The Precision and Usefulness of Preoperative Planning for Cemented and Hybrid Primary Total Hip Arthroplasty

Alejandro González Della Valle, MD,* Gastón Slullitel, MD,† Francisco Piccaluga, MD,† and Eduardo A. Salvati, MD*

Abstract: We evaluated the utility of a preoperative planning technique with a review of preoperative radiographs, templates, plans, charts and 6-week postoperative radiographs of 139 total hip arthroplasties (THAs) (116 cemented and 23 hybrid) to determine size, orientation of the implants, and cement column mantle, location of the planned and achieved center of rotation, and limb-length discrepancy. The acetabular component size was predicted exactly in 116 hips (83%) (within ±1 size in 138 hips [99%]); the femoral component size was predicted exactly in 108 hips (78%) (within ±1 size in 138 [99%]). In 75 arthroplasties (45%), the center of rotation was within 2 mm of horizontal and vertical distance from the plan, and in 127 (91%) arthroplasties, it was within 4 mm. The inclination of the cup averaged 44° (range, 30°–58°). The stem was in a neutral alignment in 122 hips (88%), varus in 11 hips (8%), and in 2° of valgus in 6 hips (4%). In 103 arthroplasties with a normal contralateral hip or a THA, the average limb-length discrepancy was 1.71 mm. Preoperative planning is useful to predict the implant size, position, and alignment, to restore the center of rotation, and to equalize limb length. Key words: total hip arthroplasty, cemented, hybrid, preoperative planning, limb-length discrepancy, center of rotation.

Preoperative planning and templating has been early advocated as an integral part of total hip arthroplasty (THA) by John Charnley [1] and Maurice Muller [2]. However, during the 1970s, there were limited implant designs and few sizes available. Currently, there are numerous implant designs, with different modes of fixation, provided in varied sizes, offsets, and modularity to match the patient’s anatomy, and maximize the range of motion and stability of the arthroplasty, making preoperative planning indispensable. However, few studies have evaluated their usefulness [3–5], with some focusing only on the predictability of the component’s sizes [5].

A technique of preoperative planning and templating routinely used at The Hospital for Special Surgery, which has been refined by the senior author (E.A.S.) and used for the last 2 decades, has not been evaluated for precision and predictability. The aim of this study was to investigate the usefulness
of this technique of preoperative planning to aid the execution of a THA and to provide the surgeon with accurate information on the final implant size, position, and orientation; position of the center of rotation of the arthroplasty; limb length; and prevention of possible complications.

**Materials and Methods**

A retrospective review of the preoperative radiographs, templates, plans, operative reports, and 6-weeks postoperative radiographs of 146 consecutive primary THAs (120 cemented and 26 hybrid) in 140 patients was performed. They underwent surgery between August 2000 and June 2002 at a single institution (Hospital Italiano de Buenos Aires). Seven hips (7 patients) with insufficient data were excluded from the analysis, leaving 139 hips (116 cemented and 23 hybrid) in 133 patients (6 bilaterals) for the study.

The series consisted of 43 men and 90 women, with an average age of 67.6 years (range, 23–88 years). Preoperative diagnosis was osteoarthritis in 86 hips, displaced femoral neck fracture in 23 hips, avascular necrosis in 8 hips, juvenile rheumatoid arthritis in 4 hips, developmental dysplasia of the hip in 7 hips, and other diagnoses in 11 hips. A normal contralateral hip guided the preoperative plan in 76 hips. A contralateral successful THA served as a guideline for limb length in 27 hips.

One hundred sixteen cemented polyethylene cups (73 Ogee [De Puy, Warsaw, IN] and 43 flanged cups [Osteonics, Allendale, NJ]) and 23 hemispherical uncemented cups (19 Durolock [De Puy] and 4 Vitalock [Howmedica, Rutherford, NJ]) were used in this series. Selection of the acetabular fixation was based on the patient’s age, with uncemented cups implanted in patients younger than 60 years using a 2-mm under-reaming technique [6]. Cemented, polished, tapered stems from 3 different manufacturers were used: 51 C-Stem (Johnson & Johnson, Warsaw, IN), 47 Exeter (Howmedica), and 41 CMK (Stratec, Overdorf, Switzerland).

All preoperative and postoperative radiographs were obtained with a standardized source-to-object distance of 1 m, which results in an average magnification of 20% ± 6% (2 SD) [3,7], by the same group of radiology technicians. No magnification markers were used.

All surgeries were preceded by a preoperative plan and templating performed on standardized plain radiographs. The preoperative radiographs consisted of an anteroposterior view of the pelvis centered over the pubic symphysis, with the hips in 10° to 15° of internal rotation when possible, and a lateral frog-leg view of the affected hip. If stiffness on the arthritic hip prevented obtaining an appropriate lateral view of the femur, the patient was rotated to allow the thigh to lie flat on the table.

The preoperative plan, templating, and surgery in this series were performed or supervised by 1 of the authors (A.G.D.V.), who was mentored by the senior author (E.A.S.).

The templating began by drawing a “horizontal reference” line through the base of the teardrops and determining 3 radiographic landmarks in the acetabulum: the base of the teardrop, the ilio-ischial line, and the superolateral margin of the acetabulum (Fig. 1). When the base of the teardrops was not clearly visible, a horizontal reference line drawn at the most distal aspect of the sacroiliac joints was used. The cup template was superimposed on the radiograph, with the appropriate cup size placed at 40° to 45° of inclination, with the inferior margin leveled approximately with the teardrop base, and the medial border approximating the lateral cortex.
of the teardrop. In the continent acetabulum, we aimed to achieve complete superolateral coverage of the cup and minimal removal of the supportive subchondral bone (Fig. 1). A 2-mm cement mantle thickness was allowed for cemented cups. If the lateral coverage of the cup was incomplete because of acetabular dysplasia, the lateral uncovered area was measured to be reproduced during surgery. With the cup template in place, the center of rotation of the cup was marked on the radiograph using a soft pencil. The presence of intraosseous cysts to be curetted and grafted before cup implantation, and peripheral osteophytes to be removed after cup insertion, were recorded. Superolateral osteophytes were occasionally used to provide supplemental coverage in dysplastic acetabuli; otherwise, they were marked on the radiograph to be removed during surgery.

When the limb-length discrepancy was of hip origin, as determined by subtracting the distance from the “reference line” to the junction between the proximal corner of the lesser trochanter and the femoral neck of both hips, the difference was added to the altitude of the cup’s center of rotation to determine the altitude of the center of the prosthetic head (Fig. 1). In patients with fixed pelvic obliquity or other sources of limb-length discrepancy, the functional limb-length discrepancy was measured by placing blocks under the affected side until the patient felt that the limb lengths were equal [8]: equalization of the functional discrepancy was one of the surgical goals. It should be noted that in patients with significant flexion or abduction-adduction contracture of hip origin, correctable during surgery, determination of leg-length discrepancy with blocks can be misleading.

For the femoral plan, a stem was selected so that the template rasp profile would match the diameter of the femoral canal, and that the offset would reproduce the patient’s anatomy. For the Exeter and C-Stem, we selected the stem size whose rasp filled the metaphyseal section of the femur; for the CMK stem, we selected the stem size whose rasp filled the diaphysis, and therefore, centralized the stem. The template was aligned parallel to the longitudinal axis of the proximal femur and centered within the intramedullary canal. The altitude and medialization of the center of the prosthetic head was compared with the center of rotation of the templated cup, and adjustments were then made to compensate for limb length. With the stem template in place, 3 distances were measured: 1) from the proximal corner of the lesser trochanter to the neck cut; 2) from the proximal corner of the lesser trochanter to the newly established center of rotation of the prosthetic head; and 3) the width of the calcar, medial to the stem at the level of the neck cut (Fig. 2). The last measurement allowed assessment of the stem alignment in the frontal plane: if a shorter distance was observed with the rasp in place, malalignment in varus was suspected, and valgus was suspected when the intraoperative distance was greater than templated.

Surgery was performed or supervised by a single attending surgeon (A.G.D.V.). The surgical approach was posterolateral in 131 hips, lateral in 4 hips, and transtrochanteric in 4 hips. While positioning the patient, special attention was paid to assure a strict, constant, lateral decubitus during surgery for those undergoing a posterolateral approach. No fixed pelvic or femoral markers were used to determine length before dislocation. After hip dislocation, the lesser trochanter was routinely exposed. The altitude of the neck cut, as determined in the preoperative plan, was reproduced with a ruler. Exposure of the acetabulum included routine identification of the superolateral margin of the acetabulum and the base of the teardrop. The hemispherical reaming of the acetabulum was started by medial reaming up to the lateral wall of the teardrop, followed by reaming in the cephalad direction.

Fig. 2. After superimposing the femoral template of the adequate size and offset, 3 distances were measured: from the proximal corner of the lesser trochanter to the neck cut (A), from the proximal corner of the lesser trochanter to the center of rotation of the prosthetic head (B), and the width of the calcar medial to the stem (C).
of the natural acetabular opening, to reproduce the medialized and lateral coverage of the cup as predicted in the plan.

After femoral broaching and with the trial prosthesis in place, the distance from the proximal corner of the lesser trochanter to the center of rotation of the head was measured with a ruler. In 81 patients with a normal contralateral hip or with a successful, well-fixed arthroplasty, the surgeon aimed to equalize limb length. In 22 patients with acute femoral neck fracture, a 3- to 6-mm over-lengthening was considered if inadequate soft-tissue tension was detected during trial reduction. In 36 patients with a shortened contralateral limb, the surgeon aimed to restore the normal hip biomechanics, whereas equalization of limb length was a secondary objective; if added stability was needed, an extended offset stem was implanted. The depth of insertion of the stem was determined based on the preoperative measurements and the stability and soft-tissue tension assessed during the trial reduction of the prosthesis. Soft-tissue tension was assessed by gentle push and pull with the hip in extension and in 30° to 40° of flexion, by assessing the resistance to hyperextension with the knee in 90° of flexion, and by assessing the tension of the anterior capsule with the hip in extension and external rotation. All stems were cemented using a modern cementing technique, which included a distal plug, vacuum mixing, retrograde injection, and pressurization with a cement pistol.

Measuring Methodology

A retrospective review of the operative report was performed to determine the implanted component size, removal of osteophytes, complications encountered during surgery, and the need for adjuvant screw fixation, morselized or structural bone graft.

The preoperative standardized radiographs were compared with the 6-week control radiograph to determine the altitude and lateralization of the planned and achieved center of rotation of the cup relative to the base of the teardrop, as reported by Eggli et al [4]. Cup inclination was measured as the angle determined by the “reference line” and the cup opening [4]. Cup version was determined by the method described by Ackland et al [9] in all 23 uncemented cups and in 43 cemented cups with a continuous equatorial wire marker.

Cementing technique of the cup was rated on the anteroposterior radiographs of the pelvis according to Ranawat et al [10].

Stem alignment was measured as the angle between the major diaphyseal axis of the proximal femur and the longitudinal axis of the stem. Cement mantle on the femur was classified according to Barrack et al [11].

Limb length was compared with the contralateral hip by subtracting the vertical distance from the “reference line” to the proximal corner of the lesser trochanter of both sides [12]. A negative value indicated a shortened limb, and a positive value indicated a lengthened one.

All measurements were performed by one of the authors (G.S.) to avoid interobserver variability, using 20% magnified rulers. Only distances ±2 mm and angles ≥2° were considered for this study.

Differences were compared using the chi-square test for nominal variables or summarized data and an unpaired t-test for comparison of continuous variables. The alpha error was set at 0.05.

Results

Prediction of the Component Size

The exact acetabular component size was predicted in 83.4% of hips (116 of 139); 101 of 116 cemented cups, and 15 of 23 cementless cups. The implanted cup was within ±1 size in 99.2% of hips (138 of 139). The exact femoral component size was predicted in 77.7% of hips (108 of 139). Agreement was within ±1 size in 99.2% of hips (138 of 139). A templated, standard offset stem was changed to an extended offset during surgery in 3.6% of hips (5 of 90).

Prediction of the Center of Rotation of the Arthroplasty and Positioning of the Acetabular Component

The average vertical distance from the base of the teardrop to the templated center of rotation of the arthroplasty was 15.4 mm (range, 8–30 mm; SD, 3.0 mm); in the postoperative radiographs, it was 15.9 mm (range, 8–29 mm; SD, 3.4 mm). The average horizontal distance from the base of the teardrop to the templated center of rotation was 28.8 mm (range, 21–35 mm; SD 3.0 mm); in the postoperative radiographs, it was 28.8 mm (range, 19–39 mm; SD, 3.6 mm). In 54% of hips (75 of 139), the arthroplasty center of rotation was within 2 mm of horizontal and vertical distance from the templated center of rotation; in 91.3% of hips (127 of 139), it was within 4 mm. In the remaining 8.7% of hips (14 of 139), the center of rotation was located
either within a range of −8 to 9 mm of vertical distance (5 hips) (average, −1.4 mm; SD, 4.9 mm) or within −7 to 6 mm of lateral distance (11 hips) (average, −1.8 mm; SD, 5.3 mm) from the templated center of rotation. In all 5 patients requiring medial acetabular morselized or superolateral structural bone graft, the arthroplasty center of rotation was implanted within 4 mm of horizontal and vertical distance (vertical height range, 0–2 mm; lateral displacement range, −2 to 3 mm).

Component Orientation and Cementing Technique

The average inclination of the acetabular component was 44° (range, 30°–58°; SD, 4.7°). One hundred twenty-six cups (90.6%) were implanted in 35° to 50° of inclination. Seven cups (5%) were placed in >50° of inclination. There were no superomedial dome gaps detected in the series. Among 116 cemented cups, cement grading was 3 in 79 cups (68%), 3.5 in 28 cups (24%), 4 in 8 cups (7%), and 5 in 1 cup (1%). In 23 uncemented cups and 43 cemented cups with a circumferential wire marker, the anteverision averaged 12.9° (range, 0°–29°; SD, 7.0°). The alignment of the stem was neutral in 122 (88%), 2° of varus in 7 (5%), 3° to 4° of varus in 4 (3%), and in 2° of valgus in 6 (4%). Eight of the 11 stems implanted in at least 2° of varus and all 4 stems implanted in >2° of varus were Exeter stems. The cementing technique was Barrack A in 48 patients (34.5%), Barrack B in 85 patients (61.2%), and Barrack C1 in 6 patients (4.3%).

Equalization of Limb Length

The average postoperative limb-length discrepancy was 2.8 mm (range, −6 to 20 mm; SD, 4.6 mm). Among 81 elective arthroplasties with a normal contralateral hip or a stable THA, the average limb lengthening was 1.29 mm (range, −6 to 10 mm; SD, 3.44 mm). Seventy-three of 81 patients (90.1%) had a limb-length discrepancy within 5 mm. One patient had a contralateral foot drop and was intentionally overlengthened 9 mm. A second patient underwent a staged removal of hardware and THA for a posttraumatic avascular necrosis of the femoral head and was deliberately overlengthened 10 millimeters because of the poor soft-tissue tension observed at surgery.

Among the 22 arthroplasties in the femoral neck fracture group, the average limb-length discrepancy was 3.27 mm (range, −3 to 8 mm; SD, 3.13 mm). Seventeen of 22 patients (77.3%) had a limb-length discrepancy within 5 mm.

The remaining 36 surgeries had a shortened contralateral limb, resulting from moderate-to-severe osteoarthritis in 27, avascular necrosis in 3, congenital hip dysplasia in 2, failed THA in 2, slipped capital epiphysis in 1, and stress fracture in 1; therefore, the surgeon aimed to restore the operated hip’s normal biomechanics. Among these 36 patients, the average limb-length discrepancy was 6.11 mm (range, −2 to 20 mm; SD, 4.98 mm). Eight of 36 patients (22.2%) presented a limb-length discrepancy of at least 1 cm in this group.

Resection of Peripheral Osteophytes, Bone Graft, Screw Fixation, and Complications

Peripheral osteophytes were planned to be resected in 92 hips: adequate resection was accomplished in 86 hips (93.4%), and in the remaining 6 (6.5%), the resection was incomplete. Medial morselized bone graft was planned and used to augment a deficient medial wall in 4 patients with acetabular protrusio. A superolateral structural femoral head autograft with screw fixation was used in 1 patient with a dysplastic hip. Thirty-four patients required grafting of acetabular cysts, and in 5 patients (15%), the filling of the graft was incomplete. There was 1 patient who required adjuvant screw fixation of the cup because adequate press-fit fixation could not be achieved.

Intraoperative complications included an undisplaced greater trochanteric fracture during proximal femoral opening in a patient with coxa vara, which was treated with trochanteric wiring and with an uneventful evolution.

Discussion

This method of preoperative planning is designed and executed in a sequence that follows the steps of surgery and can be easily interpreted by all operating room personnel. The plan uses consistent anatomic landmarks that can be clearly visualized during surgery and corroborates the accuracy of the measured distances, thus minimizing errors based on single measurements. The acetabular templating and measurements are based on the visualization of the inferior border of the teardrop and on the superolateral margin of the acetabulum on preoperative radiographs and during surgery, reliable and accurate anatomic landmarks to determine acetabular position [13–15].
The altitude and inclination of the implanted cup can be corroborated during surgery by comparing the vertical distance between the inferior border of the cup and the cotiloid notch, and by reproducing the superolateral cup coverage predicted with the cup template (Fig. 3). Meticulous exposure and clear visualization of the cotiloid notch and the superolateral acetabular margin, and reproduction of the cup coverage achieved during templating, resulted in cup inclinations ranging from 35° to 50° in 126 hips (90%).

The predictability of the size for cemented cups was 87% (101 of 116) and 100% within ±1 size. Eggli et al reported similar results in 100 arthroplasties performed by a single, experienced surgeon, in which the component size could be predicted in 90% of the arthroplasties. The authors used radiographs with a 1.5-m source-to-object distance, resulting in less magnification and variability than the standard 1-m distance used in our study [4].

For uncemented cups, the plan predicted the component size in 65% of hips (15 of 23) and in 96% of hips (22 of 23) within ±1 size.

Although predictability of the size of uncemented acetabular components was lower than for the cemented counterparts, the difference was not statistically significant, perhaps because of the relatively small number of uncemented cups. Factors that may account for an inferior predictability of the uncemented cup size include: the precise hemispherical under-reaming (2 mm) required for implantation of uncemented cups without adjuvant screws; a more forgiving reaming technique required for implantation of cemented cups; and that the Ogee cup used in 73 surgeries is provided in fewer diameters.

Prediction of the acetabular and femoral component size within ±1 size was achieved in 97.4% of components (271 of 278), allowing the nurse to have the implants available in the operating room, thus expediting the surgery. If no preoperative prediction is made, the time delay in bringing each of the 2 components from the implant room to the operating theatre in one of the author’s institution is approximately 2 minutes. By having both components available in the operating room, 400 minutes (6.6 hours) of operating room time would be saved for every 100 surgeries. Furthermore, prediction of the stem size allows consistent preheating of the stem to 44°C, which reduces the cement porosity [16,17] and curing time, without affecting its mechanical properties [18].

This preoperative plan improves proximal stem alignment by measuring the calcar width medial to the stem. If the hip is rotated because of the severity of the osteoarthritis, the templating can be corroborated on the contralateral hip. This resulted in achievement of a neutral alignment of the stem in 87.7% of hips (122 of 139). Restoration of the center of rotation of the arthroplasty has proved to influence the survivorship of the reconstruction [19,20]. In the present study, preoperative planning predicted the center of rotation within 4 mm of the vertical and horizontal prediction in 93.5% of hips (130 of 139).

We were able to equalize limb length within 5 mm in 87.3% of hips (90 of 103) with a normal contralateral hip or a successful, well-fixed THA. Although we found the distances measured from the proximal corner of the lesser trochanter to be precise and reproducible, few patients have a less prominent lesser trochanter with ill-defined corners, which may introduce measurement errors (Fig. 4). In the latter group, the altitude of the center of the prosthetic head can be related to the altitude of the tip of the greater trochanter to corroborate the precision of the distances measured from the lesser trochanter (Fig. 3).

Our study confirmed that preoperative planning is successful in achieving limb-length equalization. Similarly, Eggli et al reported a limb-length discrepancy of 2 mm (SD ±1 mm) in 100 elective arthro-
plasties [4]. Woolson reported a limb-length discrepancy within 6 mm in 86% of 351 surgeries performed with preoperative planning [13].

Despite the fact that the exact magnification of the preoperative radiographs was not available in our study, templating of a standardized radiograph predicted the implant size within ±1 size in all but 2 components, and the limb length within a close margin, ranging from −2.5 to 4.73 mm. The variability in magnification produced by the patient’s different body habitus was contemplated during surgery: less magnification was expected in thin patients, and more magnification was expected in obese patients. The utility and precision of preoperative planning performed on digital radiography, with known magnification may improve these results [21,22]. The feasibility of computerized preoperative planning on digital radiographs software remains to be determined.

Our study demonstrates that preoperative planning of THA is useful to achieve the goals previously defined, and to have the adequate-size implants available in the operating room to assure expedient surgery.

Acknowledgment

The authors acknowledge Miss Brenda Morteo for the preparation of the manuscript and management of radiographic files.

Fig. 4. The lesser trochanter can have a well-defined proximal corner (A) or can be less prominent, with ill-defined corners (B), introducing variability to the measurements.

References

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