Sex Differences in Hip Morphology: Is Stem Modularity Effective for Total Hip Replacement?

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By Francesco Traina, MD, Manuela De Clerico, BSc, Federico Biondi, MD, Federico Pilla, MD, Enrico Tassinari, MD, and Aldo Toni, MD

Introduction

Total joint arthroplasty, one of the most successful orthopaedic procedures, predictably relieves pain and improves function for patients with a painful arthritic hip joint[1]. This high success rate has increased patient expectations, particularly those regarding hip function, after the surgery. To achieve better function and to reduce the implant dislocation rate, more attention has been given to the role of the restoration of femoral offset and soft-tissue balancing[2,3]. Surgeons today are committed to restoring the anatomy in each case independent of the patient's age or sex or the pathological condition of the hip.

Anatomic studies of hip anatomy, specifically on the femoral side, have shown sex-based anatomic differences[4-8]. Women tend to have a shorter femoral neck, a thinner femoral shaft, a lower cervicodiaphyseal (CCD) angle, a lower femoral offset, and greater anteversion of the femoral neck (Fig. 1). These differences should be addressed during revision hip surgery in order to restore hip anatomy. In particular, to achieve proper soft-tissue balancing, the femoral offset should be accurately restored. The femoral offset is represented by the perpendicular distance from the center of the femoral head to the long axis of the femur (Fig. 2). McGrory et al.[9] found a correlation between a lack of restoration of femoral offset and abductor muscle weakness and limping. These results depend on hip mechanics, with a fulcrum between body weight and the hip abductors (Fig. 3). The length of the lever arm of the hip abductors is smaller

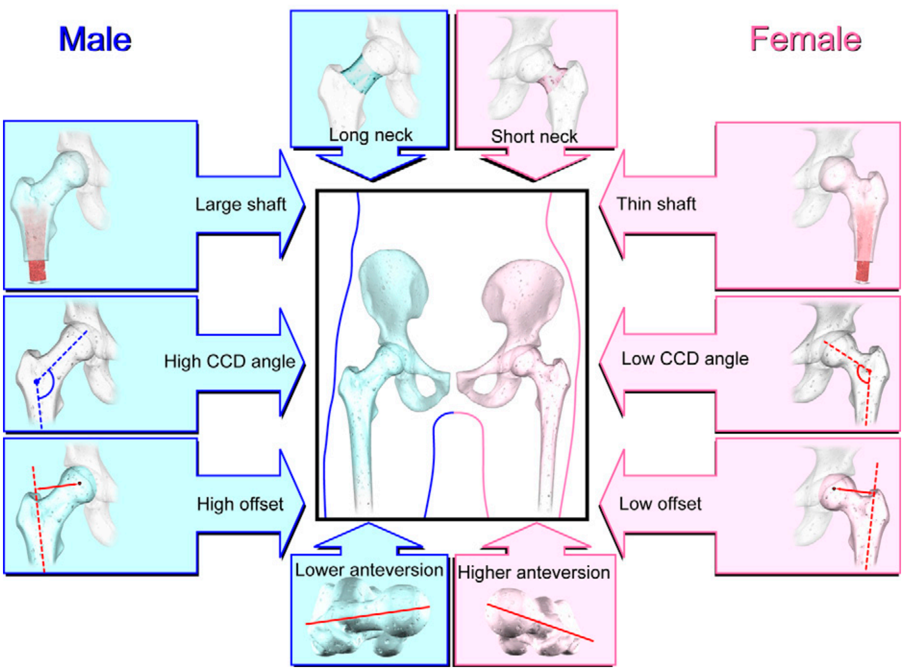

Fig. 1
Anatomic differences in hip morphology between men and women. CCD = cervicodiaphyseal.

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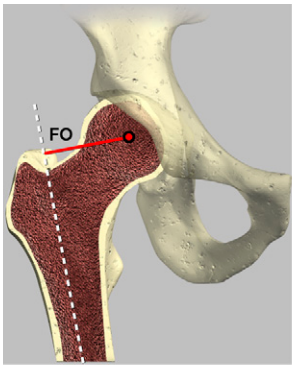


Fig. 2

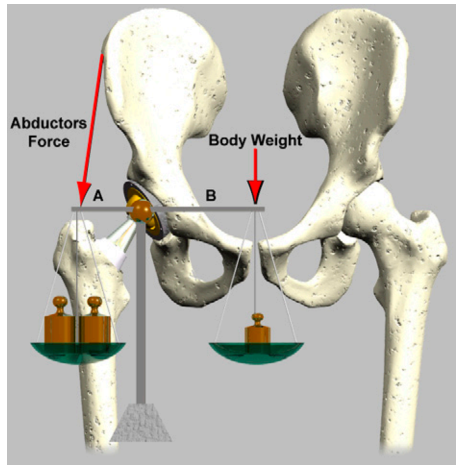


Fig. 3

Fig. 2 Femoral offset (FO), which is the perpendicular distance from the center of rotation of the hip to the long axis of the femur. **Fig. 3** Schematic diagram showing hip mechanics. The body weight lever arm (B) is the distance from the center of the femoral head to a vertical line through the symphysis pubis. The abductor lever arm (A) is the perpendicular distance from the center of the femoral head to a line drawn from the anterior superior iliac spine and tangential to the greater trochanter. Since B is greater than A, the abductor force required to balance the body in an upright position should be larger than the body weight.

than that of body weight. Therefore, the abductors must generate a force that is larger than body weight to maintain a level pelvis. In contrast, an increase in femoral offset increases the lever arm of the abductors, reducing the force required to balance body weight and thereby reducing the incidence of Trendelenburg gait.

To restore femoral offset accurately, careful preoperative planning is mandatory and careful implant selection is recommended. Surgeons can choose among different implant designs—standard monoblock stems, high-offset monoblock stems, or modular stems—to restore offset.

Modular stems have some theoretical advantages in that they allow adjustment, independent of stem size, of the CCD angle, offset, neck anteversion, neck length, and lower-limb length. In contrast, with monoblock stems, offset and neck length are directly proportional to stem size (the larger the stem, the higher the offset and the longer the neck) and neck version is fixed (Fig. 4). Also, with monoblock stems implant length increases proportionally with increasing implant offset, whereas with modular neck stems length is independent of implant size. An anatomic study of the proximal part of the femur showed that monoblock stems

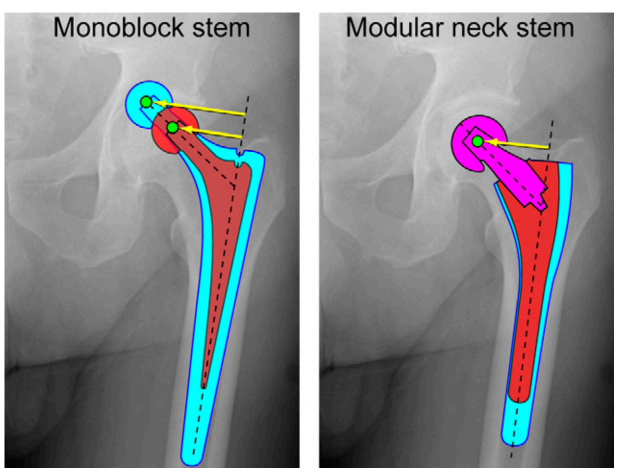


Fig. 4

Diagram showing how, with monoblock stems, femoral offset (yellow arrows) is proportionally dependent on stem size while this is not true with modular neck stems.

TABLE I Differences Between the Sexes in the Present Series

	Mean	Standard Deviation	P Value (Student t Test)
Age *(yr)*			>0.01
F	63.6	9.2	
M	63.7	8.8	
Height *(cm)*			<0.01
F	161.7	6.5	
M	172.2	6.7	
Weight *(kg)*			<0.01
F	69.7	11.4	
M	81.7	11.1	
Body mass index *(kg/m²)*			<0.01
F	26.7	4.0	
M	27.6	3.3	

restore offset in one of three patients[3,10], whereas modular stems, with their versatility, have been shown to restore offset and to balance the soft tissues even in demanding cases—for example, in patients with high-grade developmental hip dysplasia[11].

Hips with primary arthritis can have anatomic variations that are difficult to restore with monoblock stems (Fig. 5). For example, in the case of a wide femoral canal and a short femoral neck, anatomy usually seen in older women, a cementless monoblock stem necessarily increases femoral offset to achieve good primary implant stability. In the same patient, a modular neck and stem allow the surgeon to achieve good implant stability independent of femoral offset. Another challenge could be a thin femoral shaft with a long neck and a high offset; in such a case, the offset of a monoblock stem is limited by the thin shaft that requires a small femoral component. If these anatomic variations are not properly considered during total hip replacement, they

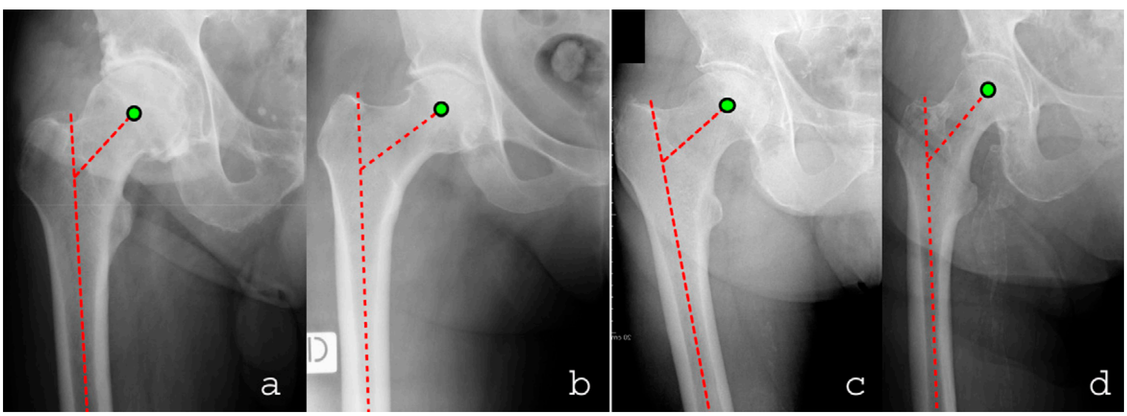


Fig. 5

Radiographs showing hip shapes that are difficult to restore with use of monoblock stems: large shaft, short neck, low offset (a); thin shaft, long neck, high offset (b); large shaft, short neck, high offset (c); and thin shaft, long neck, low offset (d).

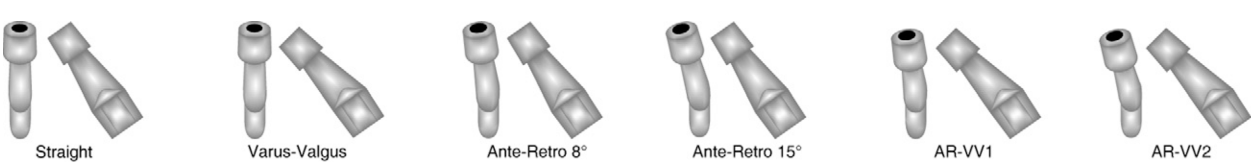
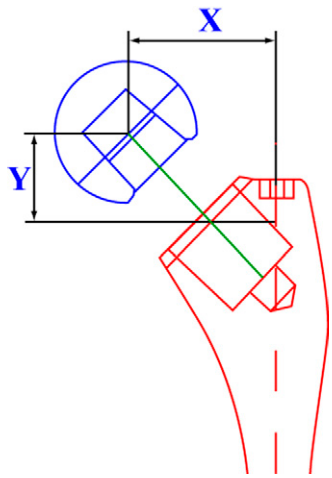


Fig. 6

Six different neck models were available: straight, varus-valgus (8°), anteverted-retroverted (8° and 15°), and the combination of 6° of varus and 4.5° of retroversion for the left and the right side.



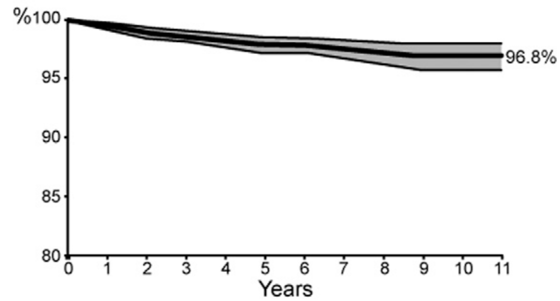


Fig. 7 Fig. 8

Fig. 7 Diagram showing how implant offset (X) and neck length (Y) were calculated in each patient. **Fig. 8** Estimated Kaplan-Meier survival curve with 95% confidence intervals at eleven years for the 2131 modular neck prostheses.

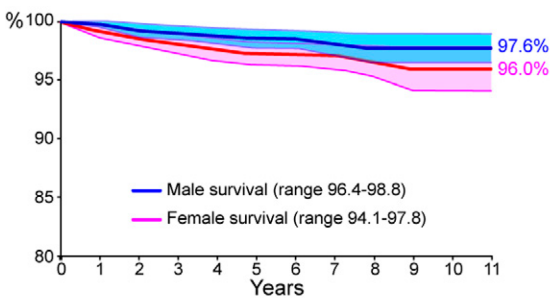
could lead to high dislocation rates[12-15] and to limb-length discrepancies.

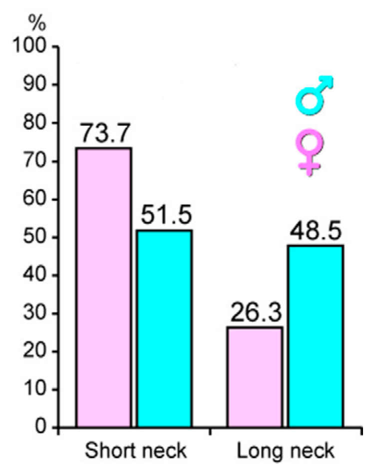
The aim of this study was to evaluate the effectiveness of a modular neck and stem, which has been extensively validated in experimental and clinical studies[16-19], with regard to restoring hip anatomy in both women and men, thereby reducing the prevalences of dislocation and limb-length discrepancy.

Materials and Methods

To evaluate the ability of a modular system to restore hip anatomy, we reviewed the results following implantation of 1051 modular stems in men and 1080 in women (Table I). All of the operations were performed by skilled surgeons. The goals of the total hip arthroplasties were reconstruction of hip anatomy and avoidance of limb-length discrepancy and hip instability. The criteria for inclusion in the study were a primary diagnosis of degenerative hip arthritis, implantation of a modular neck prosthesis (Wright Medical Technology, Arlington, Tennessee) between 1995 and 2004, and a minimum duration of follow-up of five years (range, five to thirteen years). Exclusion criteria were inflammatory arthritis or a primary hip arthroplasty for a reason other than degenerative arthritis.

The modular neck was taper-locked to the stem by an oblong conical profile taper. Necks were available in two lengths—short (28 mm) and long (38.5 mm)—and there were six different models, each available in both lengths (Fig. 6).





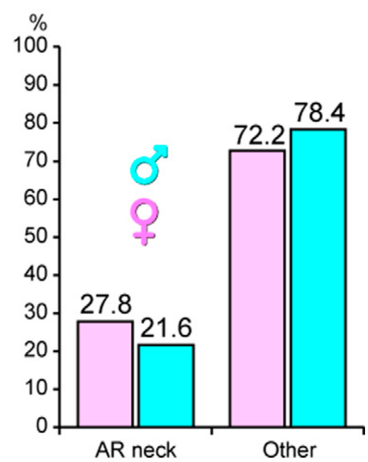


Fig. 9 Fig. 10 Fig. 11

Fig. 9 Comparison of estimated Kaplan-Meier survival curves at eleven years between 1080 prostheses implanted in women and 1051 prostheses implanted in men (p = 0.07). **Fig. 10** Distribution of modular neck lengths in men and women. **Fig. 11** An anteverted-retroverted (AR) neck was used more frequently in women than in men.

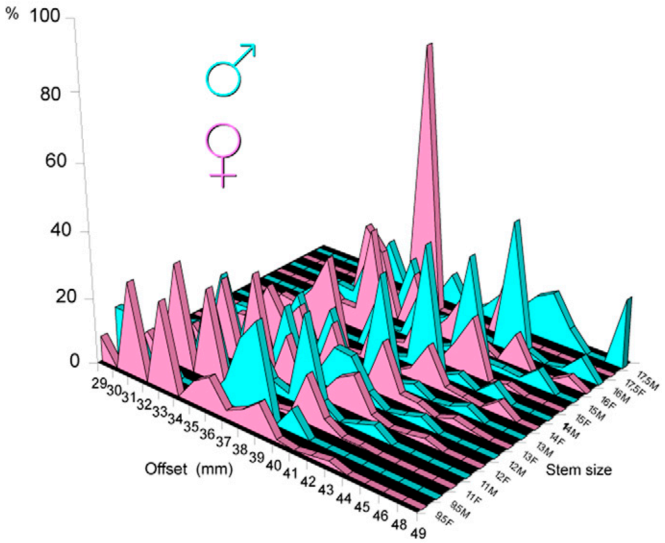


Fig. 12

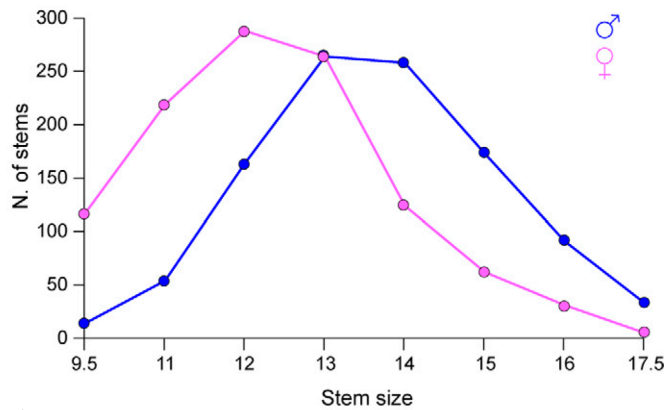


Fig. 13

Fig. 12 Offset distribution correlated with stem size distribution in both women and men. Offset in women was lower than that in men independent of stem size. **Fig. 13** Distribution of stem sizes in women and men. The implant used in this series is available in eight different sizes. Smaller stems were predominantly used in women.

This wide choice of different geometries provided with the two neck lengths offered a range of possible offsets of 13.5 mm. The differences between the men and women in terms of implant offset, implant length, and hip dislocation were evaluated (Fig. 7).

Kaplan-Meier survivorship analysis was carried out with an end point of revision for any reason except infection. We compared implant survival between women and men with use of the Wilcoxon test. Categorical variables (stem size, neck length, and neck version) were analyzed with use of the Pearson test for significance. The Student t test with the Levene test for equality of variance was used to analyze continuous variables (offset, height, weight, and body mass index).

Source of Funding
This study was carried out without external funding sources.

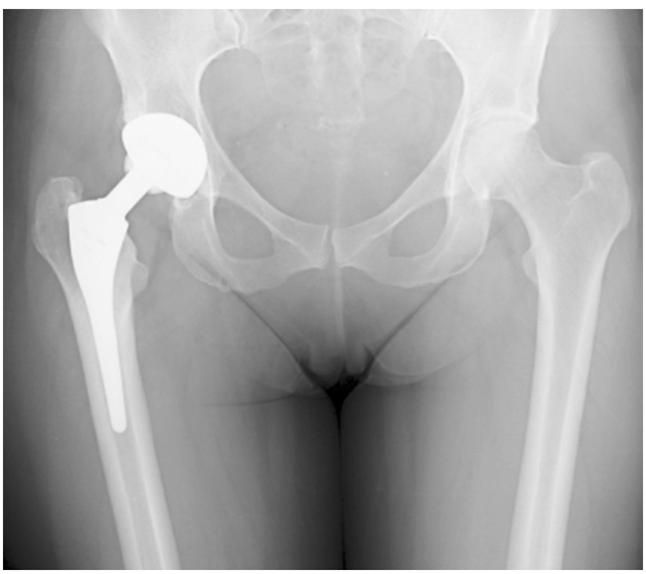


Fig. 14

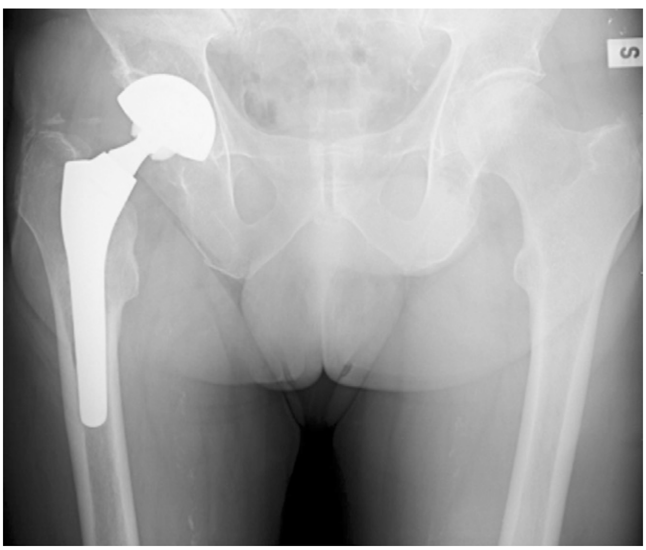


Fig. 15

Fig. 14 A patient with a small femoral canal and a long femoral neck. Prosthetic modularity allowed restoration of proper anatomy, with avoidance of limb-length discrepancy and restoration of femoral offset. **Fig. 15** A patient with a large femoral canal and a short femoral neck, anatomy typical of older women. In this case, a short neck of the femoral component allowed the surgeon to restore offset and lower-limb length independent of the large stem size required to fill the femoral canal and achieve good primary stability.

Results

The estimated cumulative survival rate at eleven years was 96.8% (95% confidence interval, 95.7% to 97.9%) for all hips (Fig. 8), whereas it was 96.0% (95% confidence interval, 94.1% to 97.8%) for women and 97.6% (95% confidence interval, 96.4% to 98.8%) for men (p = 0.07) (Fig. 9).

The distributions of prosthetic neck lengths and versions differed between men and women (Figs. 10 and 11). A short neck was used in 73.7% of the women and 51.5% of the men (p = 0.0001). An anteverted-retroverted neck was used in 27.8% of the women and 21.6% of the men (p = 0.0001).

The average amount of implant offset was 36.9 mm in women and 39.7 mm in men (p = 0.0001) (Fig. 12). The distribution of stem sizes differed significantly between the sexes, with a small size used in 31% of the women and in 6% of the men (p = 0.0001) (Fig. 13).

The average femoral neck length used to recover lower-limb length was 41.9 mm in women and 44.3 mm in men (p = 0.0001). Neck length was not always correlated with stem size.

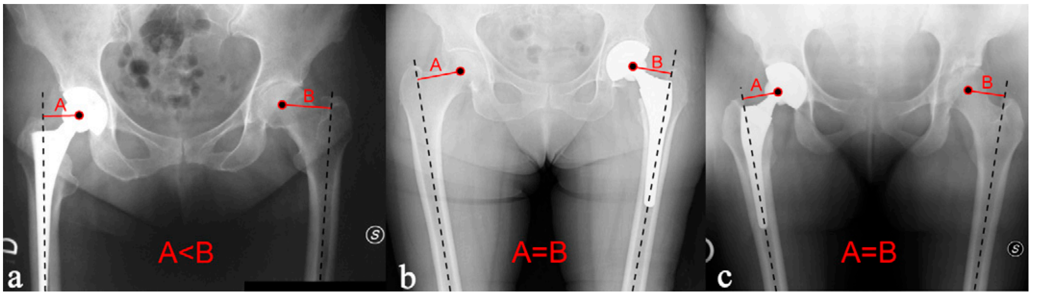


Fig. 16

a: A patient with a thin femoral shaft, a large femoral offset, and a short neck. A monoblock prosthesis was used to achieve equal lower-limb lengths, and the offset was reduced. *b:* A patient with a large femoral shaft, a large offset, and a short neck. A modular neck prosthesis allowed the surgeon to restore hip offset, equalizing the lower-limb lengths. *c:* A patient with a thin femoral shaft, a long neck, and a low offset. A modular neck prosthesis allowed the surgeon to restore the hip anatomy.

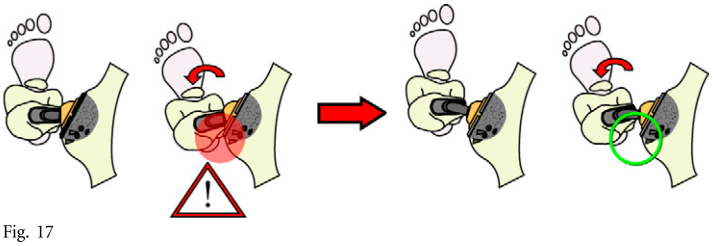


Fig. 17

Diagram showing how a retroverted neck helps to reduce the risk of implant impingement and dislocation in hip adduction-external rotation.

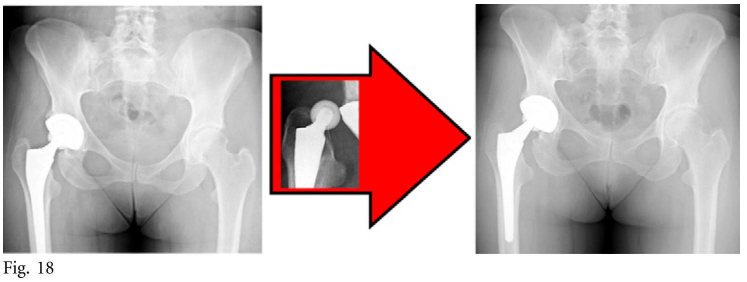


Fig. 18

A woman with a short straight modular neck, reducing lower-limb length and decreasing hip offset. After dislocation (center), revision surgery was performed. A long retroverted neck was implanted in order to equalize the limb lengths, restore femoral offset, and avoid impingement in adduction and external rotation.

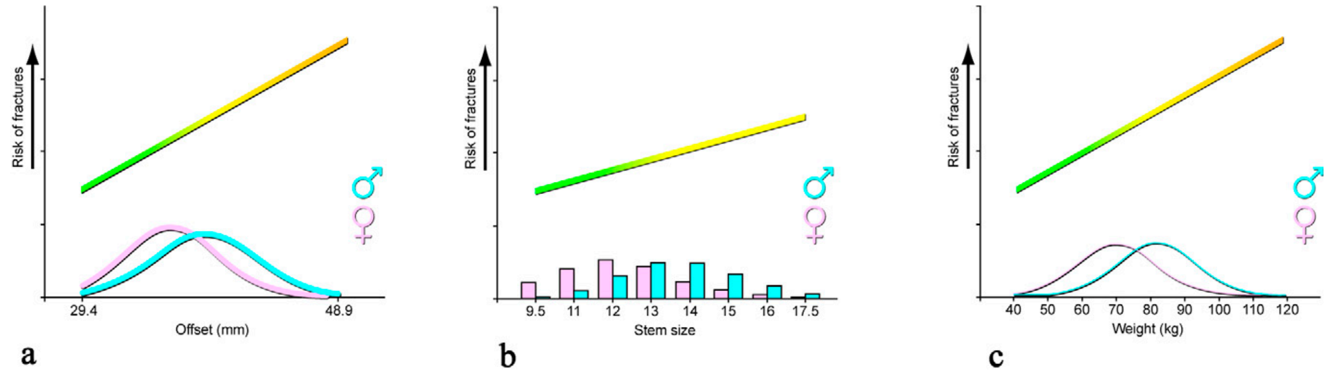


Fig. 19

The relative risk of failure of modular implants in men and women. Analysis of the demographic characteristics of the two populations under investigation in this study showed a lower risk of neck failure in women than in men. This lower risk of failure in women is due to an average lower implant offset (a), smaller stem size (b), and lower body weight (c). High offset, large stems, and high body weight increase the risk of modular neck failure.

A long neck was used with 29.8% of the small stems, and a short neck was used with 50.2% of the large stems (Figs. 14 and 15).

The dislocation rate in these patients was 0.7% (0.9% in women and 0.5% in men).

Discussion

The aim of this study was to assess the ability of a modular neck and stem to address differences in hip anatomy between the sexes. The results of this retrospective analysis of 2131 modular total hip replacements implanted in 1051 men and 1080 women with primary arthritis showed that the distributions of stem size, implant offset, and neck length differed significantly between women and men. These differences correspond to the differences typically seen in hip anatomy between the sexes (Fig. 1) and suggest a real ability of modular hip systems to address such anatomic variations.

Some monoblock prostheses increase offset and neck length and elevate the center of rotation proportionally with increasing stem sizes. These designs cannot be applied to all anatomic variations and may be especially disadvantageous for women.

Three aspects of the function of hip joint replacements are influenced by femoral offset: hip strength, motion, and stability. Increasing the lever arm of the muscles increases abductor strength, decreases the prevalence of a Trendelenburg gait, and enhances implant stability[3]. An anatomic study indicated that use of a monoblock prosthesis does not accurately restore the hip center of rotation and femoral offset in up to 67% of patients[10]. Furthermore, it was noted that eight different neck-shaft-angle solutions are required to restore the anatomy accurately in only 50% of patients.

Modular neck stems are particularly useful when there is a mismatch between the stem size and neck length and when there is a large amount of neck anteversion (Fig. 16). Both of these situations are seen more frequently in women than in men, and this anatomic difference between the sexes, which is not always addressed by monoblock stems, could result in a higher dislocation rate.

A study of 51,345 revision total hip arthroplasty procedures showed that the most common reason for revision arthroplasty in the United States is dislocation (22.5%), followed by mechanical loosening (19.7%) and then infection (14.8%)[20]. The prevalence of hip dislocation reported in the literature ranges from 1.5% to 3%[12-15], and dislocation is more frequent in women than in men (a female-to-male ratio of 4:1). In this study, the overall prevalence of dislocation was 0.7%, with a female-to-male ratio of 2:1 (a 0.9% rate in women and a 0.5% rate in men). This improvement may have been due to the effectiveness of the modular necks with regard to balancing the offset and soft tissues and preventing impingement due to femoral neck version (Fig. 17). Furthermore, dislocation of a modular stem usually requires only a revision of the neck. Stability is achieved by replacing the modular neck, increasing the neck offset or changing the amount of neck version, a procedure that does not require a revision of the osseointegrated component (Fig. 18).

One limitation of this study is its retrospective nature, although all patients were routinely followed and data were collected prospectively. Another limitation is that the clinical results were not compared between the two groups because different clinical scores were employed to evaluate the patients, making any meaningful comparison impossible. For this reason, the rates of revision and dislocation of the prostheses were compared instead.

Modular neck prostheses have the potential to restore hip anatomy accurately; however, the surgical technique must be accurate to achieve this result. Understanding the relative positions of the cup and stem is fundamental to choosing the best neck solution. Preoperative planning is mandatory, and the preoperative plan should be followed. If for any technical reason the position of the implanted cup or stem differs from what was planned, use of a different neck can help to recover proper offset and correct implant length. For example, if the stem is less well seated in the femoral canal than was planned the surgeon can choose a shorter neck with an equal offset, or if the intraoperative evaluation of the implant's range of motion shows impingement in external rotation a retroverted neck can be chosen, without changing the length of the limb.

Even if implant modularity has some evident advantages, it introduces a major risk of implant failure. A neck failure rate of 0.027% (thirty-five of 130,000 prostheses) was reported by the manufacturer of the implant evaluated in this study (Wright Medical Technology). There were no neck failures in the present series, but we wondered if the risk of failure differs between the sexes and explored the question by analyzing the demographic parameters of the two populations under investigation. Laboratory mechanical tests have shown that failure of modular necks is related to neck offset (neck length + head length), stem size (the larger the stem, the higher the risk), and body weight[18]. On the basis of these parameters, there is a lower risk of neck failure in women than in men (Fig. 19).

In conclusion, the ability of a modular neck total hip system to address anatomic variability of the hip was evaluated in this study. Our results show that women and men were treated with different modular components to achieve proper anatomic reconstruction of the hip anatomy. The long-term results did not differ significantly between the sexes, and the hip dislocation rate, particularly in women, was lower than those in other reports[13-15]. We can conclude that modular neck prostheses that allow adjustment of offset, neck version, and lower-limb length independent of stem size are helpful in restoring hip anatomy in both women and men. ■

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