THE EFFECTIVENESS OF DUAL OFFSET STEMS IN RESTORING OFFSET DURING TOTAL HIP REPLACEMENT

P. DOLHAIN, H. TSIGARAS, R. B. BOURNE, C. H. RORABECK, S. MAC DONALD, R. MC CALDEN

Commonly, total hip prostheses have had a higher neck-shaft angle than the host bone and thus a tendency to reduce the femoral offset. Restoration of the femoral offset may be important as it has been shown to enhance hip stability and to improve the range and strength of abduction. The purpose of this study was to determine which of two designs was best able to restore femoral offset in comparison to the contralateral normal hip. Two hundred and two primary total hip patients were included in a radiographic study. Measurements were taken from a postoperative anteroposterior radiograph of the pelvis. The Synergy femoral component with a more varus neck-shaft angle of 131° and a standard or high offset option tended to restore the femoral offset more reliably than did the Mallory-Head femoral component with a neck shaft angle of 135°.

Keywords : total hip arthroplasty ; femoral component ; offset.

Mots-clés : prothèse totale de hanche ; composant fémoral ; latéralisation.

INTRODUCTION

Charnley was among the first to emphasize the importance of restoring normal hip biomechanics as a goal of total hip replacement. One of the cornerstones of his philosophy was restoring or increasing the abductor moment arm (5). He considered offset restoration to be a factor under control of the surgeon at the time of total hip replacement surgery and accomplished this by using components of appropriate offset, making the neck cut at the appropriate level and lateralising the greater trochanter. Now that trochanteric osteotomy is no longer a standard approach, the major tool at the disposal of the surgeon for increasing the abductor moment arm is restoring or increasing the femoral offset (32). Femoral offset is defined as the perpendicular distance between the long axis of the femur and the centre of rotation of the femoral head. Commonly total hip prostheses have had a relatively high neck-shaft angle and therefore a tendency to reduce the femoral offset (3), since the average femoral neck-shaft angle has been found to be about 125° (2, 25, 29). Multiple operative factors including the level of the femoral neck osteotomy, the varus/valgus positioning of the femoral stem, femoral neck length and the position of the acetabulular components all have an influence on the offset of the replaced hip. In addition, femoral design is very important in restoring the femoral offset.

The purpose of this study was to determine which of two prosthetic designs was best able to restore femoral offset in comparison to the contralateral limb.

Department of Adult Reconstructive Surgery, London Health Sciences Centre, University of Western Ontario, London, Ontario, Canada.

Correspondence and reprints : Dolhain Pieter, Onze Lieve Vrouw Middelares Ziekenhuis Deurne, Dienst Orthopedie, Stevenslei 20, 2100 Deurne, Belgium.

E-mail : pieterdolhain@hotmail.com.

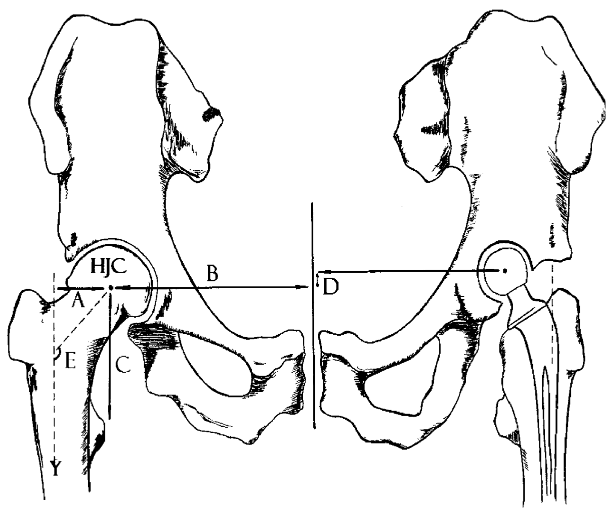

Fig. 1. — Radiographic measurements and definitions
A : Femoral offset
B : Body moment arm
C : Head centre height
D : Vertical displacement of joint centre
E : Neck-shaft angle
HJC : Hip joint centre
Y : Mid-diaphyseal femoral axis

MATERIALS AND METHODS

Two hundred and two patients who had undergone a unilateral primary total hip replacement were included in a radiographic study.

Radiographic measurements were taken from a postoperative anteroposterior radiograph of the pelvis, with symmetrical obturator foramina and inclusion of at least the upper third of both femora (fig. 1).

Since rotation of the femur has a significant effect on the measurements of both the neck-shaft angle and femoral offset, the femora had to be internally rotated approximately 15 to 20° to bring the femoral neck into the coronal plane (12, 18). This criterium was considered to have been achieved when both medial cortices of the greater trochanter were superimposed (19, 26).

Preoperative radiographs of the affected hip were not used as a baseline measurement of offset, because of significant osteoarthritic joint destruction and distortion. An assumption , that both hips have a similar morphology, prior to the onset of osteoarthritis, has been supported by previous authors (7, 10, 13). This allowed the contralateral hip to be used for the comparative measurements. We excluded patients with a diagnosis of rheumatoid arthritis, congenital dislocation of the hip or patients undergoing revision surgery. Patients with femoral stems implanted in varus or valgus greater than 3 degrees were also excluded.

Two different cementless implants with tapered geometries, but with a different neck-shaft angle were used for reconstruction of the affected hip. Patients were placed in one of the two cohorts based on the femoral component used at operation.

From 307 cementless Mallory-Head total hip replacements (Biomet Inc., Warsaw, Indiana), inserted between October 1987 and September 1990, we were able to identify 93 patients with unilateral hip disease and satisfactory anteroposterior postoperative radiographs. The neck-shaft angle of the Mallory-Head femoral component was 135°, with one offset option for increasing size stems (fig. 2).

Between January 1997 and April 2000, 463 cementless Synergy total hip replacements (Smith&Nephew, Memphis,TN) were implanted. A subset of 109 patients, having a unilateral total hip replacement for primary osteoarthritis of the hip with a disease-free contralateral hip, were selected into the study (fig. 3). The Synergy femoral component has a neck-shaft angle of 131° and was available in standard and high offset versions. The high offset version of the Synergy femoral stem is achieved by shifting the neck of the prosthesis medially in association with an increased femoral neck length, while the neck-shaft angle remains 131° (fig. 4).

All radiographic measurements were performed by a single observer (P.D.). The initial measurements were then corrected for magnification, by using the known diameter of the prosthetic femoral head. Measurements were taken for both the operative and the nonoperative sides. All measurements were recorded and statistically analysed once the magnification factor had been applied to the data.

The hip joint centre was defined using concentric circular templates, applied over the native and prosthetic femoral heads (fig. 1-HJC). The mid-diaphyseal femoral axis was then determined (fig. 1-Y). The lateral (horizontal) distance, from the hip joint centre, perpendicular to the mid-diaphyseal femoral axis, defined the femoral offset (fig. 1-A). The perpendicular distance from the hip joint centre to the midline of the pelvis represents the body moment arm (fig. 1-B). The vertical distance on the pelvic midline between perpendiculars from the normal and prosthetic joint centres defined the vertical displacement of the joint centre (fig. 1-D). The vertical distance from the joint centre to the most prominent point of the lesser trochanter defined the head centre height (fig. 1-C). Finally the angle between the femoral neck

Fig. 2. — Postoperative anteroposterior radiograph after implantation of a Mallory-Head femoral stem.

Fig. 3. — Postoperative radiograph after implantation of a Synergy high-offset stem.

and the mid-diaphyseal femoral axis defined the femoral neck-shaft angle (fig. 1-E).

The measurement of the neck-shaft angle and the femoral offset on the nonoperated and operated side was performed for all patients included in the study. The other measurements (horizontal and vertical displacement of the joint center, head centre height and body moment arm) were performed for 87 patients in the Mallory-Head group, and for 94 patients in the Synergy group. These 181 patients were comparable to the general population of 202 patients regarding sex and age.

Optimization of leg length and offset requires the ability to perform accurate intraoperative measurements. A specialized, intra-operative leg length and offset device was used in all cases. Like most devices, this jig relies on repeated measurements of the distance between fixed points on the ilium and the femur (14, 17, 33, 34). The iliac pin was inserted via a separate stab incision. The lateral aspect of the greater trochanter was marked, and with the hip in full extension, the predislocation leg length and offset were recorded (fig. 5). After reduction of the trial implants, and the limb in full extension, changes in leg length and offset were assessed. Adjustments were made to length or offset by using a longer femoral head in the Mallory-Head prosthesis or by using the femoral component with the high offset

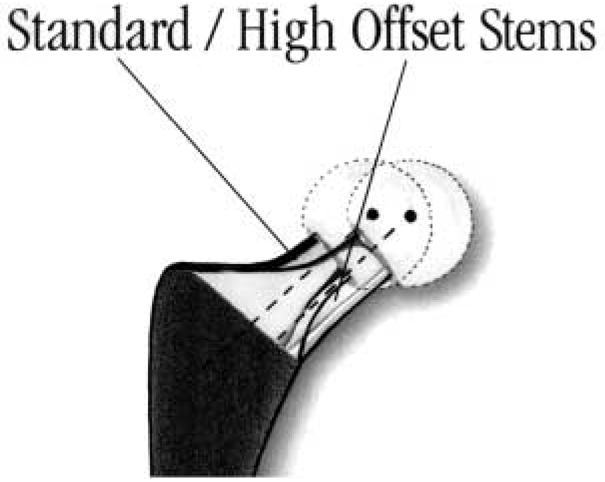

Fig. 4. — Figure of a Synergy femoral stem, depicting how the higher offset is achieved by medialization of the femoral neck, in association with an increased femoral neck. The neck-shaft angle can remain consistent.

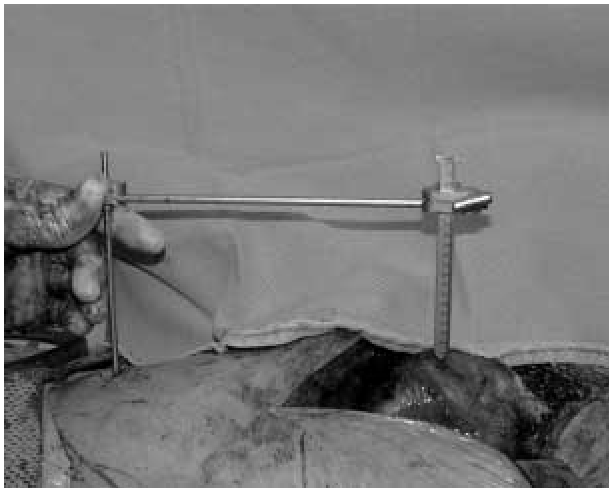

Fig. 5. — Device used for intra-operative measuring of femoral offset and leg length (Smith & Nephew, Memphis, TN).

option in the Synergy system. It should also be noted that particular attention was paid to securing the pelvis, since shifts in position during surgery can significantly affect intra-operative measurements.

RESULTS

The mean age for both groups was 64 ± 10 years. The sex distribution was 49 men (53%) and 44 women (47%) in the Mallory-Head group, and 57 men (52%) and 52 women (48%) in the Synergy group. Primary osteoarthritis was the sole reason for replacement in all cases included in this radiographic study. The mean Harris Hip Score at one year follow-up was 94.3 ± 10 for the Mallory-Head population and 94.2 ± 6 for the Synergy group.

The mean femoral neck-shaft angle of the non-operative side was 126° ± 6 for the Mallory-Head group and 125.5° ± 6 for the Synergy group (table I).

The Mallory-Head group had a mean femoral offset of 38.2 ± 5.6 mm of the non-operative side and 34.7 ± 5.7 mm of the operated side (p<.001). This meant that femoral offset was undercorrected by a mean of 3.5 mm. The mean horizontal displacement of the joint centre with respect to the pelvis was –3.7 mm and the mean vertical displacement was 6.8 mm. The mean head centre height was 49.1 ± 6 mm on the non-operative side and 59.7 ± 7 mm on the operated side. This meant that the proximal femur was postoperatively lengthened by a mean of 10.6 mm. The mean body moment arm was 90.3 ± 6 mm on the non-operated side and 86.6 ± 6 mm on the operated side.

The mean femoral offset of the Synergy group was 39.1 ± 5mm and 39.6 ± 6 mm of the non-operated and operated sides, respectively (P = .118). With respect to the pelvis, the mean horizontal displacement of the replaced joint centre was -3.7 mm and the mean vertical displacement was 5 mm. The mean head centre height was 50.6 ± 6 mm and 57.8 ± 7 mm on the non-operated and operated side respectively, which means that the proximal femur was postoperatively lengthened by a mean of 7.2 mm. The mean body moment arm was 90.8 ± 5 mm on the non-operative side and 86.9 ± 5 mm on the operative side. There was no significant difference in the preoperative femoral offset, between the two groups.

For this study, successful restoration of femoral offset was defined as reconstructing the hip joint centre to within 4 mm , as compared to the non-operative side. Using this criterion, femoral offset

Table I. — Radiographic measurements

	Number	Average	Standard Deviation	Minimum	Maximum
MALLORY-HEAD.					
Neck-shaft angle (°)	93	126	6	114	140
Femoral Offset (mm)					
nonoperated	93	38.2	6	24.7	55.2
operated	93	34.7	5	23.6	46
Horizontal displacement of joint centre (mm)	87	-3.7	5	-19.6	10.2
Vertical displacement of joint centre (mm)	87	6.8	5	-4.1	18.9
Head centre height (mm)					
nonoperated	87	49.1	6	27.9	63.4
operated	87	59.7	7	44	76.5
Body moment arm (mm)					
nonoperated	87	90.3	6	76.3	106
operated	87	86.6	6	66.7	101.7
SYNERGY					
Neck-shaft angle (°)	109	125.4	6	112	140
Femoral Offset (mm)					
nonoperated	109	39.2	6	25.9	52
operated	109	39.6	6	27.2	52.8
Horizontal displacement of joint centre (mm)	94	-3.7	6	-21.3	10.7
Vertical displacement of joint centre (mm)	94	5	6	-8	20
Head centre height (mm)					
nonoperated	94	50.6	6	32.7	66.4
operated	94	57.8	7	37.4	79.2
Body moment arm (mm)					
nonoperated	94	90.8	5	76	103.9
operated	94	86.9	5	75.7	100.6

was restored in 99 of 109 patients (90.8%) in the Synergy group. In the Mallory-Head group femoral offset was restored in 38 of 93 patients (40.8%) ($P < .001$) (figs. 6A and 6B). Scattergrams are presented for both groups (figs. 7A and 7B). The Synergy group had a correlation coefficient of +0.856, as compared with the Mallory-Head group, which had a correlation coefficient of +0.656. The 'standard' offset Synergy femoral component was used in 67cases (61%), the 'high' offset version in 42 patients (39%).

No statistical significance was detected between the neck-shaft angle measurements of the non-operated hips, nor the horizontal and vertical displacement of the acetabular sockets after total hip replacement for the two groups.

DISCUSSION

In comparing the reconstruction of the prosthetic hip joint centres of the Mallory-Head and the Synergy patient groups, the most significant difference was the undercorrection of the femoral offset in the Mallory-Head group. The acetabular sockets were similarly reconstructed, both medially and superiorly, due to reaming of the acetabulum and the proximal femur was lengthened similarly in both patient groups. The average neck-shaft angle of the non-operated sides was 125.4° for the Synergy group and 126° for the Mallory-Head group, which is similar to results found in the literature. All femoral components were similarly placed in a neutral position.

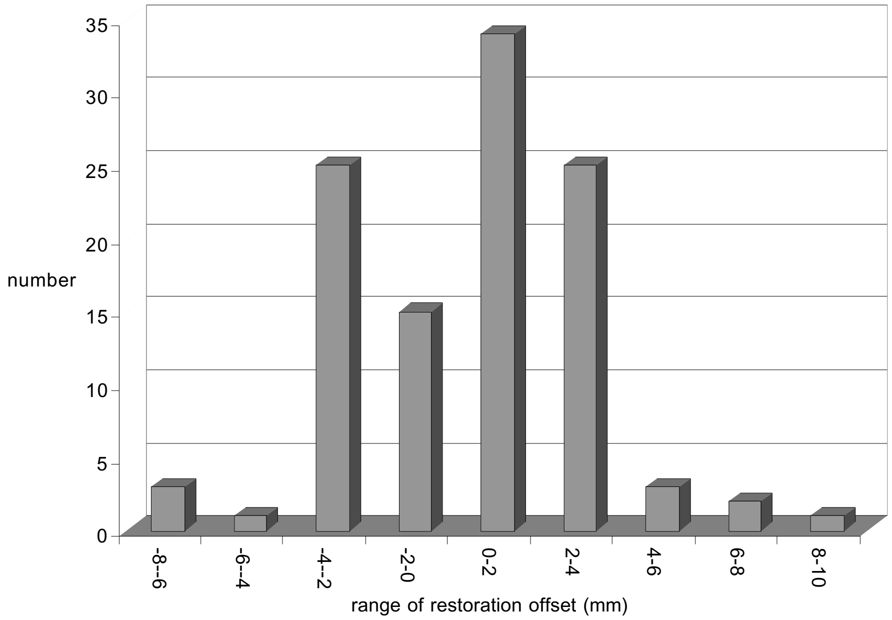

Fig. 6a. — Distribution of the restoration of femoral offset with the Synergy femoral component

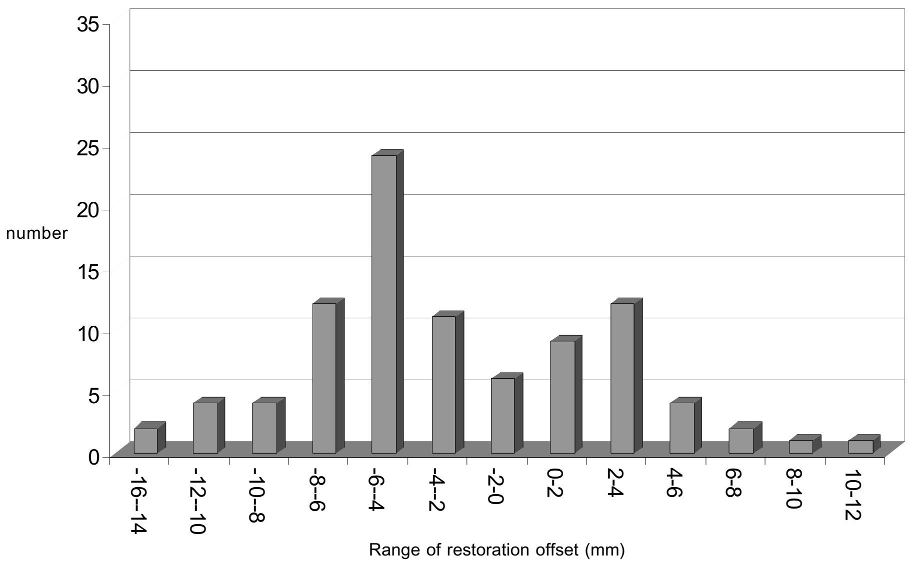

Fig. 6b. — Distribution of the restoration of the femoral offset with the Mallory-Head stem

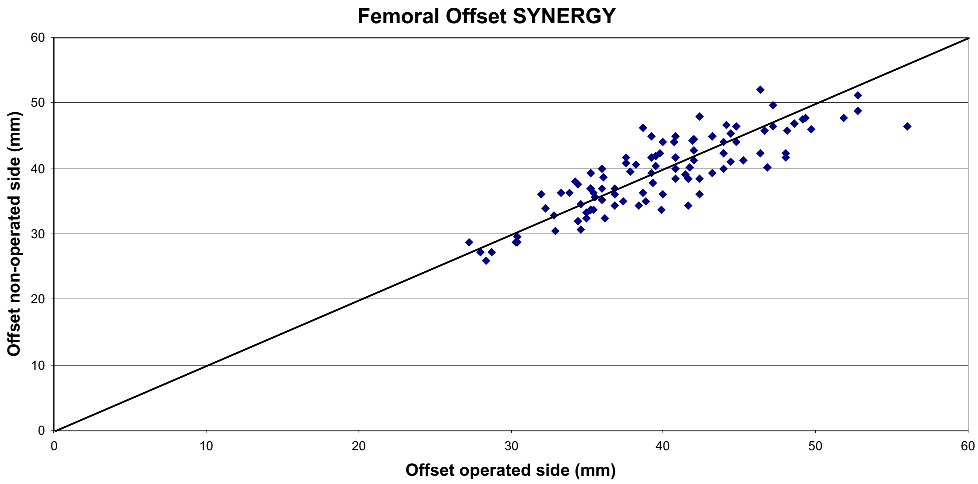

Fig. 7a. — Scattergram plotting the operative femoral offset against the nonoperative offset for the Synergy component, depicting how offset was restored or not restored.

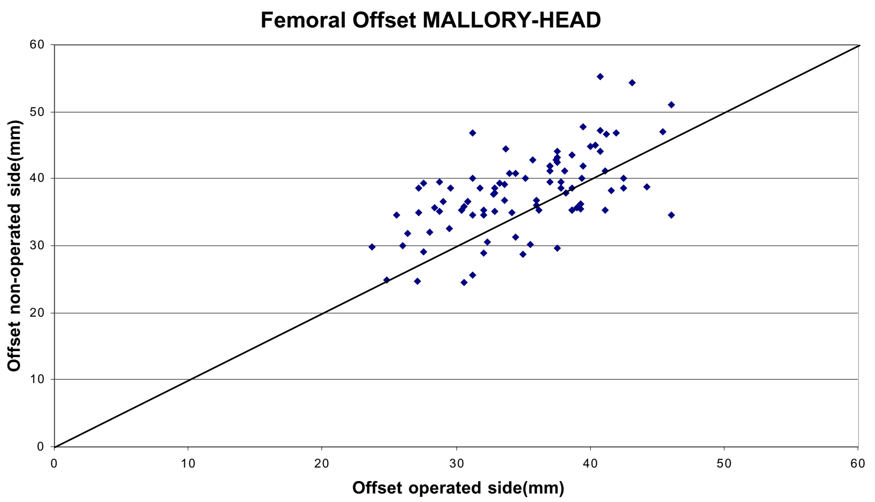

Fig. 7b. — Scattergram plotting the operative femoral offset against the nonoperative femoral offset for the Mallory-Head component.

The Synergy hip system tended to restore offset of the replaced hip more reliably than the Mallory-Head system .The Synergy group had a correlation coefficient of +0.856, as compared with the Mallory-Head group, which had a correlation coefficient of +0.656. The Synergy stem demonstrated a more linear relationship compared to the Mallory-Head group, and thus a more consistent pattern in restoration of offset was observed.

The femoral offset is an important design feature that should be optimised since it profoundly affects the mechanical function of the replaced hip. The mechanical stability of the prosthetic joint is critically affected by abductor muscle tone. The length of these muscles and the compressive force developed in the hip joint are determined by the inferior and lateral position of the greater trochanter with respect to the ilium. Decreasing the femoral offset has a number of negative effects. If the joint replacement displaces the femur medially, the mechanical efficiency of the abductor mechanism will be reduced by decreasing the abductor moment arm. This results in larger muscle energy expenditure for normal gait, and thus contributes to a Trendelenburg limp and the need for walking aids (28). In isokinetic tests, Mc Grory *et al.* (21) demonstrated reduced strength in hips with lesser offset. Reduced femoral offset also reduces the range of motion and increases the potential for femoro-pelvic impingement. Along with soft tissue laxity, all these factors can increase the risk of prosthetic dislocation.(5, 15, 22) A statistically significant increase in dislocation rate has been demonstrated when femoral offset was decreased by insertion of a femoral component with a valgus neck-shaft angle (11). Lowering the abductor moment arm (reducing offset) increases the joint reaction force, and this has deleterious implications for both polyethylene wear and acetabular loosening rates. The correlation between low offset and increased polyethylene wear has been previously demonstrated (9, 27, 30, 31).

Charnley's first generation standard femoral component had a varus stem design with a neck-shaft angle of 130° and a 45 mm offset (5). This varus angle increased the bending moment arm on the prosthesis, multiplying the effect of the hip joint load. To avoid the unacceptable number of stem fatigue fractures with the alloys used at that time, the offset for the standard component was reduced to 40 mm. This reduced the bending and torsional moment on the neck of the femoral prostheses. Despite increased fatigue resistance with modern, superalloy femoral components (32), most implant manufacturers have continued to favour the 'lesser' offset option.

Another potential concern has been that increasing femoral offset can increase strain in the medial proximal femur, and more importantly, in the medial proximal cement mantle.

It has been shown that, even though the lever arm of the bending moment is increased by the increased offset, the bending moment is only marginally increased because of the decrease in resultant force. Consequently the net change in strain in the medial cement mantle is small and uncompromising (8). Furthermore, modern cementing techniques have provided excellent long-term clinical results, with low rates of revision for aseptic loosening of cemented femoral components (4, 23, 24). A recognized clinical disadvantage of increased offset is a prominent greater trochanter, and potential bursitis.

A failure to restore femoral offset may result from the use of femoral components with a valgus neck-shaft angle, a short neck length, femoral components with a single offset stem, or medialisation of the acetabular socket. In our study sockets were placed similarly in both groups. Since there is a tendency to medialize the acetabular socket, it becomes even more important to restore the femoral offset in order to maintain the abductor moment arm.

Several approaches have been adopted to improve restoration of the hip joint centre. One option is the use of custom femoral components to match the individual anatomy of each patient. Intra-operative customization has been expensive, time consuming, and met with mixed clinical results (20). Some modular prostheses provide great versatility in allowing the anteversion of the femoral neck to be varied intra-operatively. In most cases however, the superior and medial position of the femoral head cannot be varied to any greater degree than is possible using standard femoral prostheses and modular heads.

Since offset depends on the neck-shaft angle and the neck length, another option is to supply each size of prosthesis in several neck lengths, or decreasing the neck-shaft angle. Increasing the femoral neck length does not alter the valgus neck-shaft angle of the femoral component and may affect leg length (1). Decreasing the neck-shaft angle may affect leg length as well and may be insufficient to restore femoral offset. This is suggested by the fact that the high offset femoral stem in our study was used in 39% of cases.

The level of neck resection also plays a significant role, by determining the depth of femoral component 'seating'. A low neck cut and a long prosthetic head may be combined to restore both leg length and offset, as in a case of coxa vara.

However, sacrifice of the femoral neck results in diminished torsional stability of the implant. The use of a longer head and neck segment also increases the stress placed on the prosthetic neck. Adequate femoral length may require a skirted femoral head, which can lead to reduced range of motion, impingement and dislocation. The need for a long head may exclude the possibility of using a ceramic component.

Our study suggests that reproducible restoration of femoral offset requires the use of a femoral component with distinct design characteristics. The neck-shaft angle can remain consistent, but a dual offset capability is offered by allowing the neck to be shifted medially in the high offset version. This is associated with an increased femoral neck length. This also allows the same stem body (broach) to be used, and the neck resection level does not have to be altered.

CONCLUSION

The Synergy hip with a 131° neck-shaft angle and a dual offset option tends to restore the femoral offset of the replaced hip more reliably than does the Mallory-Head femoral component with a valgus 135 ° neck-shaft angle. A lower implant neck-shaft angle, in combination with at least dual options, tends to improve the restoration of the femoral offset in total hip arthroplasty.

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SAMENVATTING

P. DOLHAIN, H. TSIGARAS, R. B. BOURNE, C. H. RORABECK, S. MAC DONALD, R. MC CALDEN. Het herstel van de hefboomarm van de heup bij middel van een prothesis met twee varianten van schaftlateralisatie.

De meeste heupprothesen hebben een nek-schacht hoek die groter is dan de gemiddelde hoek van een normale heup, en bijgevolg de neiging om de femorale offset te verkleinen. Nochtans is het behouden of herstellen van de femorale offset tijdens een totale heupprothese van groot belang : het bevordert de stabiliteit van de heup en verhoogt de beweeglijkheid en de kracht van de heupabductoren. Het doel van deze studie was om na te gaan in welke mate twee verschillende femorale componenten de offset kunnen herstellen, en dit in vergelijking met de contralaterale gezonde heup. Twee honderd en twee patienten werden opgenomen in deze radiografische studie. De Synergy femorale component met een nek-schacht hoek van 131°, en beschikbaar in een versie met standaard offset of verhoogde offset, slaagt er in om de offset nauwkeuriger te herstellen, in vergelijking met de Mallory-Head component die een nek-schacht hoek heeft van 135°.

RÉSUMÉ

P. DOLHAIN, H. TSIGARAS, R. B. BOURNE, C. H. RORABECK, S. MAC DONALD, R. MC CALDEN. Restauration du porte-à-faux fémoral dans l'arthroplastie totale de hanche, avec une tige offrant deux versions plus ou moins latéralisées.

Les prothèses fémorales ont en général un angle cervico-diaphysaire supérieure à celui des hanches où elles sont implantées, ce qui tend à réduire le porte-à-faux fémoral. Sa restauration peut être importante, car on a montré qu'elle peut améliorer la stabilité prothétique et la force des abducteurs. Ce travail a cherché à déterminer, parmi les deux tiges fémorales utilisées, laquelle était le plus à même de restituer le porte-à-faux fémoral par référence à la hanche opposée, normale. Le porte-à-faux fémoral a été mesuré sur les radiographies post-opératoires du bassin, de face, chez 202 patients qui avaient subi une arthroplastie primaire par prothèse totale de la hanche. Le porte-à-faux a été restauré de façon plus précise avec la tige Synergy, dont l'angle cervico-diaphysaire est de 131° et qui existe en deux versions – standard et latéralisée – qu'avec la tige de Mallory-Head, dont l'angle est de 135° et qui n'offre pas d'option quant à sa latéralisation.