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Current concepts and outcomes in cemented femoral stem design and cementation techniques: the argument for a new classification system

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- Cemented implant fixation design principles have evolved since the 1950s, and various femoral stem designs are currently in use to provide a stable construct between the implant–cement and cement–bone interfaces.
- Cemented stems have classically been classified into two broad categories: taper slip or force closed, and composite beams or shaped closed designs. While these simplifications are acceptable general categories, there are other important surgical details that need to be taken into consideration such as different broaching techniques, cementing techniques and mantle thickness.
- With the evolution of cemented implants, the introduction of newer implants which have hybrid properties, and the use of different broaching techniques, the classification of a very heterogenous group of implants into simple binary categories becomes increasingly difficult. A more comprehensive classification system would aid in comparison of results and better understanding of the implants' biomechanics.
- We review these differing stem designs, their respective cementing techniques and geometries. We then propose a simple four-part classification system and summarize the long-term outcomes and international registry data for each respective type of cemented prosthesis.

Keywords: arthroplasty; cement; hip replacement

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Introduction

In the 1950s, self-curing polymethylmethacrylate (PMMA), also known as bone cement, was introduced in orthopaedics practice for femoral stem fixation by Edward Haboush (New York), Frederick Roeck Thompson (New York), Kenneth McKee (Norwich), John Watson-Farrar (Norwich) and Maurice E. Müller (Bern).[1–4] Cement was initially used to stabilize or fix hemiarthroplasty stems until Sir John Charnley, in the early 1960s, popularized its use in total hip arthroplasty.[5,6] Since the 1950s the designs and techniques used for cemented implants have evolved dramatically, based on biomechanical engineering principles and PMMA properties.[7–11] Nowadays there are a variety of cemented femoral implants that are used for either hemi or total arthroplasty with excellent clinical and radiographic outcomes,[12–18] but the nomenclature remains confusing. We review these differing stem designs, their respective cementing techniques and geometries, we propose a simple four-part classification system, and summarize the long-term outcomes and national joint registry data for each respective type of cemented prosthesis.

Basic science of cemented femoral stem fixation

Bone cement

Cement properties

Polymethylmethacrylate (PMMA) has been used clinically since the 1940s in various subspecialties of surgery; mainly dentistry, ophthalmology, and plastic surgery. It was introduced in hip surgery in the 1950s and is described as a synthetic self-curing material that is used to fill up space or to create an interlock.[1,19–22] PMMA, as the name implies, is a polymer of methyl methacrylate and polymerizes through an exothermic reaction. PMMA has viscoelastic properties and can undergo creep and stress relaxation.[21,23–25] Creep or cold flow is the tendency of a solid material to move slowly or deform permanently and results from long-term exposure to mechanical stress below the yield strength of the material.[21,23,24] All PMMA cement undergoes creep, this can produce movement of cement in any direction and increases with temperature and stress level.[26] Stress relaxation is the decrease in stress in response to constant strain generated in a structure.[27] PMMA tolerates compressive loads (90 MPa) better than shear forces (50 MPa) and is weakest in tension (25 MPa).[21,25] PMMA bone cement is most commonly loaded with antibiotics that are heat stable, the benefits of which are well documented in the literature.[28] Adding antibiotics to PMMA changes its mechanical properties by reducing tensile stress more than compressive stress, and studies suggest that this should not exceed 5% addition by weight.[29] The mechanism of cement failure was initially thought to be due stem–cement interface debonding,[30] but recent studies show that cement failure occurs due to crazing.[31] Crazing is time, temperature, and stress-dependent damage behaviour in polymers.[32,33] A craze is a small crack-like defect and has load-bearing capacity due to stretched fibrils connecting the opposite faces of the craze. The process of crazing is thought to be responsible for fracture propagation in cement over time.[32]

Cement viscosity

Bone cement is available in different levels of viscosity, this ranges for low to high. High-viscosity cement is widely used and has good clinical performance.[34,35] The theoretical advantages of low-viscosity cement are easier handling during cementation due to reduced stickiness, longer polymerization time, improved penetration into cancellous bone and lower curing temperature. A randomized controlled trial using radiostereometric analysis (RSA) reported no statistical difference in mean migration or in clinical outcome after 10-year follow up.[36]

Registry data

Data published from both the Nordic Arthroplasty Register Association (NARA) and the British National Joint Registry (NJR) report no statistical significance in revision rates between the different viscosity levels, but they did report higher revision rates between different brands of cement.[37,38] Higher revision rates were reported when CMW1 (Depuy-Synthes, Warsaw, Indiana, USA) and CMW3 (Depuy-Synthes, Warsaw, Indiana, USA) compared to Palacos (Heraeus, Hanau, Germany) and Simplex (Howmedica, Mahwah, New Jersey, USA) cement were used with similar implants at 10 years.[37,38] Fixation of femoral implants in cement depends on cementing technique and stem design. Modern cementing techniques are associated with significantly lower hip arthroplasty revision rates as reported in national joint registries.[14,39,40]

Femoral preparation

Meticulous femoral bone preparation is essential for long-term survivorship of cemented stems. The femur is prepared with the aim to provide a clean and stable cement interlock between the two interfaces, i.e. bone–cement and cement–implant. There are two main techniques of femoral broaching which depend mostly on the implant design. The most common technique is the standard or over-broaching technique where the implant is smaller than the same size broach used. This allows for a cement mantle of 2 mm or more depending on the implant design. Several studies based on clinical, radiological, and histological analyses, have suggested that a thin cement mantle is subjected to increased strain and may fragment.[41,42] Although clinically a thick cement mantle has very good outcome,[12,43] a recent study reported that increased cement thickness results in increased stem subsidence and migration in association with a tapered polished stem.[44] There is still a lot of debate over what constitutes an optimal cement thickness[8,45,46] and whether defects in the cement are detrimental.[47,48] Another femoral preparation technique is the line-to-line or 'French paradox' technique, where the implant inserted is the same size as the last broach used, producing a very thin cement mantle.[46,49,50] This technique is commonly associated with complete removal of the medullary cancellous bone and occasionally reaming of the canal.[49] Both line-to-line broaching and the standard technique have very good outcomes reported in the literature.[48,51,52] The cementing technique used is dependent on the implant design and implants which are designed for the standard technique tend to do worse if a line-to-line cementing technique is used.[50,53,54] Skinner et al reported survival rate of 97.2% for standard technique and a 98.8% survival rate for the line-to-line cementing technique 10 years after total hip arthroplasty.[41] They concluded that the common suggestion for the necessity of a thick complete cement mantle may be incorrect.[31]

Modern cementing techniques

Modern cementing techniques aim to improve the cement–bone interlock by thorough cleansing of the bone bed using pulsatile lavage, use of distal cement restrictor, retrograde application using a cement gun and pressurization of the cement.[55–57] Pressurization and pulsatile lavage of cancellous bone have been identified to be significant factors with regard to improved cement penetration and improved cement shear strength.[57,58] The introduction of a distal cement intramedullary restrictor allowed for cement containment and better pressurization. This resulted in improved cement penetration and better clinical outcome.[59,60] Retrograde cement application using a cement gun and sustained cement pressurization further improved the cement–bone interdigitation.[61–63] There are several clinical studies that compare outcomes of cemented stem fixation before and after the introduction of modern cementing techniques that confirm their improved benefit.[12,64–66]

Surface roughness

Studies suggest that all cemented prostheses migrate in the cement mantle.[67] The ideal surface roughness of the implant it still debatable. The original Charnley was a polished stem with an average roughness of 0.1 mm; this was later changed to an average surface roughness of 0.75 mm or higher in an attempt to improve the interlock between the cement and the implant.[68–71] Although high surface roughness improves the cement–implant interlock, it also increases wear debris if the implant becomes loose. This results in extensive osteolysis in areas of mantle defects.[72] Finite element models demonstrate that local cement stresses have a complex relationship with surface roughness and that these are not directly proportional. At roughness values of Ra = 15 μ local cement stresses are high, and beyond that local stresses were reduced due to reduced micromotions with improved interlock between the two interfaces.[73] From published studies we know that certain femoral stem types do better with a polished surface than a rough surface.[74] An example of this was the temporary change of the Exeter stem from a polished to a matt surface as part of a change to 316L steel to increase strength and reduce costs. The Exeter with matt surface has increased surface roughness to about 1 μm, while the polished stem was less than 0.1 μm.[75,76] This resulted in an increase in aseptic loosening with reported rates of up to 20%.[69,76] Similar results were found when a matt Harvard (Ra 2.2 μm) stem was compared to a smoother surface Charnley stem (Ra 0.8 μm), with the smooth surface stem having better survival rates.[77] There are rough surface stems such as the Lubinus SPII, that have an excellent outcome reported in the literature and arthroplasty registries, which demonstrates that aseptic loosening may be a multifactorial event rather than just being related to surface roughness.[18,78,79]

Stem material

Material selection for total hip arthroplasty (THA) is very important; the material must resist cyclic loading in a demanding environment and be well tolerated by the body. The material chosen needs to be corrosion resistant, have adequate material strength, be inexpensive to manufacture and be available in large quantities. Alloys of cobalt-chromium, iron and titanium are the most common metals used in hip implants. With its Young modulus approximating to that of bone and PMMA, titanium is an attractive material to be used in femoral stems. Although cemented titanium stems are known to fail earlier than their cobalt-chromium equivalent,[80,81] some authors report excellent results with different and longer stem designs.[82–86] Failure in titanium cemented stems is thought to be related to the poor wear properties of titanium and its susceptibility to crevice corrosion. There are a few reports on titanium stems exhibiting crevice corrosion but none in relation to stainless steel and cobalt-chromium.[87,88] Nowadays most cemented implants are made of proprietary cobalt-chromium or stainless-steel alloys; these are usually inert, resistant to corrosion and have excellent outcomes in the literature.[12,14]

Designs utilized in cemented arthroplasty

Cemented implant fixation design principles have evolved since the 1950s and various femoral stem geometries are currently in use to achieve this. The aim of each design is to provide a stable unit between the implant–cement and cement–bone interface. Cemented stems have classically been classified into two broad categories, *taper slip* or *force closed*, and *composite beams* or *shaped closed* designs. While these simplifications are acceptable general categories, they miss important design features, have different broaching techniques and make comparisons misleading. With the evolution of cemented implants, the introduction of newer implants which have hybrid properties, and the use of different broaching techniques, the classification of these implants into these simple categories becomes increasingly difficult. A more comprehensive classification system would aid in comparison of results and better understanding of the implants biomechanics. We propose the following classification system.

Cemented stems can be classified according to their geometry, broaching technique, and biomechanics. We define four general types based on shape, broaching technique used and biomechanics, with all four categories having a revision version (Table 1 and Fig. 1). The revision stem can be subclassified into long and short versions of the primary stem. In this classification Type 1 and Type 2 stems use traditional broaching techniques which allow for a cement mantle of 2 mm or more. Type 3 implants use a line-to-line broaching technique often referred as the ‘French paradox’ with a cement mantle of 1 mm or less. Type 4 are anatomical stems and have mixed features when compared to the other types and have a consistent cement mantle of 2 mm along the length of the stem. While future prosthesis may not fit into one of these categories, this classification system represents the great majority of the cemented stems currently in use and with long-term follow up.

Type 1

Type 1 stems, known as *taper slip* or *force closed* are tapered in two or three dimensions, double and triple tapered respectively. They are usually flat and thin in the antero-posterior plane and wide in the medio-lateral

Table 1. Classification system of cemented femoral stem design. Revision stem for each type can be subclassified into the short or long version, R_s and R_l respectively (e.g. Type 1R_s)

Classification system of cemented stem design

Type	Subtype	Geometry	General category	Description	Fixation	Cement mantle	Example
1	1a	Double taper	Collarless Polished Tapers – Force closed	Flat and thin antero-posteriorly, wide medio-lateral. Tapers distally in both planes. Polished.	Force closed	2 mm to 4 mm	Exeter, CPCS, CPT, MS-30
	1b	Triple taper		Flat and thin antero-posteriorly and narrows medially, wide medio-lateral. Tapers distally in three planes (AP, ML & medially in the axial pane). Polished.	Force closed		C-Stem
2	2a	Rounded, Flanged	Flanged and roughened – Shape closed	Round and thick with minimal tapering distally, can be flanged and have a collar.	Shape closed	2 mm to 4 mm	Charnley, Excia, Spectron EF
	2b	Tapered, Flanged		Narrowed antero-posterior, wide medio-lateral straight stems, flanged an usually have a collar.	Shape closed		Cemented Synergy, Cemented Summit
3		Single wedge	Press-fit Wedge – Line to line	Rectangular cross section. Flat stem, thin in the antero-posterior plane, wide medio-lateral straight stem. Rough or polished surface.	Shape closed, 3-point fixation	1 mm or less	Mueller, CMK, Cemented Taperloc, Quadra C, Cemented Avenir, Cemented Corail, Cemented TwinSys
4		Anatomical	Curved Anatomical	Curved, rounder, wider mediolateral than antero-posterior, posterior bow in metaphysis, anterior bow in diaphysis, inbuilt neck anteversion.	Shape closed	2 mm	Lubinus SP I and II, Olympia

Note. AP, Antero-Posterior; ML, MedioLateral.

plane. The component tapers distally primarily in the medio-lateral plane and antero-posterior plane, while in some designs medially as well.[16,43] Surface roughness in these implants is usually low with a polished surface finish.[43,75] These implants tend to have rounded edges and rotational stability is achieved through a rectangular cross-section and in some implants through the third taper.[15,16] Type 1 implants are collarless and have a distal hollow centralizer that allows a central position of the stem and controlled subsidence in bone cement. This is known to be central to the mechanical behaviour of stem of this design.[89] Subsidence of Type 1 stems, as a rule, takes place within the first two years after surgery, then becomes slower or completely stops after this time.[90] While various authors have reported continued subsidence probably throughout the entire life of the stem,[91,92] continued subsidence after the second year or more than 5 mm must be considered as definitive loosening.[93] Type 1 stems utilize force closed fixation, which means that the cement and bone are loaded principally in compression and shear forces are reduced. Furthermore, for Type 1 stems the major load component is radial compression.[7,94]

Preparation of the femoral canal requires broaching and no distal reaming. The broaches are diamond edge and serve to remove bone rather than impacting it; this leaves a bed of porous cancellous bone in the shape of the implant. The broaches are at least 2 mm bigger than the same size stem. Utilizing modern cementing techniques, this allows a cement mantle of 2 mm or more which interdigitates with cancellous bone. Attention to the native metaphyseal diaphyseal anatomy and the implant is important. In Dorr type A femurs, where the diaphysis narrows substantially, the slim distal taper of the implant may engage distally with little or no cement mantle increasing the risk of implant failure.[95]

Type 2

Type 2 stems can be rounded and tapered, and in contrast to Type 1 they have a rough surface finish; these implants are known as the *shape closed* or *composite beam* type. Type 2 implants may have an array of design features including flanges, collars and flutes. Type 2 implants are wider than Type 1 implants in the antero-posterior dimension, with rounded edges and curved or shoulder back. These design features are used to improve rotational stability and prevent stem subsidence and debonding at the implant cement interface. In an attempt to maximize the interlock between the stem and the cement, several authors have investigated the relationship between surface roughness and shear strength achieved at the interface.[96]

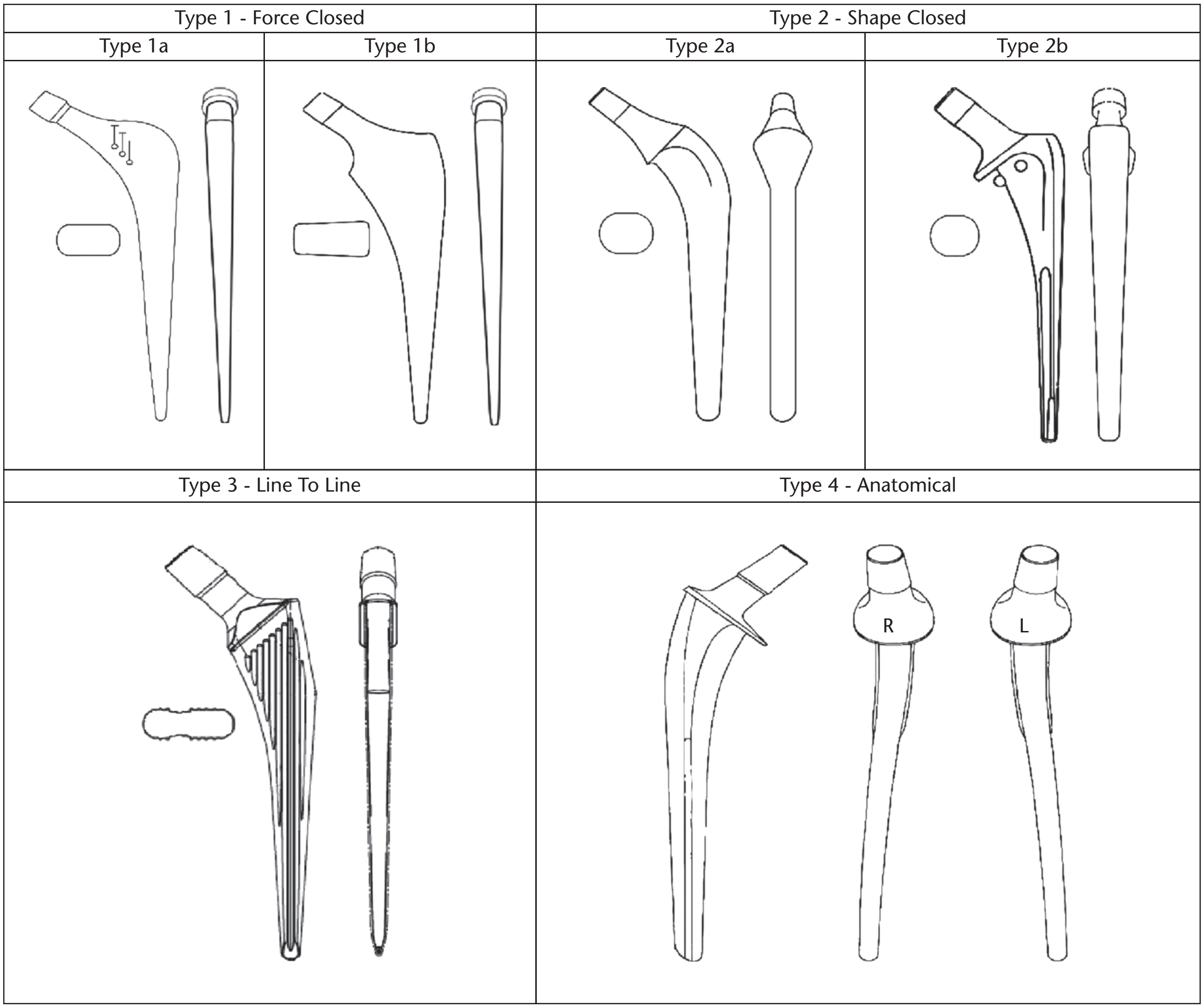

Fig. 1 Schematic diagram demonstrating the classification system of cemented femoral stem design. Revision stem for each type can be subclassified into the short or long version, R_s and R_l respectively (e.g. Type 1R_s).

Contrary to Type 1 stems, subsidence in Type 2 implants is associated with stem loosening.

Preparation of the femoral canal requires reaming and broaching, with these implants the calcar needs to be cleared with a curette to achieve optimal cement mantle in this region. Broaches tend to be of the impaction type and are used to impact cancellous bone. Type 2 implants have solid centralizers that assist stem alignment but do not allow the stem to subside.

Type 3

Type 3 cemented stems are designed to achieve a press-fit fixation in the anterior-posterior plane with a self-centring effect.[97] They are rectangular in cross-section and were originally designed with a rough surface coating. Like Type 2 stems they are used to achieve a composite structure with bone and cement. Composite beam effect in Type 3 implants is achieved with a self-centring, press-fit design, a thin cement mantle and close stem–bone contact in the coronal plane.[46] Though some implants may share similarities in their appearance, they often possess a design difference that makes them function in a manner that is dissimilar to each other. An example of this is the Charnley (Depuy-Synthes, Warsaw, Indiana, USA) (Type 2) and the CMK stem (ZimmerBiomet, Warsaw, Indiana, USA) (Type 3). Compared to the Charnley stem, the CMK has a smoother surface finish (Ra 0.04 µm), it is rectangular in cross section, has a higher caput-collum-diaphyseal (CCD) angle and is wider and thickened proximally. These differences give the CMK its press-fit, self-centring, canal-filling properties found in Type 3 implants.[48,98,99] Modern versions of Type 3 implants have low surface roughness, flutes to improve cement interlock and may or may not have a small collar. The design of Type 3 implants achieves optimum adaptation by increasing rigidity, decreasing stress peaks and minimizing micromotion.[51]

Femoral canals are usually prepared using the line-to-line technique with either impaction or complete removal of cancellous bone. Since the implant is the same size as the last broach used, these implants need to be hammered down the canal as one would with an uncemented implant.[46,48] Type 3 implants are self-centring and do not make use of a distal or proximal centralizer. Cement mantle thickness varies along the length of the stem and in some regions the stem is in direct contact with cortical bone.[100]

Type 4

Type 4 stems are curved, anatomic stems that match the femoral geometry.[10,18,78,101] Type 4 stems can have a rough or polished surface coating. Anatomic stems are three-dimensionally tapered and can have flutes and collars which enhance rotational stability and limit subsidence.[18] Both polished and rough anatomic stems work as a composite beam.[18] Their three-dimensional geometry follows the natural femoral torque and provides a natural anteversion within the implant.[101]

Standard broaching technique is used for this type of stem, which allows a constant cement mantle of around 2 mm in thickness. The anatomical shape of Type 4 stems allows them to maintain a uniform cement mantle throughout the length of the stem.[10]

Revision stems

All four types of primary cemented stems are available in revision versions which can be either a shorter or longer version of the stem with similar mechanical properties to the primary stems described above.

Results of use of cemented stems

Cemented stems are not perfect, and problems exist with both their use and the use of cement. These include loosening at either interface, stem fractures, stress shielding and proximal femoral fractures. The long-term results of successful designs of each type are presented.

Type 1

Type 1 stems are one of the original cemented stems used for total hip arthroplasty and have been the subject of many published reports. The polished collarless taper can be further subdivided into double tapers (Type 1a, Exeter, CPT) and triple tapers (Type 1b, C-Stem). Type 1 stems have been used for the past 48 years, with excellent results. Westermann et al recently published 10-year data of Exeter V40 stems with 100% survivorship for aseptic loosening.[102] Swedish Hip Arthroplasty Registry (SHAR) data from 2017 report 93% survivorship for Exeter stems (Stryker, Kalamazoo, Michigan, USA) at 12 years and 94% for MS30 stems (ZimmerBiomet, Warsaw, Indiana, USA) at 10 years.[79] The Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) reports an average revision rate at 15 years of 6.7% for the MS30 stem (ZimmerBiomet, Warsaw, Indiana, USA), 7.3% for the Exeter stem (Stryker, Kalamazoo, Michigan, USA), 6.55% for the CPT (ZimmerBiomet, Warsaw, Indiana, USA), 5.2% for the CPCS (Smith&Nephew, Watford, UK) and 13% for the C-Stem (Depuy-Synthes, Warsaw, Indiana, USA). The cumulative revision rates were dependent on the combination of stem and cup used. Certain combinations had higher revision rates than others, such as Exeter V40 – Exeter contemporary had a higher revision rate (4.5%) than the Exeter V40 – Mallory Head (2.8%) combination.[103] The National Joint Registry (NJR) of England, Wales and Northern Ireland reports an average revision rate at 14 years of 2.26% for the MS-30 (ZimmerBiomet, Warsaw, Indiana, USA), 3.93% for the C-Stem (Depuy-Synthes, Warsaw, Indiana, USA), 4.45% for the CPT (ZimmerBiomet, Warsaw, Indiana, USA) and 4.48% for the Exeter stem (Stryker, Kalamazoo, Michigan, USA).[104] Junnila et al reported from the NARA similar survival rates as other registries with 10-year survival rates of 96.6% (MS-30), 95.8% (C-Stem), 94.9% (CPT) and 93.5% (Exeter).[14] The most common cause of revision throughout all registries is aseptic loosening.

Type 1 stems are being used extensively throughout all age groups and disease process around the hip, with all reporting excellent results in both the young and the elderly. Schmitz et al reported on 104 cemented Exeter stems with a mean follow up of 13 years and survivorship of 97.1% for all causes of revision, and 100% survivorship for aseptic loosening at 10 years in patients under 40 years of age.[66] Burston et al reported 100% survivorship for aseptic loosening at 10 years follow up in patients under 50 years old in a consecutive series with a combination of 2 different Type 1 stems.[105] Lewthwaite et al reported a survival rate with an endpoint of reoperation for any reason of 94.4% at 10 years and 92.6% at a mean follow up of 12.5 years when using a Type 1 stem in patients aged 50 years or younger.[106] While Yates et al reported 100% survival rates for aseptic loosening as endpoint and 95.9% survival with revision of Type 1 stems for any reason at 10-year follow up in 191 consecutive THRs.[43]

Recently, with Type 1 stems, there is increasing concern about the increased rate of periprosthetic fracture when compared to other cemented stem types.[107–112] Grammatopoulos et al reported a case series of 21 consecutive periprosthetic fractures around Type 1 stems, 67% of cases were classified as Vancouver B2 and 29% were B1 types.[111] The B2-type fractures had common radiological and intraoperative findings: a spiral fracture with extensive fragmentation of bone and cement, debonding of cement and cement fractures. The authors found that, intraoperatively, these fractures were more difficult to manage than suggested by the preoperative radiographs.[111] In 2015, Brodén et al published on 1357 patients who underwent THA with a Type 1 stem; 3.3% of these patients sustained a periprosthetic fracture occurring within one year of surgery.[109] They have also reported that they had a higher rate of periprosthetic fractures in patients older than 80 years.[109] Data from the NJR of England, Wales and Northern Ireland show that the revision risk ratios due to periprosthetic fractures for Type 1 stems (CPT, Exeter, C-Stem) is higher (0.46, 0.12 and 0.14 respectively) compared to the Type 2 stems (Charnley, 0.07).[107] Palan et al reported that the risk of revision of periprosthetic fractures depends on the design, with some Type 1a (CPT) stems having a higher incidence than the Type 1b (C-Stem).[107] This may be related to the radius of the shoulder of Type 1a stems with the CPT stem having a smaller radius than Type 1b stems (C-stem).[107] A study by Brodén et al showed a high incidence of early periprosthetic fracture with a Type 1a stem (CPT) and suggested that this design may act as a wedge, splitting the femur following a fall.[109] This corresponds to data published by other authors which demonstrates that Type 1 stems have a higher rate of periprosthetic fracture when compared to other cemented stem types.[108,110,113–115] Overall, long-term results of Type 1 stems are excellent. These stems have proven to be reliable in both young and old patients, and for multiple pathologies.

Type 2

Type 2 stems are the second most common type of cemented stems in use. Studies have demonstrated excellent short, medium and long-term results after the use of Type 2 stems.[13,14,40,45,79,103,113] Type 2 stems are based on the design of the Charnley low friction arthroplasty and include Charnley elite (Depuy-Synthes, Warsaw, Indiana, USA), cemented Summit (Depuy-Synthes, Warsaw, Indiana, USA), cemented Synergy (Smith and Nephew, Watford, UK), Spectron EF (Smith and Nephew, Watford, UK), and cemented Excia (B.Braun, Melsungen, Germany). The Charnley low-friction torque arthroplasty has reached 42 years of clinical application. Most osteolysis in these implants was noted in Gruen zones 1 or 7. Another study by Callaghan et al reported 78% survivorship of the Charnley prosthesis at 35-year follow up.[116] Garellick et al reported 96% survival of the Spectron stem with excellent clinical and radiological outcomes at 11-year follow up.[117,118] Urschel et al reported excellent results for a Type 2 cemented stem with 99.5% survivorship at six-year follow up.[119] Callaghan et al reported a 6% rate of aseptic loosening in the Charnley implant at 25-year follow up and 90% of patients retained their original implant.[120] Smith et al had similar results with 5% revision rate of the Type 2 stem for aseptic loosening.[121] The AOANJRR reports a revision rate of 12.5% for the Charnley (Depuy-Synthes, Warsaw, Indiana, USA), and 13.5% for the Spectron EF (S&N, Watford, UK) at 15 years.[103] The British NJR reports revision rates of 5.07% for the Charnley stem (Depuy-Synthes, Warsaw, Indiana, USA) and 4.07% for the Stanmore (ZimmerBiomet, Warsaw, Indiana, USA) at 14-year follow up.[104] Overall long-term results of Type 2 stems are excellent, although there are increasing concerns with some implants that are exhibiting higher revision rates compared to others at the 10 to 15-year follow up.[14,122,123]

Type 3

Type 3 stems are extensively used in central Europe. Studies have demonstrated excellent short, mid and long-term results with their use.[51,52,124–128] Type 3 stems include the Mueller straight stem (ZimmerBiomet, Warsaw, Indiana, USA), CMK (ZimmerBiomet, Warsaw, Indiana, USA), cemented Taperloc (ZimmerBiomet, Warsaw, Indiana, USA), CCA (MathysOrtho, Bettlach, Switzerland) and, more recently, the cemented Avenir (ZimmerBiomet, Warsaw, Indiana, USA), cemented Twinsys (MathysOrtho, Bettlach, Switzerland), Quadra C (Medacta, Castel San Pietro, Switzerland) and cemented Corail (Depuy-Synthes, Warsaw, Indiana, USA). The 10-year survival rate of the Mueller straight stem ranges from 98.3% to 91.2%.[127,128] Räber et al reported 92.7% stem survival after 15 years for the Mueller straight stem, but the clinical results were influenced by high cup revision due to loosening.[129] Similar results were reported by Riede et al with a survival rate of 94% at 15 years.[125] Kerboull et al reported an overall survival rate at 20 years of 85.4% using the CMK stem in those younger than 50 years of age.[130] Similar results for the CMK were reported by Nich et al, with a survival rate of 88.5% at 15-year follow up using revision for any reason as an end-point.[131] El Masri et al reported survivorship of 94% at 17-years follow up for the CMK stem using a line-to-line cementation technique.[48] Short-term results for the TwinSys cemented stem show excellent results at two-years follow up, with 100% survival for aseptic loosening.[126] When it comes to registry data, the Müller straight stem has a revision rate of 3.7% at 14 years in the British NJR, and 2.4% at seven years in the Dutch registry (LROI).[104,132] Quadra C has a 2.5% revision rate at five years in the AOANJRR and the Covision straight stem has 93.7% survival at seven years in the SHAR.[79,103] Overall results of Type 3 stems are excellent and are a good option for younger and older patients and those with Type C proximal femoral geometry.

Type 4

Excellent outcomes have been achieved with the use of Type 4 stems.[133–137] Type 4 stems are widely used in the

Nordic countries. Type 4 stems include the Lubinus SP (Link, Hamburg, Germany) and the Olympia (Biomet, Warsaw, Indiana, USA). Taylor et al reported 99% survival for a polished Type 4 stem with a nine-year follow up.[101] Oxford Hip Scores were good to excellent in more than 90% of patients.[17] Savilahti et al reported 96% survival for a rough surface Type 4 stem with mean follow up of seven years.[138] Junnila et al have analysed the NARA for the most common cemented stems and reported 92% survival rate at 15 years for Type 4 stems.[14] Mukka et al carried out a prospective cohort study between a Type 1a and a Type 4 stem, and reported a 3.8% incidence of periprosthetic fractures for a Type 1a stem compared to 0.2% for a Type 4 stem in patients older than 80 years of age.[110] Registry data show that the Lubinus SP II has a cumulative revision rate of 2.53% at seven years in the LROI[132] and 94.2% survivorship at 11 years in the SHAR.[79] Overall, Type 4 stems have excellent results and are an excellent option for all patient types.[78,79]

Revision stems

Most of the stem types have a revision version of the stem. The revision version is available in either a long or a short version with variable outcomes. Short Type 1 revision stems are widely used across the globe due to the cement-in-cement technique popularized by the Exeter Group.[139,140] Cnudde et al analysed 1179 first-time revisions in the SHAR and reported similar survival at six years when using either a Type 1 stem (94%) or a Type 4 stem (95%) for a cement-in-cement revision technique.[141]

Conclusion

Cemented femoral stem fixation is generally associated with excellent long-term results independent of the stem type used. All stem types demonstrate broadly similar survival rates. Differences in material composition seem to affect the outcome, with cemented titanium stems having a higher failure rate. The geometric design seems to influence the incidence of periprosthetic fractures with Type 1 stems, demonstrating a higher rate, compared to other types.[14,107–110,115]

It is important for the practising surgeon to understand the various types of cemented implants since Type 3 and Type 4 stems are available both in a collarless polished surface or matt surface variety. Type 3 and Type 4 stems have different femoral preparation and biomechanical behaviour than the classic collarless polished tapers, Type 2 stems.

Failure rates have decreased with modern designs, although no type is completely free from the risk of aseptic loosening. The outcomes associated with the newer designs will need to be compared with the excellent long-term results of the classic stems. Although registry data have been extremely useful in following survivorship of different cemented implants, it is still unclear what the indications are for using one stem type over the other. The basic classification system described in this article should simplify the understanding of each type of stem and can be expanded accordingly.

Future studies

Future studies on cemented implants should address activity level, deformities and bone type. This would allow more information on when to use the different design types. It is important to report clinical findings, outcomes, complications and bone changes related to the different design type used and any new design introduced.

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