedures. In the United States, where the vast majority of stems are uncemented, the revision burden is approximately 18%, whereas in Sweden, where the vast majority of stems are cemented, this figure is 6%.[64] Revision burden is a particularly worthy of scrutiny when one considers that mortality following revision surgery is more than double the rate after primary surgery. Avoiding revision surgery thus has implications for the mortality associated with THA.[65-67]

A number of meta-analyses and literature reviews have concluded that cemented fixation is gold standard in THA in terms of re-operation rate in older patients[68] or in all patients regardless of age.[69,70] Two reviews looking particularly at acetabular fixation, found cemented acetabular components to have the lowest all-cause re-operation rate and to demonstrate more reliable performance beyond the first postoperative decade.[71,72]

The British Medical Journal in 2015 published a report on revision rates in THA following an analysis of registry evidence. This concludes that cemented devices have better revision performance than uncemented devices and that "greater use of cementless as opposed to cemented devices does not reflect the apparent superior performance of cemented devices."[73]

Optimum positioning

A cemented stem can be considered to be customized for the patient and can be used in almost all situations, including where there is femoral deformity. The cement mantle allows components to be positioned optimally with respect to the patient's anatomy and leg length. Version and offset can all be altered independently to ensure good restoration of anatomy and a stable, well-functioning hip replacement.[64]

Specific bone physiology

Cemented components are especially beneficial in osteopenic or osteoporotic bone where deeper penetration of cement provides excellent fixation across a wide surface area, in irradiated bone where biology may be impaired, and in the Dorr C stovepipe femur[74] where the enlarged metaphyseal region makes it difficult to gain adequate purchase with an uncemented component.[64] Cement also allows the local delivery of antibiotics where indicated. Uncemented stems are less forgiving and may be contra-indicated where bone stock and quality are poor, or where there is abnormal proximal femoral morphology.

Short-term clinical outcomes

While discussion of survivorship and revision reflects the long-term performance of THA, the patients' experience in the short-term is also of utmost importance. Uncemented stems are associated with a significant risk of thigh pain due to a modulus mismatch between the stiff cobalt chrome stem and the more compliant cortical and cancellous bone.[36,64] Multiple studies have demonstrated better pain relief and short-term clinical outcomes, including earlier weight bearing, with cemented THAs. A detailed review of these can be found in the meta analysis of randomized controlled trials comparing cemented and uncemented hips by Abdulkarim *et al*.[75] Some studies have found contrary results; however, a recent review by Rolfson *et al*. of patients on the Swedish Hip Arthroplasty Register found patient reported outcome measures in the 1st postoperative year were better in uncemented than cemented hips.[76]

Peri-prosthetic fracture

Thien *et al*. studied the incidence of periprosthetic fracture around the femoral component in cemented and uncemented hips in the 2 years following implantation. They found a rate of 0.07% for cemented stems and 0.47% for uncemented stems; a relative risk of 8.72 (95% confidence interval, 7.37–10.32); $P < 0.0005$, albeit in the context of a low absolute risk.[77]

Femoral impaction grafting

Femoral impaction grafting works better in cemented THA. A medium-term follow-up of 100 stems using a long stem proximally coated uncemented prosthesis demonstrated a 50% failure rate and 10% incidence of aseptic loosening.[78] In contrast, a series from PEOC, using polished-tapered stems and the technique described by Steele *et al*.[79] found a rate of aseptic loosening of 1%.[80]

Ease of revision

Revising cemented polished taper-slip THAs is relatively straightforward. If access is needed to the acetabulum then the stem can easily be knocked out and a new stem re-cemented into the original mantle at the end of the procedure.[64] If the stem requires revision to allow change in version or offset, this can be done using the cement-in-cement technique.[45]

Costs

Uncemented prostheses are generally more expensive than cemented or hybrid options, and their increasing use has contributed to a large increase in the cost of THA. Pennington *et al*. who carried out a cost-analysis study concluded that uncemented prostheses do not improve health outcomes sufficiently to justify their higher costs.[81]

Concerns Regarding Cemented Total Hip Arthroplasty

Bone-cement implantation syndrome and mortality

Bone-cement implantation syndrome (BCIS) is a poorly understood phenomenon that currently has no agreed definition.[82] It is characterized by a number of clinical features from hypoxia, hypotension, and cardiac arrhythmias to increased peripheral vascular resistance and cardiac arrest.[83] It is most commonly associated with, but not restricted to, hip arthroplasty, where it generally occurs at one of five stages femoral reaming, acetabular or femoral cement implantation, insertion of the prosthesis, and joint reduction.[83]

The pathophysiology of BCIS is unclear. Initial theories focused on the release of methyl methacrylate into the circulation causing vasodilation. More recent research has suggested micro-embolisation of fat, forced out of the marrow and into the bloodstream. Several other mechanisms including histamine release,[84] complement activation,[85] and endogenous cannabinoid-mediated vasodilatation have also been proposed.[86]

While there is no clear evidence with regards the effect of anesthetic technique on BCIS, the general principles of management include pre operative identification of high-risk patients, optimization of their cardiovascular reserve before surgery and intra operative maintenance of normovolemia and high inspired oxygen concentrations.[82] BCIS is a reversible time limited phenomenon so aggressive resuscitation and supportive treatment are essential to reduce associated morbidity and mortality.[82]

There is no accurate data regarding rates of BCIS in hip arthroplasty but overall mortality rates have been studied. Sierra, in his review of mortality and contemporary cementing techniques during cemented THA with the Exeter stem, reported one operative death in a series of 9082 total hips over a 17-year period: A 0.01% prevalence of sudden death. With current contemporary cementing techniques and a specialized anesthetic protocol, he suggested the incidence of sudden death during cemented THA should be "near zero."[87] Pennington *et al*. found no difference in mortality following THA across prosthesis types after adjusting for potential confounders (age, sex, American Society of Anaesthesiologists grade, body mass index, articulation type, funding source, and date of surgery). The hazard rate for mortality after total hip replacement using cemented versus uncemented prostheses was 1.01 ($P = 0.75$).[81] Jämsen *et al*. in their review of the Finnish hip registry showed no difference in mortality in 4509 octogenarian patients having cemented, uncemented and hybrid hip replacement for primary osteoarthritis.[88] Hunt *et al*. revealed, using data from the National Joint Registry of England and Wales, that the use of cement was unrelated to mortality in 409096 patients undergoing total hip replacement.[89] Costa *et al*. reviewed 16496 femoral neck fractures treated with hemiarthroplasty or total hip replacement and showed that "overall peri-operative mortality is significantly lower when cement is used."[90] However, to achieve good outcomes, attention to surgical details as outlined above is essential.

Conclusion

Cemented THA is an operation with abundant evidence of excellent outcomes. Registry data and reports confirm excellent survivorship and low revision rates. The stem can be placed in the optimum position for a patient's anatomy with length, rotation and offset, all independently determined by the surgeon. It can be used in patients with femoral deformity, osteoporotic bone, or following radiotherapy, and in young or old alike. Short-term clinical outcomes in terms of pain relief and early mobilisation are good. Femoral impaction grafting has shown better results in combination with cemented THA, and revision in cemented THA is straightforward using the cement-in-cement technique.

Many of the reasons that may have caused surgeons in the past to move away from the use of cemented implants have been found to be unwarranted and the evidence does not support the increasing using of uncemented implants. In particular, the risk of mortality in cemented THA has not been found to be higher than uncemented THA, and importantly in today's economic climate, economic analysis confirms that cemented THA is a highly cost-effective option.

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