

Brief Report

Three-Dimensional Computerized Selection of Hip Prostheses in Patients With Congenital Dislocated Hips

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A B S T R A C T

This study assessed the effectiveness of the combined use of computed tomography (CT) and computer-aided design (CAD) in the preoperative evaluation and implant selection in 20 patients (20 hips) with congenital dislocation of the hip who were scheduled to undergo total hip arthroplasty. Computerized selection of the femoral implant with optimum fit and fill was made after a three-dimensional reconstruction of the femoral canal using CT data and CAD. Implantation of all sizes of 5 noncemented and 2 cemented femoral

implants was simulated using CATIA software (IBM, Kingstone, NY). When patients underwent surgery, 18 of 20 preselected prostheses agreed by type and size with the prostheses implanted. The remaining 2 preselected implants agreed by type only. In patients with dislocated and dysplastic hips, combined use of CT and CAD allows effective preoperative planning by providing the surgeon with vital information about the proximal femoral canal geometry and the possible femoral implant with optimum fit and fill to be used.

Total hip replacement (THR) in congenital dislocated hips, which have anatomic variations, presents difficulty for the surgeon in applying a stable implantation at the right position and consequently providing satisfactory function.¹⁻⁴ Conventional radiographic evaluation of the congenital dislocated hip prior to THR is often inadequate, as the complexity of the anatomy in these difficult hips cannot be sufficiently assessed.⁵⁻⁷ Computed tomography (CT), on the other hand, provides the surgeon with important anatomic detail not readily obtained from radiographs.

This study assessed the effectiveness of CT and computer-aided design (CAD) in preoperative evaluation and

implant selection in patients with congenital dislocation of the hip who later underwent THR.

MATERIALS AND METHODS

From 1994-1996, a total of 20 patients (19 women and 1 man; 20 hips) with congenital dislocation of the hip were evaluated preoperatively with CT and CAD. Average patient age was 60.9 years (range: 52-69 years). The right hip was affected in 15 patients and the left hip was affected in 5 patients. All patients underwent THR performed by one of the authors (T.A.X).

Each patient was examined supine using a Philips Tomoscan LX (Philips Medical Systems, Veempluis, The Netherlands) whole-body scanner. A standard protocol using a three-axis grid (x, y, and z axes) for the orientation of the femur was maintained in all examinations. As any movement by the patient

could disrupt the orientation of the femur within the three-axis system that appeared in each scan, patients were required to remain motionless during the procedure.

Serial transverse 5-mm slices were obtained through the proximal femur to a level 12 cm below the lesser trochanter. Each study consisted of approximately 28-32 slices.

Each CT image included a transverse slice of the proximal femur and standard x and y axes, which were scaled in 1-cm increments. These images were transferred via diskette into Adobe PhotoShop 3.0 software (Adobe System Inc, San Jose, Calif). Images then were adjusted to their actual size based on the centimeter scale on each axis, and a new x-y coordinate system with 0.01-cm increments was superimposed onto the first x and y axes of the CT.

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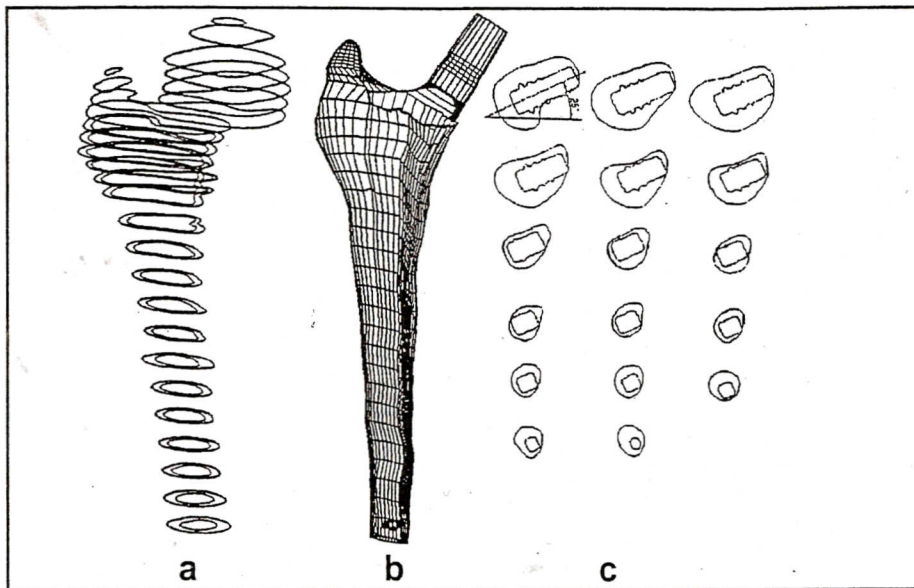


Figure: A 3-D model (splines) of the proximal femur is created using CATIA software (A). Next, a surface model (wire frame) of the proximal femur with an osteotomy at the femoral neck region and with the prosthesis implanted is created (B), and the position of the prosthesis in the femoral canal is determined using cross-sections of the inner cortex of the femur and the inserted prosthesis (C).

A number of points ranging from 150-300 for each image, depending on the size and location of the transverse slice of the femur (proximal CT slices needed more points than distal slices), were selected manually for the outer and inner cortex of the femur. The points for the inner cortex were positioned at the transition area of the inner cortex and medullary femoral canal. The positioning of the points in each case was done by the same author (I.D.G.).

Data for the x and y coordinates of each point of every image were entered into a workstation RISC computer system 6000 using CATIA software (IBM, Kingstone, NY). This software, which is a computer-aided design/manufacturing/engineering program, automatically generates a contour (splines) of the inner and outer cortex according to the given coordinates of each point in each image. Entering the data (coordinates of each point) of all images, the software automatically analyzes the data and produces a surface and solid three-dimensional geometric model of the proximal femur.

To define the accuracy of the computer-generated model, prior to patient testing, a 5-cm² polyethylene cube was scanned using CT, and a computer-gen-

erated surface and solid 3-D model were created with the CATIA software. The dimensions of the 3-D cube model and the actual cube were compared, and the dimensions were identical.

After creating the 3-D model of the proximal femur, a simulated osteotomy of the femoral neck was performed. Detailed mechanical graphics of seven standard femoral implants (five cementless and two cemented) were obtained from the companies that provided the implants and were reproduced using the CATIA software by one of the authors (K.V.). The prostheses were the Omnifit (Osteonics, Allendale, NJ), Prophor (Osteo, Selzach, Switzerland), Spotorno (Protek, Berne, Switzerland), Wagner (Protek), Harris-Galante 100 CDH (Zimmer, Warsaw, Ind), Elite Plus (Depuy, Warsaw, Ind), and Charnley (Depuy).

Selecting the appropriate femoral implant included the following steps. A preliminary trial of simulated implantations of the smallest sizes of each femoral implant was performed. The amount of the implant exceeding beyond the borders of the inner cortex was determined as depth of implant penetration and could be easily assessed geometrically by eliminating the

outer cortex of the femoral model and retaining only the inner cortex, which presented a 3-D surface or a line in cross-section areas.

Femoral implants with dimensions of their smallest sizes greater than the size of the femoral canal and penetrating into the cortex of the proximal femur were excluded for further implantation. Each of the remaining prostheses underwent a simulated implantation, and all sizes of implants that had greater dimensions than the proximal femoral canal also were excluded for further implantation.

Next, the implants that could "fit" into the femoral canal were implanted, and their surface contact area with the endosteum of the proximal third of the femoral canal was determined. The values of the surface contact area between the implant and bone canal model in its proximal third were computer generated, and if the values indicated the contact area was >50%, the implants were considered acceptable for implantation. If the values were <50%, the implants were considered unacceptable and a cemented implant was selected.

Final selection of the optimum femoral implant was based on the implant that had the largest contact area with the proximal third of the femoral canal model and the best position in the femoral canal. Implant position in the femoral canal was assessed using its cross-section analysis (Figure). Intraoperatively, prior to implant insertion care was taken to ream to the same diameter of the preselected stem so the rasp could pass easily into the femoral canal without removing any cortical bone.

RESULTS

In all patients, preoperative evaluation with CT indicated that the femoral head, having been dislocated since birth, had no contact with the true acetabulum and was completely displaced at a variable distance proximal to the iliac wing. Furthermore, the intramedullary canal of the proximal femur was often dysplastic, distorted

and narrow so that an extra small prosthesis usually was required.

Fifty percent of endosteal contact was defined as a borderline between implanting cemented or uncemented prostheses. Any prosthesis that had <50% of endosteal contact with the proximal third of the femoral canal model was considered unacceptable and a cemented prosthesis was implanted.

From the simulated implantation of the 20 prostheses in our study, 13 implants had an endosteal contact area >50% and were uncemented. In 7 prostheses, the endosteal contact was <50%, thus requiring a cemented implantation.

The size and type of the 20 prostheses, which were submitted to simulated implantation, were compared with the prostheses implanted intraoperatively. Eighteen prostheses (13 uncemented and 5 cemented) agreed by type and size with the prostheses implanted intraoperatively. Two preselected prostheses, both of which were cemented, agreed by type but not by size: one of the preselected implants was one size larger and the second implant was one size smaller than the implants actually used.

DISCUSSION

A significant problem in THR for congenital dislocated hips is the selection of a femoral implant and assessment of its fit and location preoperatively. Although preoperative templating radiographs with multiple stem designs and sizes are available, they usually lead to suboptimal femoral stem selection because of the magnification and rotation error of the radiographs. Furthermore, it is difficult from the two-dimensional templating with radiographs to correctly represent the 3-D morphology of the femoral canal. A similar problem is present during surgery, as the surgeon can evaluate the implant fit only at the osteotomy level and define its stability by applying loads that are less than physiologic.^{8,9}

A method for better preoperative assessment and selection of a femoral

implant was established in our department using CT and CAD. Selection of an optimum femoral implant was based on available femoral prostheses that had the best fit and fill. The selected implant was submitted to further simulated implantation, and its surface contact area with the femur was determined.

Reuben et al¹⁰ reported that standard cementless femoral prostheses can obtain only 50% surface contact with endosteum at surgery. They described a knowledge-based CAD/CAM system for the design of a hip prosthesis. The custom prosthesis was consistently able to achieve a higher degree of canal fill, which appears low in the proximal region of the femur because of the presence of the greater and lesser trochanters.

Clarke et al¹¹ reported a method of computerized templating in uncemented THR to assess component fit and fill. Their method is based on two-dimensional results, superimposing computerized templates of three different uncemented femoral components on anteroposterior and lateral radiographs of the femur.

In our study, the results of the simulated implantation technique are based on 3-D analysis using seven different femoral components for implantation. The femur model obtained from the CAD system presents a geometric 3-D model. The fit and fill of the implanted prosthesis was determined by its surface contact area with the inner cortex of the femur and by its position in the femoral canal using cross sections of the femur and implanted component.

Previous studies have shown standard cementless femoral prostheses can obtain only 50%-60% endosteal contact.^{10,11} In selecting an uncemented femoral prosthesis, it is important for the contact area between the implant and endosteum in the proximal femur to be >50%. If a high degree of canal fill in the proximal femur is obtained, then the degree of stress shielding may be reduced and the femoral implant is less likely to demonstrate instability in

rotational forces. Maximal fill of the femoral canal by the prosthesis promotes initial stability and long-term optimal stress transfer to the bone.

The cause of the mismatch of the two femoral implants in our study was possibly a result of using cement for their insertion and creating a variable circumferential mantle of cement around the prosthesis.

CONCLUSION

The combined use of CT and CAD and the application of the simulated implantation technique is helpful in preoperatively evaluating difficult hips prior to THR. This method provides the surgeon with vital information about the morphology and dimensions of the proximal femur, and easier selection of the optimal femoral implant is possible.

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