The Evolution of the Femoral Stem Design in Total Hip Arthroplasty

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Since the introduction of Dr. John Charnley's "low-friction arthroplasty" in 1962,[1] the general concepts of total hip arthroplasty have remained greatly unchanged. He laid the foundation for a predictably successful surgical intervention for an ailment previously difficult to treat. The low-friction arthroplasty featured a monoblock stainless steel femoral stem, high density polyethelene, self-curing polymethyl-methacrylate (PMMA), and aseptic technique. Although the general principles of arthroplasty have remained remarkably similar, implant design has evolved over the past 50 years. The following is a review of the evolution of the femoral stem.

Long-term results of Charnley's total hip arthroplasty, including 35-year follow-up, reflect a 78% femoral stem implant survival.[2] Patients surviving 20 years after primary total hip arthroplasty had a femoral stem revision rate of 15%. Fifteen patients of the original 330 survived 35 years after the index procedure and had a femoral stem revision rate of 47%. Over the years, numerous changes have evolved, including improvements in cement technique, changes in implant design, and a trend toward biological fixation with press-fit implants.[2]

Cementing technique has evolved numerous generations and now includes vacuum centrifugation, pulsatile lavage, pressurized cement, and distal and proximal centralizers. These interventions have led to a more uniform, symmetric cement mantle.[3] Cemented femoral stems have evolved into 2 main types of design. The "loaded taper" stems rely on the principle that cement (PMMA) functions well under compression, generating radial compressive forces and resultant hoop strength.[4] These stems characteristically "creep" up to 1 mm over the first year and subsequently stabilize. The design rationale includes a polished, round, collarless, straight, tapered stem that facilitates creep while generating minimal particle debris.[4]

Conversely, the "composite beam" cemented stem has design features that allow minimal micromotion and employ an interference fit with the bone and cement mantle. These stems typically have a rough surface, are often rectangular, can be straight or anatomic, and occasionally have a collar. Both types of cemented stems have been shown to be successful, however the design rationale must comply with the planned mode of fixation and stay true to those principles. The disadvantage of the interference fit of the "composite beam" cemented stem is that even minimal micromotion can generate particle debris and potentially result in osteolysis. This may have led to the evolution of cementless, press-fit femoral stem design.[4]

As early as 1979, Lord reported early results of an "experimental" study of an uncemented total hip replacement.[5] He stated that "living bone that undergoes remodeling provides for long-term anchor of the prosthesis."[5] The anatomic medullary locking (AML) stem was the first cementless femoral implant approved for use in the United States (US). The design featured a straight, cobalt-chrome, extensively porous coated stem that employs distal, diaphyseal fixation. The stem has an exceptional track-record, including up to 98% survivorship at 20 years.[6] Disadvantages include proximal stress shielding and occasional thigh pain.[6]

Around the same time, the porous coated anatomic (PCA) stem was introduced in the US. This cobalt-chrome stem featured an anatomic sagittal curve and proximal porous coating. Long-term results were also favorable for survivorship, including nearly 90% rate of ingrowth and a 7% femoral stem revision rate at 15 years.[7] The major disadvantage of this stem design was a high prevalence of thigh pain, up to 30%.[8,9] The concepts of the AML and PCA are still in use to this day, with slight modifications that substantially reduce thigh pain.[7]

As total hip arthroplasty is now made available for younger, healthier, and more active patients, bone preservation is essential.[10] Proximal fixation with less subsequent stress shielding has become a focus. These implant designs include double taper metaphyseal filling stems and single, "M-L" (medial-lateral) taper stems. Each of these implants relies on metaphyseal fixation and ingrowth proximal to the diaphyseal and subtrochanteric regions. A double taper design allows for "fit and fill" of the metaphysis in both dimensions, theoretically allowing more rotational support.[11] However, anatomy is variable and occasionally there is a mismatch in the sagittal and coronal dimensions of the metaphysis. The M-L taper stems increase in size, largely only in the coronal dimension, eliminating this mismatch but theoretically providing less rotational stability. Both of these stem designs have an exceptional track-record of survivorship greater than 95% at 20 years and minimal thigh pain.[12,13]

Finally, short metaphyseal stems without distal extension are also available. These address the problem of metaphyseal-diaphyseal diameter mismatch. This mismatch is often encountered in young, active patients with a "champagne-flute" femur or very elderly patients with a "stove-pipe" femur. Although no long-term outcome studies exist, there are certainly advantages and disadvantages. Advantages include the elimination of metaphyseal-diaphyseal mismatch, substantial bone preservation with no reaming and minimal broaching, ability to insert with any surgical approach, and ease of implant removal and bone conservation during revision. However, disadvantages include a concern for early stability and possible fibrous ingrowth, malposition due to lack of distal extension to guide position within the canal, and subsidence. Early studies have shown minimal blood loss, lack of thigh pain, successful ingrowth, and minimal stress shielding.[12]

In conclusion, total hip arthroplasty has become a successful operation with predictably excellent results. The general concepts remain true today just as they did 50 years ago when Charnley introduced the modern design rationale. Today surgeons have a choice of multiple femoral stem implants, each with a unique set of advantages and disadvantages. Understanding the design principles and the historical evolution is important in selecting an implant that meets the goals and expectations shared by the surgeon and patient.

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