

## 5.3 Design Parameter to Improve Range of Motion (ROM) in Total Hip Arthroplasty

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### Introduction

Dislocation represents, after aseptic loosening, the second most frequent complication [1] in total hip arthroplasty (THA) with an occurrence of 2-3% following a primary THA and 10% in revision arthroplasties [2]. Factors contributing to impingement and dislocation include soft tissue, bone components, orientation of the prosthesis, design of the implants [3].

The feasible prosthetic range of motion (ROM) is a function of:

- effective position of the implanted components (influenced by pre- and intra-operative circumstances)
- technical ROM (influenced by the manufacturer's implant design)

It is well recognised that a correctly combined orientation of both components, the acetabular cup and femoral stem, during implantation will yield a maximised ROM and will reduce the risk for dislocation.

However, in current day-to-day clinical practice, even experienced surgeons are not always successful at precisely placing the prosthetic components in relation to one another. As a result of the use of reliable positioning instruments and computer-aided navigation, improvements with regard to the precision of implant positioning may be expected in the future.

The standards for a modern, modular THA have increased in recent years and are intended to provide the patient with good functionality as well as an extended durability within the human body. The mobility and stability that can be achieved following prosthetic treatment in younger, active patients is becoming increasingly more important. For this reason, special care should be taken when designing and choosing the modular prosthetic components to ensure that range of motion and stability are not impaired.

The aim of this paper is to:

- identify general design parameters influencing the technical ROM (T-ROM)
- investigate particular improvements for T-ROM after changes in the design of a femoral stem, femoral head or acetabular cup within the product portfolio of Centerpulse (a Zimmer company)
- discuss the limitations and provide recommendations for desirable component features.

### Method

A motion simulation with three-dimensional hip prostheses models was performed using a CAD program (Unigraphics 3D). Based on defined implant positions, the previous prostheses design was compared to new design versions

in terms of the maximum range of motion they provide. In each case, the technical range of motion to the point of impingement was determined for individual movements (flexion, extension, abduction, adduction, internal and external rotation).

Following design elements were analysed:

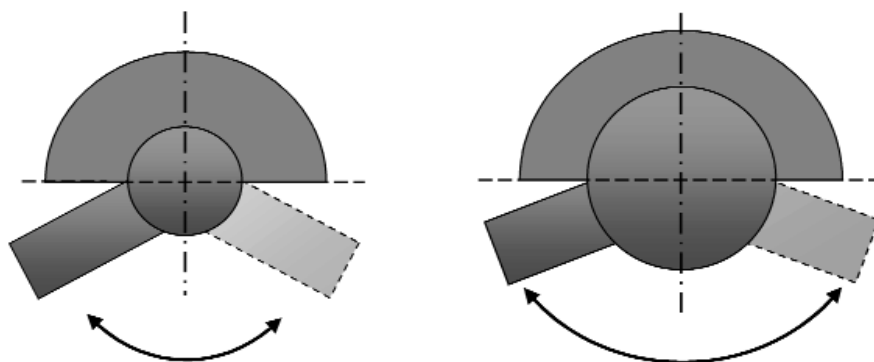
- diameter and design of femoral heads
- neck geometry and taper design for the femoral stem
- design of the entrance plane in the acetabular cup and cup profile.

In addition to these purely kinematic observations, other limiting factors were also discussed.

## Results

The attainable technical range of motion to impingement in hip prosthesis models was determined through the use of a 3D-CAD simulation with various geometries in terms of the design of the stem, femoral head and cup.

### Diameter and design of femoral heads



**Figure 1:**

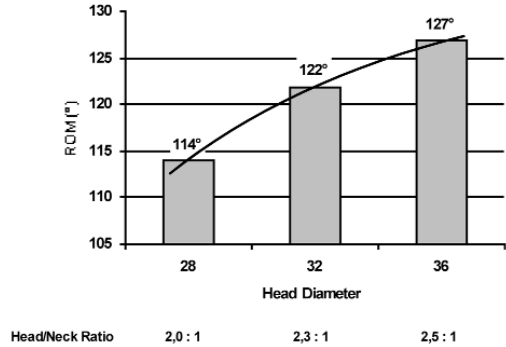
ROM is a function of femoral head size: An increased articulation diameter dramatically enhances T-ROM.

In addition a larger ratio between femoral head diameter and neck diameter enhances T-ROM.

Many total hip replacements result in limitation of ROM due to of component-to-component impingement. This is particularly true with smaller head sizes and modular femoral heads which require skirts.

Investigations done in this study have uniformly shown an increase in ROM using head sizes of 32 and 36mm, compared to head sizes 28mm or smaller for all four neck lengths. An average increase of 8 and 13 degrees respectively was shown using a 32mm or 36mm femoral head in combination with a standard femoral stem design.

**Figure 2:**  
Improvements in ROM with different head sizes in conjunction with Alloclassic™ Zweymüller™ SL stem (taper 12/14 standard) and Durasul™ Alpha liner.

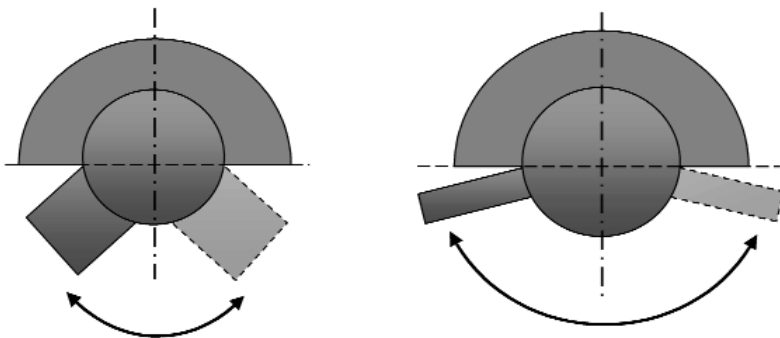


The femoral head size 28mm XL contains as a result of the longer neck length a cylindrical skirt which reduces maximum possible flexion by about 8 degrees (see Fig. 4). It is recognised that head-neck ratio is an important factor in ROM, primarily due to component-to-component impingement. Larger diameter femoral heads are the most direct way to improve this ratio. Because femoral heads 32mm and larger never require a skirt, regardless of the neck length, the larger heads show a substantial increase in ROM.

On the other hand, the percentage gain in range of motion decreases with increasing head size. This means that the size of the femoral head must be considered, in addition to biomechanical issues, to the number of achievable acetabular liner for the corresponding acetabular components. Anatomy is another limiting factor. Suitable acetabular cups with classic head diameters of 22 or 28 mm are still necessary for very small acetabulum sizes.

Besides enhanced ROM larger femoral heads offer a further distinct advantage: enhanced stability. Larger heads are set deeper into the acetabular liner than the smaller head sizes, thus increasing stability, as they must be displaced further in order to dislocate compared with that of the traditional femoral head sizes. Supporting information confirming the improved stability is available from different in vitro anatomical studies and prior clinical studies in which large femoral heads were used [4,5,6].

### Neck geometry and taper design



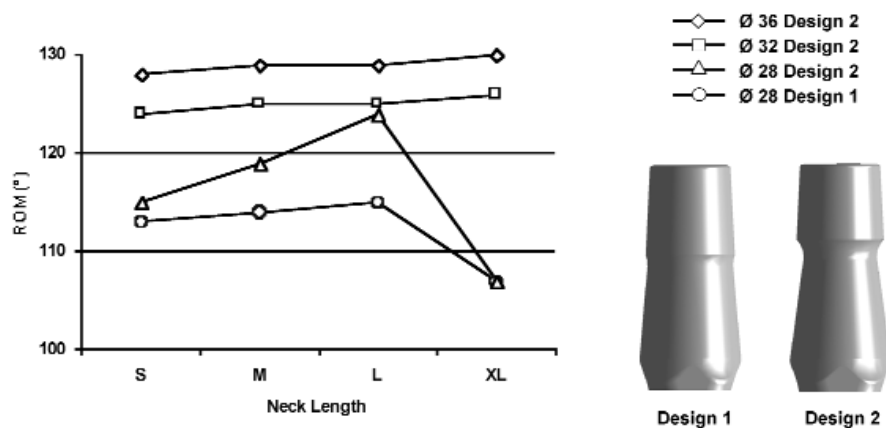
**Figure 3:**  
ROM is a function of neck diameter and taper design: T-ROM increases with decreasing neck diameter.

Early impingement that leads to the generation of debris and possible subsequent dislocation may be caused by a bulky neck diameter or an exposed large taper.

The objective was to evaluate the beneficial effect of a modified neck geometry and taper design with regard to range of motion to impingement. Two stem designs with a taper 12/14 were used, with a major difference in taper length and neck diameter below the taper. Design 1 was a current standard stem with a taper length 14.5mm and a neck diameter 13.5mm. Design 2 had a shorter taper (12.0mm) and a thinner neck diameter (11.6mm).

These two designs were analysed using different head diameters (28-36mm) and neck lengths (-4mm to +8mm). Results from the computer analysis revealed an average increase in range of motion of 5 degrees.

Shortening the taper length also results in an improvement in ROM especially for head size 28mm L, because the unused lower part of the stem taper is removed, thereby extending the slender part of the slim neck. This measure has no effect on the force of retention of the femoral head on the stem neck, since the minimum bearing taper length remains unchanged.

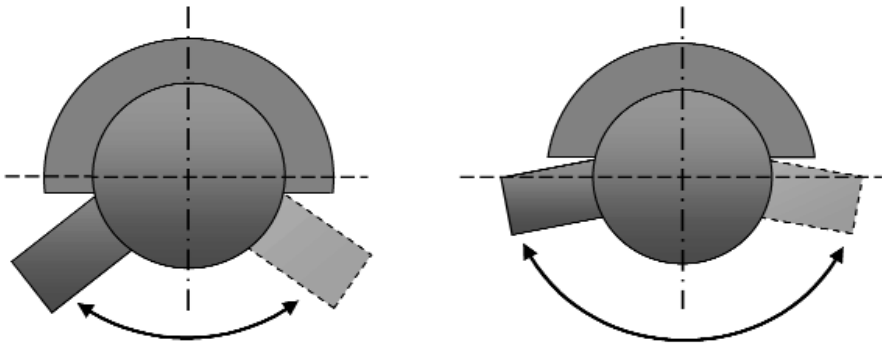


**Figure 4:**

Improvements in ROM with different neck diameter/taper design in conjunction with various femoral head sizes and neck lengths.

However, the component strength of the stem prosthesis in the neck region does impose limits. The slim neck must also reliably perform the task of load transfer, which is equal to several times the body weight. For this reason, such design changes are thoroughly tested at Centerpulse (a Zimmer company) by means of Finite Element Analyses (FEA) and dynamic fatigue testing before they are implemented. During these tests, it has become evident that the choice of material, production method and design of the prosthetic stem influence the component strength in the neck region and limit the possible extent of reduction of the neck diameter in the slimmer portion.

## Design of the entrance plane and cup profile



**Figure 5:**

ROM is a function of the acetabular cup profile: T-ROM increases due to a reduction in the entrance plane of the insert or a reduction of the acetabular cup profile. T-ROM is compromised, at least partly, with the use of hooded inserts.

With any hard-on-hard bearing (metal-on-metal, ceramic-on-ceramic), appropriate positioning of the components is crucial. Neck impingement in a soft-on-hard bearing against a polyethylene insert, although undesirable, is more forgiving with respect to potential damage to the stem or acetabular component.

The aim was to evaluate the beneficial effect with regard to ROM permitted by a slightly modified insert design for the traditional articulation diameter 28 and 32mm. The reason for only a moderate reduction of the entrance plane is to ensure a sufficient coverage of the femoral head by the metallic insert and the resulting stability in vivo.

Design 1 was the existing Metasul Alpha 28mm liner; Design 2 was a Metasul Alpha 28mm liner where the entrance plane of the metallic insert was reduced by 1mm. Design 3 was a Metasul Alpha 32mm liner.

The newly designed Metasul Alpha 28 and 32mm inserts provided improvement with regard to ROM of 7° and 15° respectively.

**Figure 6:**

Improvements in ROM with slightly modified entrance plane on Metasul™ Alpha liners for two different femoral neck geometries/ taper designs.

Diameter	ROM Std Neck	Head/Neck Ratio	ROM Slim Neck	Head/Neck Ratio
28 std Design 1	114°	2,0 : 1	119°	2,2 : 1
28 opt Design 2	121°	2,0 : 1	126°	2,2 : 1
32 opt Design 3	126°	2,2 : 1	129°	2,4 : 1

A neutral liner should be used wherever possible in order to maximise the impingement-free range of motion. This requires optimal positioning of the metal shell to match the desired orientation of the opening face.

The use of a hooded Metasul Alpha liner shows a substantial reduction in the arc of motion by 10° in the direction of the elevated rim segment compared to that of a neutral liner. This reduction in range of motion makes the rotational positioning of these designs particularly important to reduce rim impingement and potential acceleration of polyethylene wear at the rim.

## Discussion

The most important factors influencing post-operative mobility and stability of the artificial hip are the head diameter and the neck geometry, and/or the ratio of head diameter to neck diameter. Increasing the articulation diameter enlarges the range of motion. In addition, stability is increased as a result of the larger femoral head being set deeper into the acetabular cup compared to that of the smaller head sizes. As a result, the risk of impingement is significantly lowered and the risk of dislocation is reduced. However, the use of large femoral heads has only become possible as a result of extremely wear-resistant bearings (metal-on-metal, ceramic-on-ceramic, and highly cross-linked polyethylene), because the wear rates are extremely low, even with large articulation diameters [7, 8, 9].

The literature contains a wide variety of clinical studies on the subject of dislocation, in which the influence of the head diameter was also examined. The clinical results and the consequent benefit with regard to the 22mm to 32mm head diameters in use are subject to controversial discussion. On the one hand, this is due to the wide range of influencing factors, on the other, the authors believe that in the discussion to date, too little attention has been paid to an important parameter: the ratio of head diameter to neck diameter. This ratio is generally not specified in the currently published studies, in spite of the fact that it is precisely this parameter that significantly influences the dislocation rate. In order to obtain a sufficient post-operative hip mobility and stability, total hip endoprostheses should provide a head-neck ratio of at least 2:1 [6]. When determining this ratio, it is important to note that as a result of the neck geometry of the stem, and depending on the selected neck length for the femoral head, the contact point can vary along the neck of femoral stem or can even be at the neck of the femoral head.

Although the influence of the femoral offset on the range of motion was not examined in this study, it also plays an important role. An insufficient offset leads to a loss in soft tissue tension and a reduction in the impingement-free range of motion. A larger, adequate offset offers a number of advantages (Eike, 1998):

- avoids premature bony impingement
- improves the efficiency of the abductors and thereby the gait pattern
- prevents an excessively steep course of the vector of the resulting hip force.

Modern systems for THA should have a minimum range of motion of 120° so as to achieve a satisfactory outcome once implanted. These standards can easily be met and even exceeded by implementing the above mentioned design changes, and by appropriate selection of the components by the physician performing the surgery.

Therefore a recommendation for a modern modular total hip arthroplasty should in future include the following desirable component features:

- use only components which offer a head - neck diameter ratio of at least 2:1
- use largest available femoral head for each cup size
- avoid skirted heads wherever possible
- use femoral stems with favourable neck geometry
- use femoral stems with an adequate offset
- use neutral liners wherever possible.

## Summary

Increased range of motion, fewer dislocations - the large femoral heads, an optimised neck geometry at the femoral stem, as well as modification of the acetabular cup profile offer many advantages in modular hip prostheses. In combination with low-wear bearings, the large femoral heads allow an increase in the range of motion, greater stability, and improvement in the durability of artificial hips. However, the optimisation of the individual design elements is also subject to limitations: enlarging the articulation diameter can only be achieved up from a certain acetabular cup size; a narrow neck must continue to perform the function of load transfer without causing fractures *in vivo*, and a acetabular cup with a reduced entrance plane has to ensure a sufficient coverage of the femoral head. It is therefore important to balance the distribution of measures when implementing any of them into the design of a prosthesis.

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