Why Use a Custom-made Hip Prosthesis? A 10-Year Experience

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Total hip arthroplasty (THA) is now a routine procedure used to relieve pain and restore function. The results of the procedure depend on several factors: implant positioning, bone implant fixation, bone stock, and restoration of a physiological musculo-articular unit. The prosthesis may be cemented or used without cement.

In the latter case, mechanical stability relies on implant fit and fill to reduce micromotion[1] and ensure long-term fixation. This fixation is usually enhanced by surface coating of the stem.[2] While the goal of THA is routinely reached in common osteoarthritis, it is often more difficult when the anatomy of the hip is modified. In these cases, fit can be achieved by designing a stem adapted to the modified anatomy to provide optimal stress transfer.[3]

FEMORAL ANATOMY AND STEM DESIGN

The direct analysis of femoral anatomy is provided by cadaver studies. For the clinician two methods are commonly available: X-rays and CT scan. The comparison of cadaver measurement to radiographic data led P. Noble et al.[4] to develop a classification of the proximal femoral anatomy dividing the femurs in three groups. For the category of "Champagne-fluted" femurs, the designer had difficulty in achieving correct fit and fill with conventional stems.

In a similar study including cadaver radiographic and CT-scan data,[5] we found similar results with 10% of femurs where a custom-made prosthesis was the ideal solution to obtain fit and fill.

These findings confirm the laboratory studies by Walker and Robertson,[6] in which a custom design was able to optimize stress transfer and thus reduce stress shielding.

These femoral anatomy classifications concern the majority of the population but exclude all cases where the "normal" anatomy is modified for reasons of congenital disease, traumatic or iatrogenic lesion, and osteoarticular or tumoral effects. For these additional etiologies, a custom stem is often able to solve some surgical difficulties and restore hip biomechanics.[7]

CUSTOM PROSTHESIS DEVELOPMENT

The conception of the stem is achieved by computer-assisted design. The differences in the procedures start with the source of data. Some of them use two radiographic views of the femur in two orthogonal planes.[8] The next step is the use of computerized tomography images of the femur and reconstruction of femoral anatomy.[3,9,10] Finally the stem is designed by using a mold of the intramedullary femoral cavity.[11]

In our approach to custom prostheses, the custom design must include two parts: the intramedullary anatomy and the extramedullary aspect of the reconstruction. The latter integrates in the design the elements of the preoperative planning which lead to neck offset.

We started our experience of custom prosthesis in 1983 with a few cases of congenital dislocation of the hip (CDH), where it was simply impossible to insert the smallest implant available at this date, and this despite previous extensive experience of our department in THA with osteoarthritis following CDH.[12] During the first five years we used a custom design (Egoform, Landos, Chaumont, France) based on two X-rays in A/P and M/L views. When in most cases we did improve the fit and fill of the prosthesis procedure, it was still impossible to integrate the extramedullary aspect in the prosthesis design. The prosthetic neck was, as in off-the-shelf prostheses, always located in the axis of the collar or the upper part of the stem in the horizontal plane.

In some cases this has no consequence on hip function because of the natural “tolerance” of the muscles and articulation after arthroplasty. In other cases where an excessive anteversion of the upper femur occurs, this may lead to lower limb dysfunction or rapid wear of the components by focused hyperpression.[13]

In two cases where the torsion of the upper femur was measured at 45° and 50° on the bicondylar plane, we had to perform secondary osteotomy of the distal femur to correct the internal rotation of the lower limb and restore normal hip biomechanics. By measuring on the CT scan this upper femoral torsion in a group of 150 cases planned for total hip arthroplasty, we found values ranging from 20° to 85°.[14] The extreme values around 70° were obtained in cases of fused hip or high CDH and were similar to those found by other authors.[15,16]

For five years now, we have used a custom prosthesis (Symbios, Osteonics) whose design is able to integrate the extramedullary with the intramedullary aspect of the reconstruction. The intramedullary design is based on the numerical CT-scan data, and the process is achieved in several steps: selection of hard cancellous bone at each level by density gradient, with respect to certain priority contact regions on the femur and a simulation of penetration-extraction of the stem.[17] The final conception includes the extramedullary data of the preoperative planning to design the neck offset.

PREOPERATIVE DATA

The radiographic analysis is based on several views. The first one is a full view of the two limbs using scanography. The patient is supine to reduce the likelihood of movement caused by pain or flexion. The resulting scannogram will determine the exact leg length discrepancy. The second one is a frontal view of the pelvis to evaluate the position of the center of rotation. Finally, frontal and lateral views of both hips are necessary to complete planning. All X-rays must be made without error in magnification for precise measurement

Figure 1. CT-scan data with several views of the proximal femur and the reference ghost to design the intramedullary stem. View of the acetabulum (bottom right) to evaluate the anteroposterior bone stock.

Figure 2 (a, b). Three computerized tomography views are necessary for design of orientation of prosthetic neck: upper femur axis so-called helitorsion (H), posterior bicondylar plane PBCP, and second metatarsus axis.

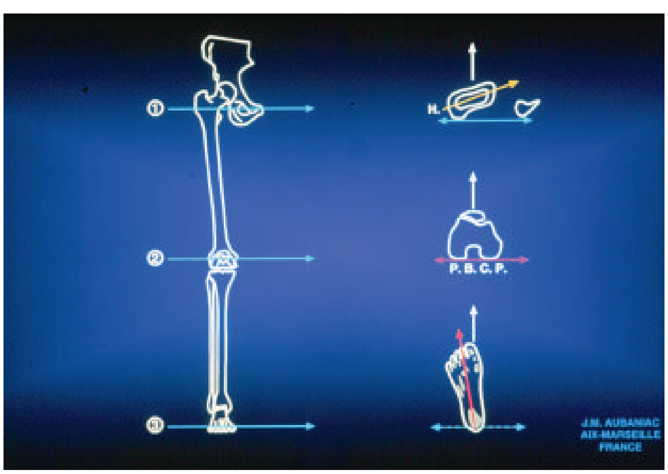

Figure 2a.

Figure 2b.

of the length and determination of the level of the neck osteotomy.

Data from the CT scans are necessary for the intramedullary design of the stem and for planning the extramedullary part of the reconstruction. To assess the intramedullary femoral anatomy, several views (every 5 to 10 mm) are made. The software then reads the CT-scan data, using a reference ghost whose numerical data are known, and the stem is designed by numerical extraction (Fig. 1). Four additional scans are necessary to complete the planning and facilitate design of the extramedullary part of the stem. The first one, through the true acetabular, reveals the acetabular bone stock. The other three provide data for anteversion of the prosthetic neck: above the lesser trochanter (giving the axis of the upper femur) by the knee condylar axis, and in the foot by the second metatarsus axis (Fig. 2).

SURGICAL PLANNING

The first step is to locate the center of rotation in the true acetabulum and the socket size. This is done on the frontal pelvis view using the data of the contralateral hip if it is healthy. In cases of bilateral lesions and in most dysmorphic or highly dislocated hips, the anteroposterior diameter of the true acetabulum will be more precisely assessed by the CT-scan view (Fig. 3).

The next step is the location of the greater trochanter according to this new center of rotation and the desired lengthening as measured on the scannogram. This position will determine the level of the femoral cut and assess the correct neck lever arm on the anteroposterior view. When extensive lengthening is required, an osteotomy of the greater trochanter may be necessary to shift the greater trochanter in the anteroposterior plane to allow correct function of the abductors. In our experience, the level of the femoral cut is always above or in the lesser trochanter (Fig. 4).

The final step is determination of neck anteversion. This is done by superpositioning the three CT-scan views previously mentioned. When using a cementless stem, the aim is accurate fitting of the prosthetic stem to the proximal femur, often excessively anteverted in dysmorphic or dislocated hips.[18] To restore normal gait conditions,[19] the prosthetic neck must be oriented posteriorly on the upper femur axis (H). The angle (AV) between this axis (H) and the prosthetic neck will be negative in most dysmorphic and highly dislocated hips (Fig. 5).

With this Symbios–Osteonics procedure, the surgeon finally gives two data: limb lengthening and lever arm. All the other elements of the preoperative planning leading to neck offset and

Figure 3 (a, b). Location of new center of rotation is done on anteroposterior radiography of pelvis (Fig. 3a) and computerized tomography view (Fig. 3b) to appreciate the acetabulum anteroposterior diameter and choose size of socket.

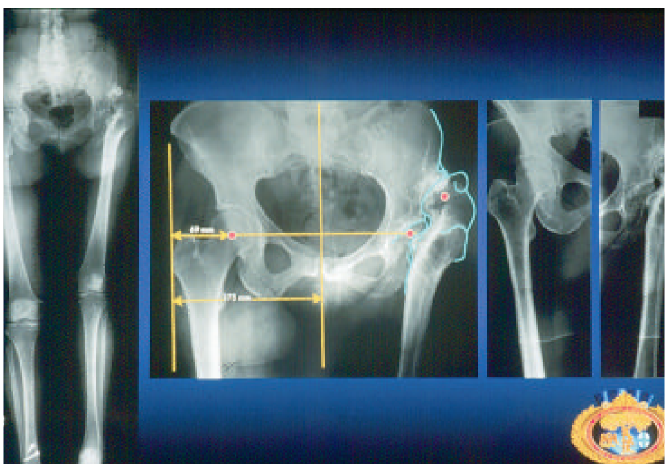

Figure 3a.

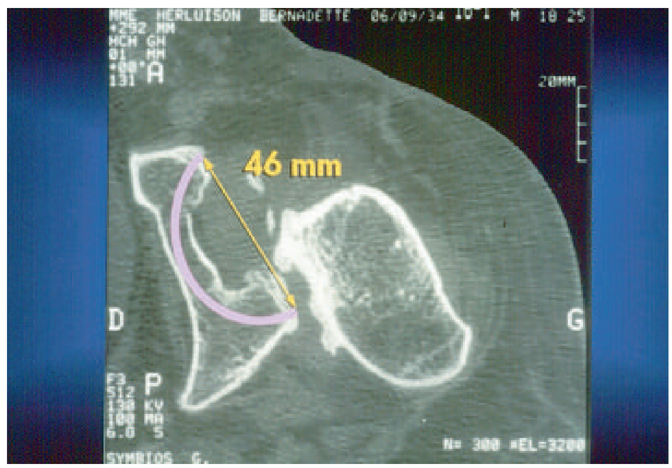

Figure 3b.

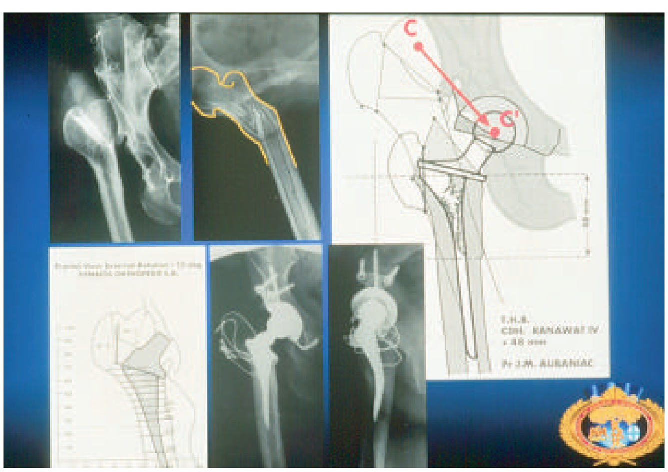

Figure 4. X-rays and preoperative planning of a right hip with high CDH (Grade IV) previously treated by osteotomy, showing the new center of rotation and the femoral cut at the level of the lesser trochanter.

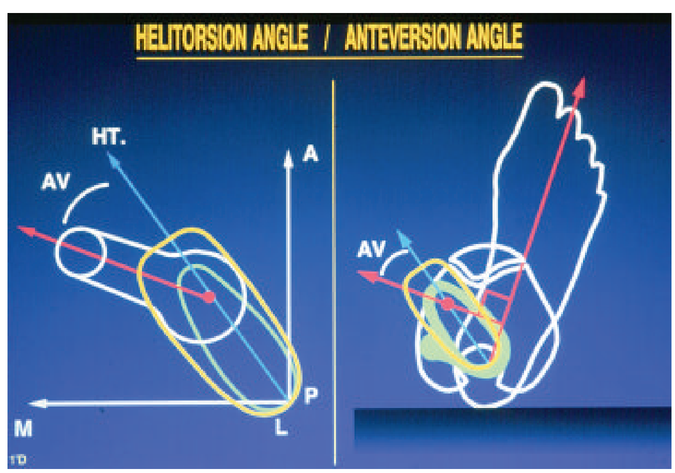

Figure 5. The angle (AV) between upper femur axis (blue line) and the prosthetic neck (red line) is negative in most dysmorphic and highly dislocated hips to create normal anteversion on the bicondylar plane.

including anteversion are automatically calculated by the software (Fig. 6).[20]

SURGICAL TECHNIQUE

An anterolateral modified Watson–Jones exposure is used in all cases.

Acetabular Component

In order to report intraoperatively the center of rotation calculated preoperatively, we use a cementless acetabular component (Centroïd, Symbios) fixed distally by a hook in the obturator foramen. This hook placed at the top of the obturator foramen reports automatically the center of rotation at the same place decided in the planning. The primary stability is achieved by the press fit on one hand and a proximal and distal fixation on the other hand. The proximal fixation is done by four screws with two in the roof, and the distal fixation is provided by the hook. The hydroxylapatite coating of the titanium cup helps for secondary fixation. This Centroïd cup in fact makes use of the principles behind both the cementless press fit Harris cup and the Kerboul reinforcement ring.[21]

Femoral Component

In highly dislocated hips or after previous procedures, wide tenotomies of the proximal third of the femur are necessary including iliopsoas, adductors, and sometimes rectus femoris, in order to avoid any stretching of the sciatic or crural nerves. The medullary canal is prepared with a smooth custom rasp in order to preserve the cancellous bone. By this manner the hard cancellous bone is compressed on the cortical bone. This will provide an optimal layer for the hydroxylapatite coated stem and give the best chances of fixation, if the custom device has provided optimal proximal fit avoiding stem micromotion. The stem design always needs an optimal proximal fit and fill and a reduced distal stem diameter to ensure a smooth stress transfer from the metaphysis to the diaphysis and to avoid thigh pain by stem diaphysis impingement (Fig. 7).

INDICATIONS AND CLINICAL RESULTS

More than 500 custom hip prostheses have been implanted at this date in the department. We have evaluated clinically and radiographically the first 337 cases in

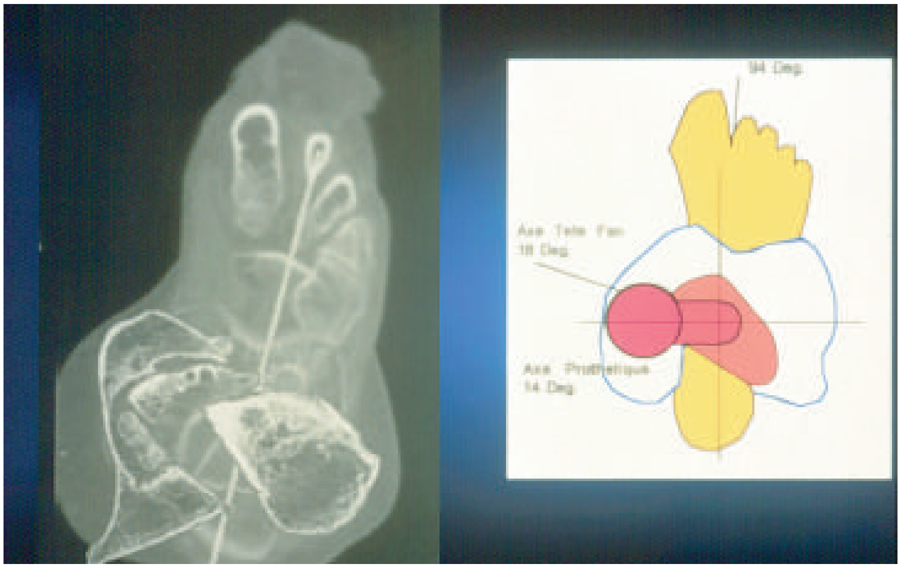

Figure 6. By superimposition of the three computerized tomography views (left), the Symbios software automatically designs the appropriate neck orientation (right). Same case as in Figures 2 and 3.

Figure 7 (a, b). Preoperative data (Fig. 7a) of a bilateral CDH treated by osteotomy for the right hip and custom prosthesis for the highly dislocated left hip (Fig. 7b).

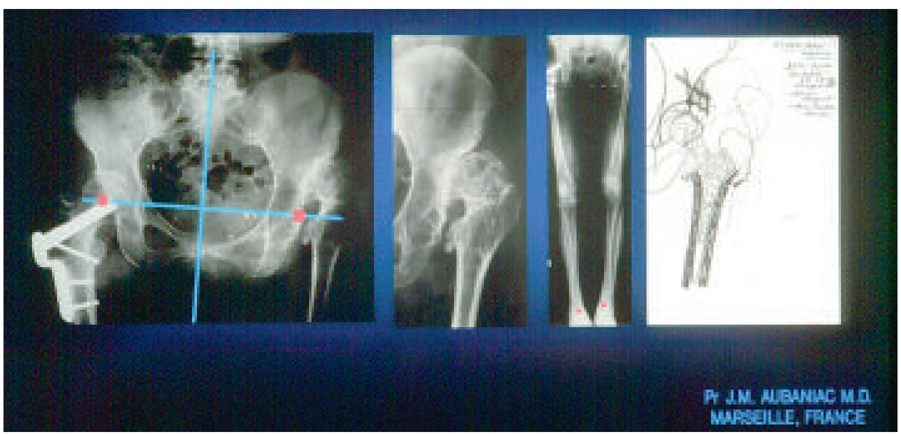

Figure 7a.

Figure 7b.

order to have a reasonable follow-up. The first 122 prostheses were X-ray–based designed (Egoform), and the following 215 cases were designed by numerical CT-scan data (Symbios).

The mean age of the patients was 49 years for Egoform and 56 years for Symbios. The sex ratio is fairly equal in both groups.

The etiologies are shown in Figure 8, with only one-third of conventional osteoarthritis usually occurring in young patients. In both groups 30% of the patients had one or two previous operations on the hip before the custom arthroplasty. The mean follow-up is 64 months for Egoform and 42 months for Symbios. The average Harris hip score was 91 points for Egoform and 93 points for Symbios at the time of follow-up.

It should be noted that the preoperative score was usually low (mean 44 points) with some patients severely affected by congenital disease or post-traumatic osteoarthritis. The complications related to the surgical technique included the following: nonunion of 2 trochanters, 2 loosened prostheses in revision with bone grafting, 5 dislocations including 3 CDH (grade IV according to Crowe),[22] and 2 infections. The complications related to the custom device were the following: 2 errors in anteversion previously mentioned with the first X-ray–based design, and 2 intraoperative femoral fractures treated with cerclage wires with no consequence on the final result.

RADIOGRAPHIC RESULTS

In order to correlate the design stem features to the arthroplasty outcome, we studied several radiographic elements according to Engh criteria.[23] The femur has been divided in 16 areas and bone remodeling studied at each level.[24] We compared the results of the X-ray–based design, Egoform (two-thirds coated) and the Symbios CT-based design (one-third coated at that time).

The results are reported in Figure 9. In both designs we found lucencies in the greater trochanter probably related to the gluteus medius action, as previously reported. Egoform showed an average bone ingrowth rate in the proximal region of 64% and Symbios 68%. Lucencies were directly related distally to the absence of hydroxylapatite coating in both designs. The amount of stress shielding (Stage III according to Engh) was 20% for Egoform and 2% for Symbios.

Ectopic ossification was fairly equivalent in both groups with 5% of Class 3 according to Brooker[25] and no symptomatic Class 4. Two cases of migration greater than 2 mm were observed in major revisions associated with extensive proximal bone grafting.

DISCUSSION

We started using custom cementless implants in 1985 to solve two problems: the impossibility of matching the anatomy of dysplastic or dysmorphic femurs and the rate of loosening of cemented implants in young patients.[26] By studying more precisely the functional anatomy of these complex cases, we rapidly realized the necessity to integrate the extramedullary data in the custom process. Indeed, in most of these cases, the surgeon must face an upper femoral torsion ranging usually between 20° and 70° on the knee condylar axis. When planning cementless reconstruction, the surgeon has three options to solve the problem of proximal fit with a correct final antev-

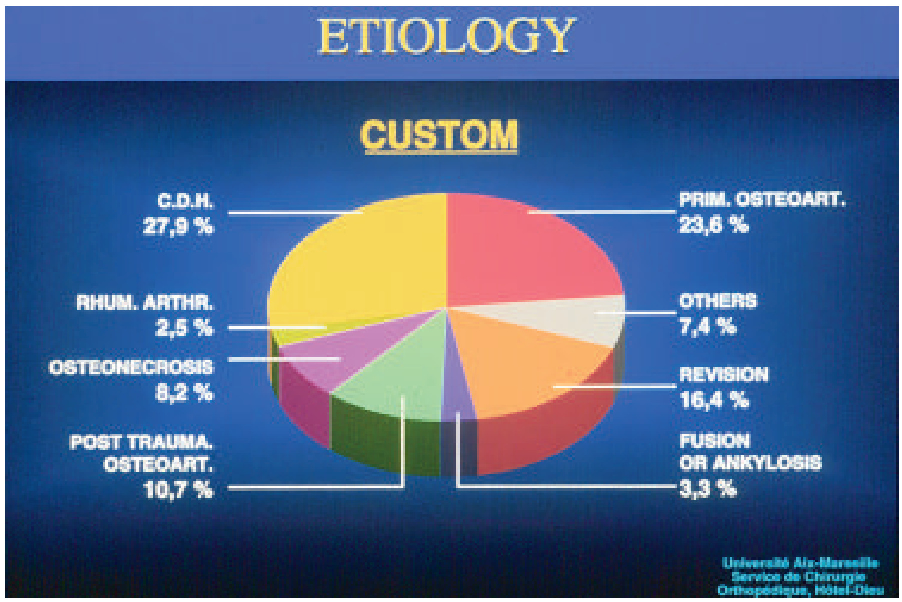

Figure 8. Etiology of the custom procedures.

Figure 9 (a, b). Radiographic analysis studying the endosteal new bone (red) and the radiolucencies (yellow) on the frontal (Fig. 9a) and the lateral view (Fig. 9b).

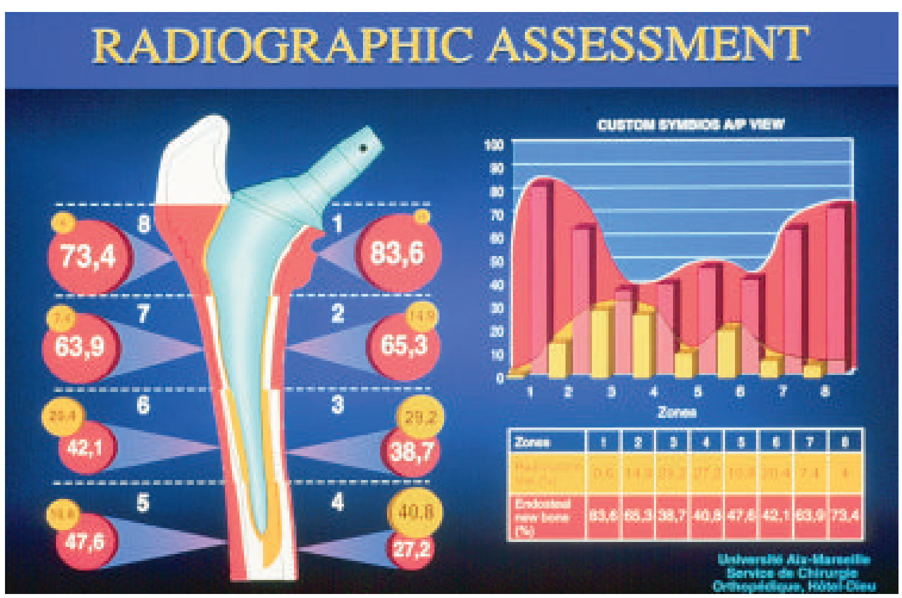

Figure 9a.

ersion for hip stability: performing an osteotomy of the upper femur[27,28] using a modular neck,[29] or designing a custom stem where the anteversion data are included in the design by CT assessment. The prosthetic neck must be oriented posteriorly on the upper femur axis to achieve a normal anteversion between 10° and 20° on the knee condylar axis (Fig. 10). This was a major reason behind our decision to use the Symbios–Osteonics custom procedure which integrates all the elements of the extramedullary planning in the design. The clinical analysis showed us a surprisingly quick recovery of function for the patients, and this may be related to the restoration of hip biomechanics provided by the three-dimensional neck orientation. The muscles around the hip and especially the abductors thus rapidly recover a correct lever arm and direction.

Several comments can be made regarding the radiographic results. The low incidence of stress shielding with the Symbios–Osteonics design compared to the Egoform is encouraging. This may create a better stress transfer with the numerical CT-based design and with respect to priority areas of contact especially in the posteromedial aspect of the proximal femur. This provides much more than a three point contact which is the usual minimal requirement for rotational stability. The incidence of distal lucencies was more of a concern. These lucencies were roughly correlated to the absence of coating. Since 1992, the amount of hydroxylapatite coating has now been extended to the whole stem with an underlayer of titanium plasma-spray on the two proximal thirds. This has undoubtedly reduced the incidence of these distal lucencies and, indirectly, the amount of thigh pain. Thigh pain has now been reduced to 2% since this new coating. To achieve this goal, the stem is designed with a progressive diminution of stem diameter from metaphysis to diaphysis. This distal stem may avoid distal femoral impingement and reduce stress shielding. The direct consequence of this reduced distal diameter is a better proximal stability. Even if we found no correlation between varus and clinical outcome after five years in the group of custom stem, this might be of concern. A correct preparation of the greater trochanter and the use of a distal resorbable tip may avoid these problems.

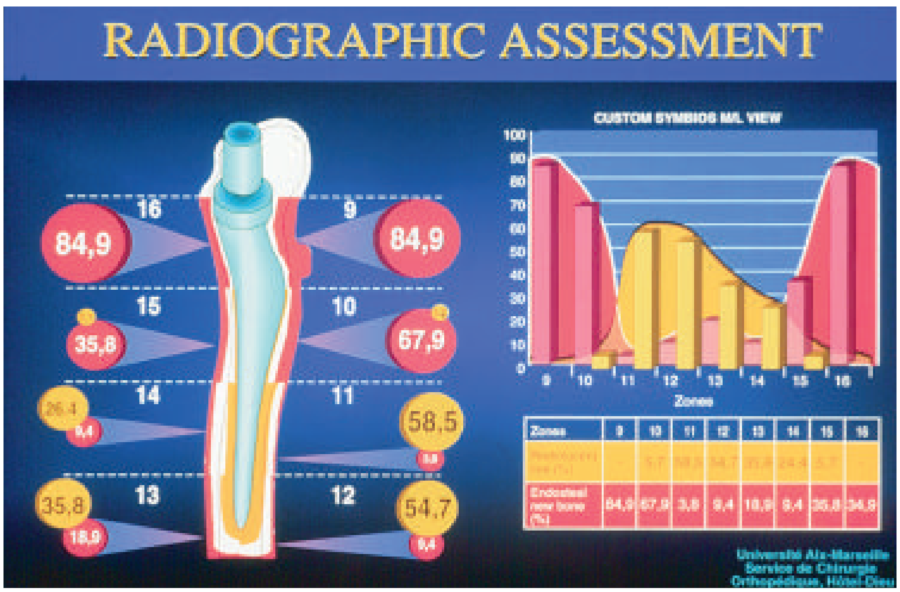

Figure 9b.

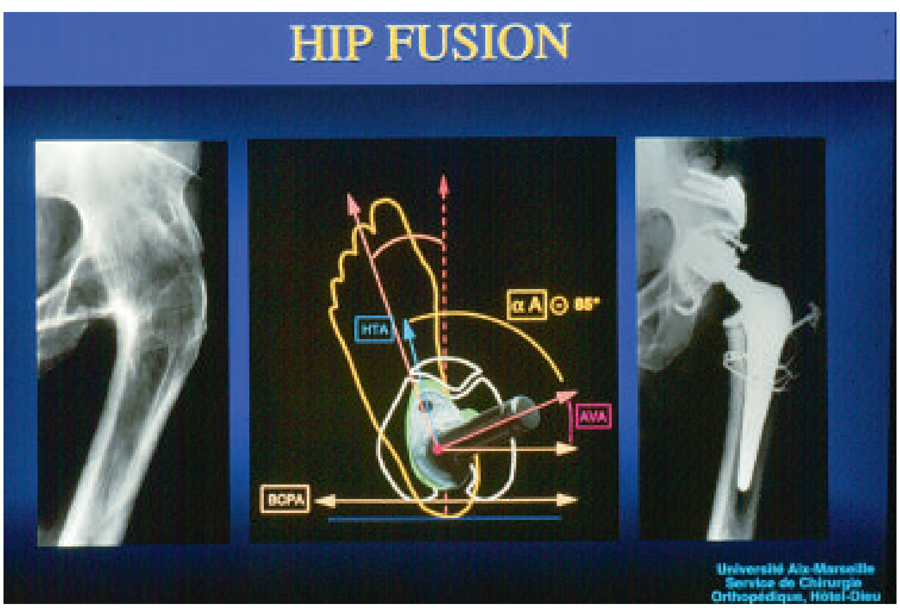

Figure 10. Example of a fused hip with an extreme antetorsion of the upper femur requiring a posterior orientation of the prosthetic neck (-85°) to restore a normal anteversion (10° to 20°) on the bicondylar plane.

The usual consequence of advanced technologies is an increasing cost. This was a major concern in health care for custom procedures at the beginning of the 1990s.

With the current improvement in technologies and the "routine" fabrication of custom stems, the cost has been reduced approaching that of a conventional anatomic cementless stem.

Is the additional cost a reasonable price to pay in case of dysplastic or dysmorphic hips? We think so, knowing that a hip revision increased the cost of the arthroplasty by a factor of two to three.

CONCLUSION

Although a long follow-up is required for all reconstruction procedures, several conclusions may be made after five years. The clinical outcome is comparable to conventional cemented stems, and the recovery of function is quick despite the severity of the affected hip. Indications may be summarized in three groups:

1. The anatomy: champagne-fluted femurs.
2. The etiology: CDH, hip dysmorphy, and revision when femoral defects are less than IIb in Paprosky's classification.[30]
3. The age: osteoarthritis in young patients.

In all these complex cases, a custom hip arthroplasty based on careful preoperative planning with X-rays and CT scan can solve many of the surgical difficulties usually encountered with these etiologies. Even though CT scan is not necessary in routine arthroplasty, it is of significant benefit for evaluating bone stock, assessing three-dimensional orientation, and providing intra- and extramedullary adaptation of the stem, when using cementless implants in these complex cases. STI

REFERENCES

1. Zalensky EB, Sasty M, Bragoon CR, et al. The effect of proximally coated prostheses on stress transfer and micromotion with and without the distal stem. Trans ORS 1990;15:203.
2. Soballe K, Hansen ES, Rasmussen HB, et al. Hydroxylapatite provides a stronger fibrous anchorage of implants with controlled micromotion. Trans ORS 1990;15:206.
3. Bargar WL. Custom cementless total hip replacement. Orthop Rev 1987;26:67-75.
4. Noble PC, Alexander JW, Lindahl LJ, et al. The anatomic basis of femoral component design. Clin Orthop 1988;235:148-65.
5. Rubin PJ, Leyvraz PF, Aubaniac JM, et al. The morphology of the proximal femur. J Bone Joint Surg 1992;74-B:28-32.
6. Walker PS, Robertson DD. Design and fabrication of cementless hip stems. Clin Orthop 1988;235:25-34.
7. Simonet JY, Argenson JN, Aubaniac JM. The use of uncemented custom-made prostheses in high congenital dislocation of the hip. J Bone Joint Surg 1993;75-B Supp III:257.
8. Moretton JC, Claudon B, Cravoisy JC, et al. Conception et fabrication assistée par ordinateur d'une prothèse fémorale de hanche. Rev Chir Orthop 1986;2:89.
9. Billard B, Colombier M, Grammont P, et al. Biomechanical principles and early results of custom-made prostheses "Morpho-adaptées." 4th annual International Symposium on Custom Prostheses; 1991. p 45.
10. Aldinger G, Marquardt K, Weipert A. Concept and technical realisation of the free-styled custom-made Aldinger hip. 4th annual International Symposium on Custom Prostheses; 1991. p 90.
11. Mulier JC, Mulier M, Isaac GH. Early operative results with an intra-operative custom system. 4th annual International Symposium on Custom Prostheses; 1991. p 91.
12. Gau M, Simonet JH, Rocca A, et al. Le traitement des luxations hautes invétérées de hanche chez l'adulte par prothèse totale recentrée. Rev Chir Orthop 1988;74:391-401.
13. Yoder SA, Brand RA, Pedersen DR, et al. Total hip acetabular component position affects component loosening rates. Clin Orthop 1988;228:79-86.
14. Argenson JN, Hostalrich FX, Essinger JR, et al. Femoral neck anteversion in custom-made hip prosthesis: A CT-Scan study of 384 cases. Proceedings of 60th AAOS; 1993. p 182.
15. Mendes DG. Total hip arthroplasty in congenital dislocated hips. Clin Orthop 1981;161:163-179.
16. Carret JP, Bonnin M, and Dejour H. Prothèses totales de hanche dans la coxarthrose sur luxation congénitale. Acta Orthop Belg 1990;56:387-93.
17. Essinger JR, Robertson DD, Esteve P. Evaluation of CT accuracy for custom prostheses designing. Proceedings of the 3rd Annual International Symposium on Custom Made Prostheses; 1990. p 5.
18. Argenson JN, Simonet JY, Aubaniac JM. The indications for cementless custom prosthesis in congenital hip dislocation. J Bone Joint Surg 1993;75-B Supp II:113.
19. Bonnel F, Chevrel JP, Outrequin G. Anatomie fonctionnelle de la posture et de la marche. Anatomie clinique. Paris: Springer-Verlag; 1991. p 587-94.
20. Argenson JN, Aubaniac JM. Preoperative planning of total hip reconstruction for congenital dislocation of the hip using custom cementless implants. J of the Southern Orthopaedic Assoc 1994;1(3):11-8.
21. Aubaniac JM, Essinger JR, Pizzetta M, et al. The acetabular component in cementless total hip arthroplasty: Centroïd cup or customization. J Bone Joint Surg 1993;75-B Supp III:257.
22. Crowe JF, Mani VJ, Ranawat CS. Total hip replacement in congenital dislocation and dyslasia of the hip. J Bone Joint Surg 1979; 61-A:15-23.
23. Engh CA, Massin P, Suthers KE. Roentgenographic assessment of the biologic fixation of porous surfaced femoral components. Clin Orthop 1990;257:107-28.
24. Bougault JJ, Argenson JN, Pizzetta M, et al. A clinical and radiographic evaluation of 337 custom-made prostheses: a one to six year follow-up study. J Bone Joint Surg 1993;75-B Supp III:258.
25. Brooker AF, Bowerman JW, Robinson RA, et al. Ectopic ossification following total hip replacement. J Bone Joint Surg 1973;55-A:1629-32.
26. Dorr LD, Takei GK, Conaty JP. Total hip arthroplasties in patients less than forty five years old. J Bone Joint Surg 1983;65-A:475-9.
27. Holtgrewe JL, Hungerford DS. Primary and revision total hip replacement without cement and with associated femoral osteotomy. J Bone Joint Surg 1989;71-A:1487-95.
28. Paavilainen T, Hoikka V, Salonen KA. Cementless total replacement for severly dysplasic or dislocated hips. J Bone Joint Surg 1990;72-B:205-11.
29. Gorski JM. Modular non-cemented total hip arthroplasty for congenital dislocation of the hip. Clin Orthop 1988;28:110-6.
30. Paprosky WG, Laurence J, Cameron H. Femoral defect classification. Orthopaedic Rev Supp:1990;9-15.