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Modular Taper Junction and Neck Strength in Total Hip Arthroplasty

Restoration® Modular Revision Hip System Technical Monograph
Modular Taper Junction and Neck Strength in Total Hip Arthroplasty

I. Established History of Modular Tapers used in THA Implants

Taper junctions have been an effective means of independently securing distal and proximal components together in modular hip stem implants.

The strength of the taper junction has been a prominent design consideration due to the high load concentration that results through this region. In addition to having adequate fatigue strength capabilities, taper junctions must be designed to withstand fretting failure and corrosion, as well as maintain torsional stability. To enhance the performance of a modular taper junction, additional treatments following the machining of the taper may be required. This monograph will describe the testing and key issues surrounding the manufacture and performance of the Restoration® Modular Hip System taper junction design.

II. Surface Treatments

Early high failure rates in femoral hip prostheses may be attributed to a range of material properties, including fatigue strength, compressive strength, and other mechanical properties. The performance of modular taper junctions in femoral stems is further susceptible to corrosion and fretting occurring from relative movement at the taper junction, and increased stresses caused by the loss of proximal bone support.

What can be done to improve the material properties?

Treatments to improve the taper strength of titanium-based femoral prostheses can be either mechanical or non-mechanical. Non-mechanical treatments harden a material’s surface by altering the surface’s structure. Examples of non-mechanical treatments are heat treatments, nitride impregnation, and anodizing. Non-mechanical treatments affect the surface to a depth less than 0.1mm.1,2

Heat treatment is a material-hardening process in which the titanium material is heated to a specific temperature, held at that temperature for the appropriate amount of time, and cooled according to prescribed methods. This process may improve the overall strength of the taper, but it does not produce a hardened surface which will significantly resist fretting failure.
II. Surface Treatments (continued)

Nitride impregnation is a surface-hardening process that introduces nitrogen into the taper surface. The nitriding process generates a very thin (typically no more than 4 microns) titanium nitride layer on the titanium.²

Anodizing is a surface-hardening process which pulls oxygen into the surface of the material, generating an oxide layer. This type of surface treatment is mainly effective on aluminum.

Mechanical treatments change the structural arrangement (i.e., microstructure) of the material’s surface molecules.³ Examples of mechanical treatments are swaging, burnishing, and shot peening. Mechanical treatments affect the surface to a depth of approximately 0.25mm – 0.50mm.³,⁴

Swaging is a surface-hardening process in which the taper is plastically deformed to its final shape using high pressures. Swaging is similar to forging except in swaging the material is cold worked.

Burnishing is another form of a mechanical surface-hardening process. In this process, the taper starts out with a machined finish, which looks like a fine thread form, or a series of hills and valleys, when magnified. The action of roller burnishing pushes the hills into the valleys through a rotation of hardened rollers over the machined surface. The result is a work-hardened surface.

Shot Peening is a surface-hardening process in which small spheres of ceramic, steel or other materials (less than 0.5mm in diameter) are used to bombard the taper surface.⁵ Each sphere (shot) acts as a tiny peening hammer imparting a small indentation or dimple on the surface (Figures 1 & 2).⁴ This process packs the surface molecules tighter and places them in compression, resulting in a layer of residual compressive stress, or work-hardened surface.

Since nearly all cracks caused by fretting originate on or near the surface of a part, compressive surface stresses induced by shot peening slow crack growth.⁴ In order for fretting forces to adversely affect the taper’s yield strength, the magnitude of stress created by fretting must exceed the magnitude of the residual compressive stresses. Hence the compressive forces ‘pre-stress’ the surface area of the taper in the opposite direction than that of the fretting forces.

Mechanical treatments provide an advantage over non-mechanical treatments in affecting the surface of the titanium-based tapers to a greater depth, and ultimately enhancing the fatigue strength of the taper.¹,²,³,⁴

To improve resistance to fretting failure and increase the fatigue strength of the taper junction, Stryker® Orthopaedics utilizes a proprietary shot peening process on its Restoration® Modular Hip System taper junction.⁶

Figure 1
SEM image of a non-shot peened modular taper junction at 500µm.

Figure 2
SEM images of modular taper junction at 500µm. The dimpled effect is a result of the shot peening process which hardens the taper junction through compression of surface molecules.
Ill. Testing

Test Methodology for this Next Generation System

The fatigue limits of the Restoration® Modular hip taper junction and neck were tested in a manner consistent with currently accepted ISO (International Standards Organization) recommendations.

The Restoration® Modular implants are dynamically tested to 10 million cycles, simulating the average load on an implant over a ten-year period.

Modular Taper Junction Testing

One of the design objectives for the development of the Restoration® Modular taper junction was the ability of the male trunnion (taper) to endure a 4450N (1000 lb.) cyclic load when used in conjunction with the largest offset proximal body (44mm base offset) and extended offset femoral head (V-40™ X-Long +12mm) (Figures 3 & 4). The total lateral offset from hip center to femoral axis, achieved using this combination of proximal body and femoral head is approximately 53mm.

The Restoration® Modular taper junction exceeds the guidelines established by ISO (2300N or 517 lb.) and meets the design objective of 4450N (1000 lb.) head load.a

To compare the effects of shot peening the taper, identical testing was performed utilizing distal stems generated through the same process minus the shot peening operation. Test results show the shot peened components to have a minimum increase in fatigue strength of 33%.b

Figure 3
ISO 7206-4 fatigue test configuration for the Restoration® Modular taper junction.

Figure 4
Results of ISO 7206-4 fatigue test configuration for the Restoration® Modular taper junction.c

Modular taper junction @ 10 million cycles.
Neck Testing

In addition to testing the taper junction, neck testing was performed on the Restoration® Modular proximal bodies. All of the proximal bodies were found to withstand fatigue loading of 5340N (1200 lb.).\textsuperscript{10} Semlitsch et al.\textsuperscript{11} suggests testing fatigue strength at 4300N (996 lb.) for the neck region of a hip stem (Figure 5). The Restoration® Modular Proximal Body neck exceeds this suggested fatigue strength.\textsuperscript{10}

Shot peening has also been used to improve the fatigue strength in the neck of the proximal bodies. Results have shown that shot peening increases the fatigue strength of Ti-6Al-4V alloy by approximately 10% - 15%.\textsuperscript{13}

Figure 5
ISO 7206-6 fatigue test configuration for the Restoration® Modular Cone Body neck.\textsuperscript{12}
Torsion Testing
Why is torsion testing needed?
The torsional stability of the taper junction is required to prevent slippage between the components, helping to ensure that proper implant anteversion is maintained during and after the surgical procedure. For hip implants, this is especially important during periods of extreme loading, which may occur during stair climbing or rising from a seated position.

The torsional stability of the Restoration® Modular Hip System was tested in a specially designed apparatus. The components were assembled using surgical technique recommendations, and the torque required to cause rotation of the proximal body with respect to the distal stem was measured. A comparison of the torsional stability of dry tapers vs. tapers coated with soft tissue, fat and marrow, was performed, and the results were expressed in Newton-meters (Nm) (Figure 6).14

What are the results for the Restoration® Modular implants?
The torsion testing showed comparable results for both dry tapers and tapers coated with the contaminates of soft tissue, fat, and marrow. This suggests that torsional stability is unaffected by contaminates.14

Figure 6
Results of torsional stability testing of the taper junction under loading.14

IV. Summary
Stryker® Orthopaedics has designed the Restoration® Modular stem implants as the next generation modular hip system for revision surgery. This system meets and exceeds current industry testing requirements. Utilizing a proprietary shot peening manufacturing process, we are confident that the modular taper junctions and proximal body necks have been designed to the highest orthopaedic manufacturing standards.

* This system is contraindicated for high activity.
1. Watanabe et al., “An Effect of Peening on Fretting Fatigue” The 7th International Conference on Shot Peening.

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