14 Metallic Alloys in Total Hip Arthroplasty

Timothy McTighe, Declan Brazil, and Warwick Bruce

INTRODUCTION

In dealing with the vast and complex problems associated with reconstructive total hip surgery, one of our greatest allies is the use of metal for implant fabrication and replacement of damaged bone;[1] however, this requires an understanding of the biological and engineering principles involved. On occasion, these principles conflict, and a compromise must be made to provide the best possible result. Total joint surgeons addressing today's complex issues are faced with learning more engineering principles as new and more complicated issues arise. The single most important parameter for implant selection is biocompatibility. Factors that determine the biocompatibility of a metal alloy are its chemical composition and corrosion resistance. In addition, there is growing concern for metal ion release from implanted materials. Ion release is not only related to composition of the alloy; it also affects the overall corrosion resistance and the selectivity of the corrosion process concerning the implant.

MATERIAL SELECTION FOR TOTAL HIP ARTHROPLASTY

Materials selected for total hip arthroplasty (THA) are typically determined by ascertaining the intended function of an implant over the life of that part. The most suitable materials for implantation are those that are well tolerated by the body and can withstand increased cyclic loading in an ever-demanding environment, especially with the physical activities and expectations of today's patients. Often, the totality of factors that must be assessed when choosing a metal for implantation is not completely considered. Typically, the user considers only one issue, which is material strength. Other critical factors of implant selection are those not contemplated by the end user; these include corrosion resistance, availability, cost, and ability to manufacture. The latter factors are more often predetermined by implant manufacturers and are not available as an option for end users during their decision-making process.

The use of metallic alloys in THA presents a unique set of problems regarding corrosion. Early experience suggests that corrosion and the release of metal ions were linked to the use of dissimilar metals, such as cobalt-chrome alloy (Co-Cr-Mo) femoral heads coupled with titanium alloy (Ti-6Al-4V) femoral stems.[2] More recent studies have demonstrated that the level of corrosion existing with the use of Ti-6Al-4V and Co-Cr-Mo combinations is acceptable.[3-5] New observation, however, suggests that, under certain conditions, some implant designs that combine Ti-6Al-4V and Co-Cr-Mo may demonstrate corrosion.[6] Additional factors with an important role on implant performance are stress levels and distribution, tissue response, trauma at the time of surgery, and relative motion between interfaces.[2] Often, the outcome indicators of each of these factors can be at odds with one another. Although the patient can control these factors to

some extent, the outcome parameters of more patient-driven factors often conflict with those of implant designers. For example, increasing the strength of an implant typically requires changing an alloy, which can increase the implant's stiffness and change manufacturing techniques. These factors are conversely conflicted with bone-tissue response, stress shielding, and increased manufacturing costs.[3] More often, balancing these variables is a difficult multidisciplinary endeavor.

Alloys Used in Total Hip Arthroplasty

Commercially pure elements with no deliberately added alloying elements and the alloys with several elements are combined to produce one metal or alloy. Medical alloys are defined by the International Organization for Standardization (ISO) or American Society for Testing Materials (ASTM) and are the majority of alloys used for medical implant manufacturing. International regulators tend to accept only materials defined by ISO and ASTM standards. Material specifications that fall outside these standards are typically not used by manufacturers, because they require significant testing and after-market clinical follow up. The ISO and ASTM standards define broad ranges in percentage composition bands, and this tends to be where manufacturers separate and differentiate their materials. The range of ISO materials that are available to manufacturers are listed in Table 14-1; not all these alloys are commonly used in the production of THA components. In addition, many of these alloys are used in the wrought condition and processed through forging or casting into their final form, which has an effect on their material properties, as shown in Table 14-1.

There is a range of mechanical properties within the titanium alloy group, and each alloy will have its own unique electrochemical characteristics, which are important in vivo. One of the most commonly used alloys for cemented total hip femoral components is high-nitrogen stainless steel alloy per ISO5832-9 composition. Table 14-2 also defines the typical mechanical properties of this alloy in the wrought bar form before processing and in its final form. There is a significant change in mechanical properties after all processing has occurred.

There is little engineering rationale regarding which alloys are used for the various femoral components in THA. The gold standard for cemented stems is high-nitrogen stainless steel, and this selection is based on historical preference. Some companies have selected cobalt-based alloys for a similar stem design merely for market differentiation or because their manufacturing expertise is in this area of material fabrication. Cobalt-based alloys are more expensive, are difficult to fabricate, and are not proved to be more clinically successful. Ti6Al4V alloy is by far the most common alloy selected for both stem and acetabular cementless components. In terms of femoral head component material selection, cobalt chrome (Co-Cr-Mo) alloy per ISO5832-12 remains the choice because of its superior wear resistance, ease of fabrication (grinding and polishing compatibility), and proven clinical pedigree.

PROCESSES USED IN THE MANUFACTURING OF TOTAL HIP ARTHROPLASTY

There are various manufacturing techniques for producing hip components. All these manufacturing processes produce different mechanical and electrochemical properties. For example, the addition of a porous sintered coating (diffusion bonding) significantly reduces the fatigue strength of components, and they require a post-sintering heat-treatment cycle (Table 14-3). The heat treatment further changes the electromechanical properties of the alloy and should be considered in the design of mating components and high weight-bearing implants. Implant designers and manufacturers should be conscious of the effects of heat treatment and various fabricating techniques.

Drop Forging

The most commonly used technique for the fabrication of femoral stem components is drop forging. Drop forging is a process whereby a hot, predetermined billet of alloy is placed in a formed mold of the finished part and mechanically pressed into shape. The molds have two parts that enable placing the billet into the forming process. The drop forging process typically requires multiple stages to forge (squeeze) the billet into final form (Fig. 14-1).

Drop forging is favored for its enhancement to mechanical properties of the alloys and its moderate cost of production. In contrast, some manufacturers have used castings of cobalt chrome to produce femoral stem components. The properties of cast components are decreased compared with forged or wrought alloys; however, the cost of production is lower, and complex shapes can be produced with much less capital and time investment in tooling.

Cementless acetabular components are manufactured primarily from titanium alloy. The most common fabrication method for acetabular components is by machined wrought bar stock or drop forging. The latter is preferred for higher volume manufacturing in which manufacturers can realize a reduction in the cost of goods. There have been some advances in fabrication techniques of acetabular components

through cold forming techniques, such as Hybrid Manufacturing (Jossi Systems, Wängi, Switzerland). These specialized cold-forming techniques produce forged parts with the least amount of material waste, while allowing intricate detail to be realized in the finished part. Manufacturers using these techniques can realize significant reductions in the cost of formed acetabular components without any loss in mechanical properties.

Investment Casting

More traditional fabrication techniques, such as the investment casting process, are less common for THA components. The investment casting process uses a wax pattern of the part that is shelled using ceramic slurry and then hardened through a thermal firing process. The wax is melted out of the shell during the firing process, and the shell

TABLE 14-1. International Organization for Standardization (ISO) Available Materials

Standard	Description	Commonly used in total hip implants?
ISO 5832-1: 2007	Implants for surgery – Metallic alloys – Part 1: Wrought stainless steel	No
ISO5832-2: 1999	Implants for surgery – Metallic alloys – Part 2: Unalloyed titanium	No
ISO 5832-3: 1996	Implants for surgery – Metallic alloys – Part 3: Wrought titanium 6-aluminum 4-vanadium alloy	Yes, worldwide
ISO 5832-4: 1996	Implants for surgery – Metallic alloys – Part 4: Cast-chromium-molybdenum casting alloy	No
ISO 5832-5: 2005	Implants for surgery – Metallic alloys – Part 5: Wrought cobalt-chromium-tungsten-nickel alloy	No
ISO 5832-6: 1997	Implants for surgery – Metallic alloys – Part 6: Wrought cobalt-nickel-chromium-molybdenum alloy	Yes, worldwide
ISO 5832-7: 1994	Implants for surgery – Metallic alloys – Part 7: Forgeable and cold formed cobalt-chromium-nickel-molybdenum-iron alloy	Yes, Europe
ISO 5832-8: 1997	Implants for surgery – Metallic alloys – Part 8: Wrought cobalt-nickel-chromium-molybdenum-tungsten-iron alloy	No
ISO 5832-9: 2007	Implants for surgery – Metallic alloys – Part 9: Wrought high-nitrogen stainless steel	Yes, worldwide
ISO 5832-10: 1996	Implants for surgery – Metallic alloys – Part 10: Wrought titanium 5-aluminum 2.5-iron alloy	No
ISO 5832-11: 1994	Implants for surgery – Metallic alloys – Part 11: Wrought titanium 6-aluminum 7-niobium alloy	Yes, Europe
ISO 5832-12: 2007	Implants for surgery – Metallic alloys – Part 12: Wrought cobalt-chromium-molybdenum alloy	Yes, worldwide
ISO 5832-14: 2007	Implants for surgery – Metallic ALLOYS – Part 14: Wrought titanium 15-molybdenum 5-zirconium 3-aluminum alloy	Yes, Japan
ASTM F1813: 01	Wrought Titanium – 12 Molybdenum – 6 Zirconium – 2 Iron alloy for surgical implant	Yes, Stryker (TMZF alloy)

TABLE 14-2. Typical Mechanical Properties of Nitrogen Stainless Steel

Standard	Young's Modulus (GPa)	Proof Stress, (MPa)	UTS, min (MPa)	Elongation (%)
ISO 5832-3Norm		780 (min)	860	10
ISO 5832-11	105	800–905	1078	21.5

Mechanical Properties of Commonly Used Alloys						
Manganese	**Nickel**	**Chromium**	**Molybdenum**	**Niobium**	**Carbon**	**Nitrogen**
2 to 4.25	9 to 11	19.5 to 22	2 to 3	0.25 to 0.8	0.08 max	0.25 to 0.5

High-Nitrogen Stainless Steel			
	Proof Stress (MPa)	**UTS (MPa)**	**Elongation (%)**
Wrought alloy	483	923	38
After forging, heat treatment	905	1078	21.5

TABLE 14-3. Typical Fabrication Methods and Finishes for Total Hip Arthroplasty Components

Alloy	Ti6Al4V Alloy ISO 5832-3	High-Nitrogen Stainless Steel ISO5832-9	Cobalt-Chrome Alloy ISO5832-12
Production method	Forging	Forging	Forging
Applicable components	Stems* Cups	Stems*	Stems* Cups*
Surface finish	Wet blasting Coarse blasting Polished	Wet blasting Polished	Wet blasting Polished
Coatings	Hydroxyapatite Plasma sprayed Sintered particles*	N/A	Hydroxyapatite Plasma sprayed Sintered particles*
Finishing	Laser marking	Laser marking	Laser marking

*Indicates that process requires post-heat treatment.

FIGURE 14-1. *Hip stem forging steps. (Courtesy Signature Orthopaedics, Ltd.)*

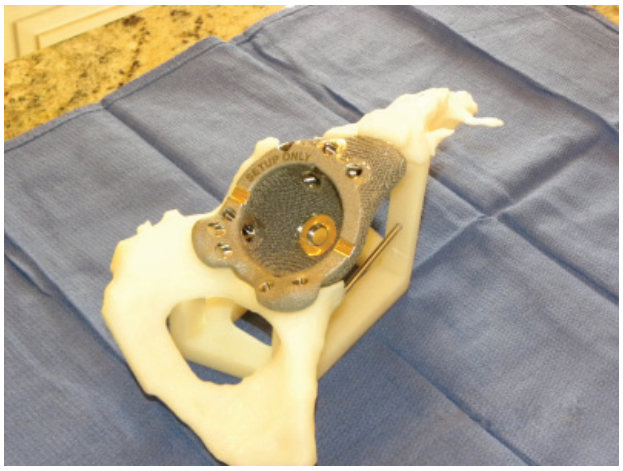


FIGURE 14-2. *Custom acetabular component that was fabricated with this EBM process. (Courtesy L. Keppler.)*

that remains is used to house liquid metallic alloy that is poured into it to produce the final part form. Investment casting techniques have evolved over the years in process control and materials, and this has led to the possibility to use "as-cast" parts with limited finishing to produce the final form. Some THA stem components are investment cast, and the majority of the stem geometry is as-cast with the taper geometry typically only requiring subsequent machining. The as-cast components are less expensive, and complex shapes can be produced. The most common material used for cast THA components is Co-Cr-Mo alloy.

Electron Beam Melting

In addition to advancements in forming techniques for acetabular components, in recent years, some manufacturers have produced acetabular components with porous structures by electron beam melting (EBM) printing techniques. EBM is identical to the rapid prototype printing technology that solidifies material powder layer by layer to create the final three-dimensional part. The EBM-fabricated parts have the benefits of reduced product lead times and cost by eliminating the separate step of applying a porous coating. These EBM-fabricated parts have been used only in low load-carrying components such as acetabular shells (Fig. 14-2).

Porosity or surface enhancement on cementless hip implants is used to provide a biologically friendly environment to facilitate bony on-growth or in-growth, which leads to long-term stability and fixation of the implant. This fixation creates a functional osseointegration by mechanical interlock between implant and bone. The surface enhancement can be accomplished with a number of methods, including defused bonding, titanium plasma spray, EBM, corundum blasting (bead, grit), and laser sintering.

Defused Bonding

Defused bonding is a solid-state process for joining metals by using only heat and pressure to achieve atomic bonding. This process is generally restricted to cobalt-chrome alloy for femoral stems because of its resistance to notching the substrate of the implant. Figures 14-3A and 14-3B show examples of a typical cobalt chrome alloy femoral stem rendering and close-up section of the porosity of the coating. The beads are bonded to each other as a result of this diffusion process, creating a three-dimensional space for interlocking of bone ingrowth.

Titanium plasma spray starts with a powder of the desired coating, which is commercially pure titanium. This powder is then fed through a gunlike device in which some form of combustion or arc is created to melt the powder and accelerate it to the substrate surface to which it sticks. The bonding strength of plasma spray is not as solid as defused bonding[7] (sintering). However, Bobyn et al.[8] and Emerson et al.[9] have reported on the effectiveness of titanium plasma spray coatings as barriers that prevent wear debris from gaining access to the endosteal surface of the femur and greater trochanter in THA (Fig. 14-4).

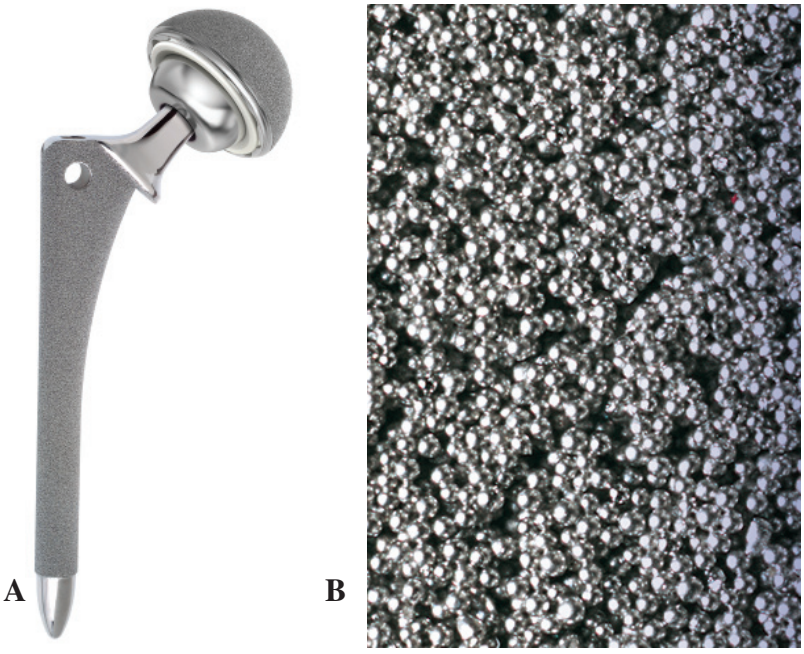


FIGURE 14-3. *(**A**) AML stem cobalt-chrome porous coated stem. (**B**) AML sintered cobalt-chrome beaded porous coated stem. (Courtesy DePuy, Warsaw, IN.)*

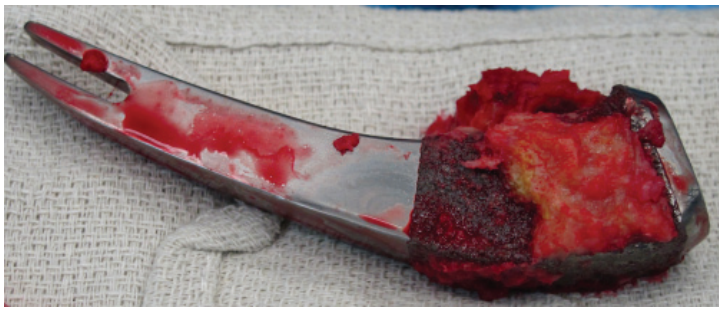


FIGURE 14-4. *A retrieved short curved titanium neck-preserving cementless stem with good bone attachment to its proximal plasma sprayed surface, CP titanium with a thin layer of hydroxyapatite coating. (Courtesy Joint Implant Surgery and Research Foundation Archives.)*

Other Methods

Corundum blasting techniques use highly pure aluminum oxide (Al_2O_3) particles that create a rough surface on titanium stems to achieve osteointegration. Some studies have suggested that contaminant particles from this fabrication process can lead to third-body wear.[10] However, there are numerous reports of grit-blasted surfaces providing mid- to long-term stable fixation.[11,12]

Direct metal laser sintering technique uses metals in a powder form. The powder is spread and processed by the action of a CO_2 laser in an inert environment and thermally controlled inside a chamber. A scanning mirror system controls the laser beam describing the geometry of the layer on the surface of the material spread. With the incidence of the laser, the particles of material are heated and reach their melting point, joining each other and to the previous layer. When the material solidifies, a new layer of powder is added, and the laser scans the desired areas again. Thus, after a layer is sintered, a new layer is deposited, and so on to finish the construction.

In the past few years, significant progress has been made in cancellous-style porous metallic implants. Zimmer's

Trabecular Metal[13] technology has led the way, and stimulated similar materials that are now being offered by a number of the implant companies. Tantalum material used in the Trabecular Metal product is made of elemental tantalum, one of the most chemically stable and biologically inert metals used in orthopaedic implants, making it highly biocompatible and corrosion resistant.[14] Tantalum is the ideal material for a biological ingrowth structure because it has high fatigue strength and a compressive modulus that allows it to bend before breaking. Most of the other cancellous-style devices are fabricated from titanium.

WORLDWIDE USE OF MATERIALS IN TOTAL HIP ARTHROPLASTY

With the rise and fall of metal-on-metal resurfacing procedures over recent years, the selection of alloys and post-treatments should stand as a warning to implant designers about the detrimental effects of post-fabrication heat treatments and alloy selection. It is worth considering the case of the Birmingham Hip Resurfacing device that was designed on the metallurgical principals of McKee Farrar, which used an as-cast cobalt chrome alloy as the bearing surface. In the as-cast condition, the Co-Cr-Mo matrix contains a hard second phase consisting of large block carbides throughout the microstructure. The carbides are harder than the Co-Cr matrix and therefore form wear-resistant areas at the articulating surface and prevent matrix-matrix abrasion, which further reduces wear.[15] Contrast this implant with others that subject the base Co-Cr-Mo alloy to additional heat treatments such as hot isostatic pressurization and sintering. For example, the DePuy ASR Hip system requires the Co-Cr-Mo beaded surface to be sintered following initial blank forging, thus adding a thermal treatment into the manufacturing process.

The addition of heat treatments such as hot isostatic pressing, solution heat treatments, and sintering all alter the microstructure of the Co-Cr-Mo alloy and directly influence the wear resistance of the material. At the high temperatures of thermal treatments, there is a diffusion of the chromium, molybdenum, and carbon atoms from the carbide precipitate of the alloy. As the alloy then begins to cool, the re-precipitation of the carbides occurs predominantly at grain boundaries, without reforming as the original as-cast morphology. Therefore, rather than large block carbides, the resulting microstructure contains smaller, finer groups of carbides that have reduced mechanical stability within the supporting matrix. In addition, the inter-carbide spaces within the matrix are also larger, and further heat treatment may then diffuse the remaining carbides at a greater rate. Consequently, during articulation against another surface, the small unstable carbides are more easily extracted, whereas the large intercarbide spaces mean the greater areas of the matrix are exposed and at a higher risk of adhesive wear.[16]

Significant variations in the clinical success of various hip-resurfacing implants have been observed.[16] These differences in implant performance can be attributed to variations in the manufacturing processes used to create the Co-Cr-Mo alloy often used for the articulating femoral head. Most notable is the contrast between the ongoing clinical success of the Smith and Nephew Birmingham Hip Resurfacing System[17] and the failure of the DePuy ASR hip resurfacing system, which was subject to voluntary recall in 2010 for exceedingly high revision rates in the midterm.[15,18]

Data regarding the most commonly used stems in each region were sourced primarily from annual reports of the national joint registries. For cemented stems, the two most common materials were Co-Cr-Mo alloys or high nitrogen stainless steel. Although a greater range of cemented stems were manufactured from Co-Cr-Mo, the number of high-nitrogen stainless steel stems implanted in recent years was generally higher than Co-Cr-Mo, almost entirely because of the popularity of the Exeter stem, particularly in Australia and the United Kingdom.

Cementless stems were manufactured almost exclusively from titanium alloys (Ti6Al4V or titanium-niobium), although companies often used unique trade names (TMZF, ISODUR F, ISOTAN F) and manufacturer-specific compositions. The one exception was the Smith and Nephew Echelon uncemented stem, manufactured from Co-Cr-Mo and recorded in the Norwegian Registry. Cementless stems were often also coated with hydroxyapatite or porous titanium sprays.

CURRENT CONCERNS WITH MATERIAL SELECTION

Worldwide ISO standards recognize the detrimental effect of galvanic corrosion cells that can be established in the body. Box 14-1 specifies implant material combinations that have been found to be acceptable. Although this list is not exhaustive, it recognizes the electrochemical effects in vivo that should be considered during implant design. When reduced taper length is combined with larger femoral heads,

BOX 14-1. Acceptable Materials for Metallic Combinations for Nonarticulating Contacting Surfaces of Implants

For applications in which one metal or alloy is in contact with another and articulation is not intended, the following metallic combinations involving the metals listed have been found to be acceptable and can be used, provided that adequate attention is given to design, surface finish, surface treatment, and metallurgic conditions:

- Cobalt-based alloys (ISO 5832-4, ISO 5832-5, ISO 5832-6, ISO 5832-7, ISO 5832-8, ISO 5832-12) / titanium-based alloys (ISO 5832-3, ISO 5832-11)
- Cobalt-based alloys (ISO 5832-4, ISO 5832-5, ISO 5832-6, ISO 5832-7, ISO 5832-8, ISO 5832-12) / other cobalt-based alloys (ISO 5832-4, ISO 5832-5, ISO 5832-6, ISO 5832-7, ISO 5832-8, ISO 5832-12)
- Stainless steel (ISO 5832-1, ISO 5832-9) / titanium-based alloys (ISO 5832-3, ISO 5832-11)
- Stainless steel (ISO 5832-1, ISO 5832-9) / stainless steel (ISO 5832-1, ISO 5832-9)

the outcome has been that industry experiences a new failure mode in THA "trunnionosis"[19] (Fig. 14-5). One factor that can drive the trunnionosis phenomena is the use of different materials at modular junctions. Fundamental science states that two different materials in a conducting media will generate a battery or corrosion cell. Consequently, all differing materials mated together in the human body will set up a corrosion cell to some extent. The extent on the corrosion cell is affected by the fluid conductivity and galvanic potential difference between the two materials.

Improvement to increase modular head contact to taper neck can be accomplished by increasing taper length by 1.9mm. This will improve surface contact reducing both micro motion and stress at the modular interface (Fig. 14-6).

Implant designers can determine the galvanic potential between materials and minimize these differences. One such concept has been proposed that involves nitriding of a Co-Cr neck that mates with the titanium short stem.[20,21] As seen in Figure 14-7, this material process reduces the galvanic potential between the materials and consequently reduces the probability of corrosion between mating surfaces. This

FIGURE 14-5. *Retrieval of taper corrosion with dissimilar metals—cobalt-chrome alloy modular neck on titanium stem. (Courtesy Dartmouth Biomedical Engineering Center.)*

fundamental design concept can be further applied to the internal surfaces of the femoral head that mate with the stem taper. This concept can greatly reduce the corrosion potential between large metal femoral heads and stem trunnions.

Corrosion of metals has many different mechanisms that all have independent driving forces. One such corrosion mechanism that has recently been attributed to the decline in the clinical acceptance of modular hip implants and recall of two products by Stryker Orthopaedics (Mahwah, NJ) is that of fretting corrosion—that is, component damage within the modular connections.[22] A main driven mechanism behind fretting corrosion is stress, or load. Increasing the stress at the modular junction will proportionally increase the extent of the fretting corrosion. Two modular hip stems that have been recalled recently are the ABG II and the Rejuvenate, manufactured by Stryker Orthopaedics. Reviewing the design of the modular junction design of these products indicates that the application of some fundamental engineering principles could have reduced the probability of fretting corrosion.[20,21] Figures 14-8A and 14-8B indicates the length of taper support versus the offset of the modular neck for the Stryker, Wright Medical, and TSI systems. The recalled products from Stryker have reduced taper support with significantly increased offset, which produces much higher stresses at the modular junction and potentially leads to a more rapid fretting corrosion rate.

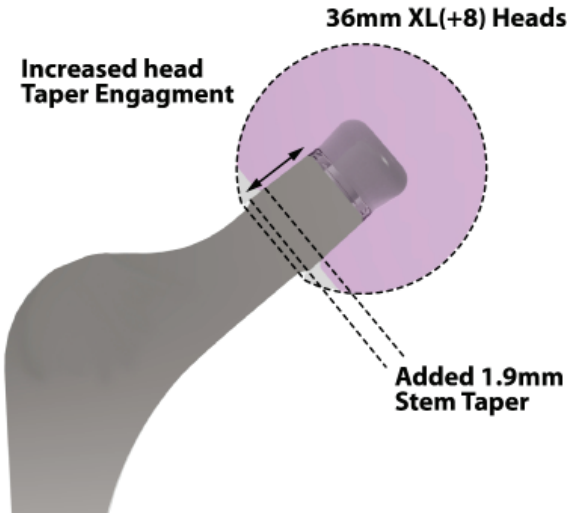
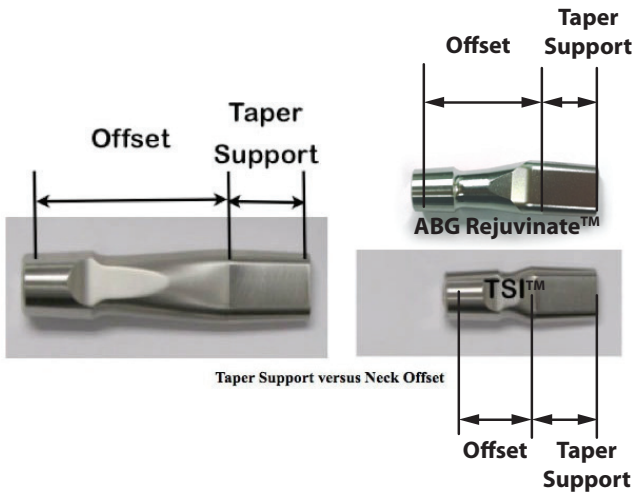


FIGURE 14-6. *Illustration showing taper surface increased by 1.9mm.*

FIGURE 14-7. *Rendering of modular cobalt-chrome alloy neck with a nitriding coating (gold) of the distal taper engagement with a titanium alloy stem. Providing a reduction of corrosive galvanic reaction with dissimilar metallic alloys. (Courtesy Chris Burgess, Signature Orthopaedics Ltd.)*

A

System	Taper Support (mm)	Offsett (mm)	% Increase
TSI – Signature Orthopaedics	17	27.5	—
Profemur – Wright Medical	15	42	53%
Rejuvenate – Stryker	13	42	55%



B

FIGURE 14-8. *(A, B) Taper support for three different modular necks, offset, and percentage increase of offset.*

SUMMARY

Over the next several decades, we will continue to see advances in THA. We believe that most advances will be in the area of design, instrumentation, surgical approach, and robotics—not necessarily new materials. The use of new materials is a costly venture, and with the growing numbers of total joint arthroplasties, it seems highly unlikely that a new material other than metal will be introduced soon. Metallic alloys have served THA well. The knowledge of implant failure and implant testing is continuing to grow, which will have a positive effect on the future survivorship of THA.

Historical design principles should be reviewed when designing new THA components. One key principle is increasing the load-carrying capacity by using the additional support of the bony femoral neck, as described by Freeman.[23] This load-sharing concept allows designers to maximize the load-carrying capacity of the commonly used alloys. This prosthesis is similar in design to other modern prostheses, but it preserves more native bone in the femoral neck of the patient during femoral preparation. Similar to resurfacing, the hope is to allow placement of an implant while leaving a viable option for revision at a later date. These prostheses are proximally porous coated; after the femoral bone cut is made, more femoral neck bone is left in situ, and the proximally coated implant and novel proximal conical flair design loads and helps to maintain this "extra" bone over time. Any bearing surface can be used by the 12/14 taper. This design approach saves a significant portion of native host bone and soft tissue, leading to easier revision surgery when the time comes.

Metallic alloys in THA are only as good as their intended design and materials will allow regarding function, performance, and clinical outcomes. Hip designs have different features that can provide solutions to difficult primary and revision reconstructive problems. However, coincident with the advantages, concerns relative to design, structural integrity, stability, and debris generation have been continuously cited since the introduction of THA. Historical review and preclinical testing might meet the required standards set by regulatory bodies to achieve market release, but often these standards do not consider the ever-increasing physical activity and loads that these devices are encountering. Ultimately, the surgeon has the burden to appreciate the performance ability of the devices he or she selects and the responsibility to ensure that patients fully understand the risks involved with the reconstructive surgery.

One area beyond our direct control is that of increased patient physical activity. There is reluctance by many orthopaedic surgeons to warn or give precautions to active patients. We are seeing unprecedented physical loads being placed on our reconstructive products, and we believe that the failure to warn patients about the increased risk of certain activities, especially beginning early activities too soon, is doing a disservice to patients and placing increased loads on artificial implants. In view of the hundreds of thousands of total hip surgeries that have been performed since Philip Wiles introduced it over 75 years ago, the relatively small number of historically reported failures is not wholly unexpected. Debate continues over cement versus cementless indications. Concerns about wear rates and performance of bearing selection still dominate the literature; however, we submit that the debate around the use of metallic alloys is essentially over. The justification for the continued use of metallic alloys has stood the test of time. Next comes the refinement of design, surface enhancements, and improvements in surgical methodology and rehabilitation. There is no debate over the fact that cost is becoming more of an influence on the decision process for selection of medical treatments and on product-development programs. Surgeons must address what treatment is best for their patient and what economic factors are going to influence their decision-making in the future.

PEARLS AND PITFALLS

- Materials selected for THA are typically determined by ascertaining the intended function of an implant over its lifespan.
- The use of metallic alloys in THA presents a unique set of problems regarding corrosion.
- There is little engineering rationale regarding which alloys are used for the various femoral components in THA.
- There are various manufacturing techniques used to produce hip components.
- All manufacturing processes produce different mechanical and electrochemical properties.
- The addition of a porous sintered coating (diffusion bonding) significantly reduces the fatigue strength of components, and they require a post-sintering heat-treatment cycle.
- Drop forging is favored for its enhancement to mechanical properties of the alloys and its moderate cost of production.

- Porosity or surface enhancement on cementless hip implants is to provide a biologically friendly environment to bone to facilitate bony on-growth or in-growth, which leads to long-term stability and fixation of the implant.
- Performance of metallic modular junctions can be affected by galvanic and fretting crevice corrosion.
- Performance of modular junctions can also be affected by material selection, surface contact area, and area of stress concentration.
- Corrosion of metal has many different mechanisms that all have independent driving forces.
- Metallic alloys in THA are only as good as their intended design and materials will allow regarding function, performance, and clinical outcomes.
- Historical review and preclinical testing might meet the required standards set by regulatory bodies to achieve market release, but often these standards do not consider the ever-increasing physical activity and loads that these devices are encountering.

ACKNOWLEDGMENTS

The authors thank Christopher Tkach for assistance with the manuscript, and Chris Burgess, Dr. Michael Mayor, and Rayna Levine for illustrations.

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