Surgeons want to perform a perfect total hip arthroplasty (THA) with every operation. Human performance has limitations, especially when performing a mechanical operation in a biological environment. Recent suggested changes to improve outcomes have been large femoral heads and anterior incisions, but unfortunately, neither has resulted in any scientific data that change has been effected. The scientific data tell us that poor component positions and impingement are the source of increasing mechanical complications. Therefore, attempts have been made to improve the surgeon's performance by precise quantitative knowledge in the operating room. Robotic-guided navigation provides numerical data for cup inclination plus anteversion and center of rotation; femoral leg length and offset; and combined anteversion of the cup and stem. The acetabular bone preparation is done with a reamer connected to a robotic arm, which prevents human error by the surgeon of reaming off line or too deep. This technology provides predictable and reproducible results.

Fifty years of innovation by surgeons has improved Charnley’s original total hip arthroplasty (THA) procedure. Bone ingrowth cup and stem designs are predictable for fixation and are demonstrating longevity. Outcome data of Charnley THA beyond 20 years show cemented femoral fixation to be durable, with overall survivorship of 70% to 75% because of cup revisions. Failures of THA before 20 years, both cemented and noncemented, occur primarily because of impingement and wear. Design changes to avoid impingement such as offset femoral stems and large femoral heads, as well as material changes such as highly cross-linked polyethylene have reduced the threat of early failure from poor design and poor plastic. Despite the substantial improvements, complications and early mechanical failures have increased in occurrence. Dislocation, periprosthetic fractures, excessive wear with metal-on-metal large head articulations because of poor component position, and squeaking and fracture of ceramic articulations, again because of poor component position, have diminished results of THA. The readmissions of patients with THA are at an all-time high of 8.6% (nearly double from 10 years ago), although mortality is the lowest ever, suggesting readmissions are not for medical reasons. Bozic et al’s review of Medicare data confirms the predominant complications are mechanical with dislocation the most common cause of revision. Medical centers in Boston and at Stanford University have reported outliers of cup inclination and anteversion of >50% suggesting 1 cause of the mechanical complications.

As a solution to dislocation, the use of the direct anterior exposure of the hip has...
been promoted by some implant companies to improve postoperative recovery, although there are no scientific data to support this marketing position. Likewise, large heads of ≥36 mm are suggested to protect against dislocation. A change to direct anterior incision by surgeons who have used a posterior approach increases complications.9 The use of large heads has detracted from meticulous attention to component position, especially the acetabulum, because the surgeon assumes the large head protects against failure and provides better function.9 With metal-on-metal large heads, the consequence has been increased wear and cyst formation.10

In 2011, the greatest weakness of the THA procedure is our human performance as surgeons. Today’s implants and materials promote longevity. To improve survivorship at 20 years to ≥95%, the outliers in our technical accomplishment of hip reconstruction must be eliminated.1,6,7 The procedure must be performed so that the technique is predictable and reproducible for 100% of patients. As surgeons working only with our experience, intuition, and instinct, we cannot help but make judgment errors—human errors—because we are performing a mechanical operation in a biological environment. This situation creates risk for unintended complications, and the risks are enhanced when we use a standardized operation for variable hip anatomy. Assumption of 15° anteversion of the femoral stem and cup versions of 45° inclination and 15° to 20° anteversion are the standards we have used. But all scientific data in the past 15 years have proven that hip anatomy is abnormal with impingement of the hip causing cartilage destruction.11-13 The use of large heads has detracted from meticulous attention to component position, especially the acetabulum, because the surgeon assumes the large head protects against failure and provides better function.9 With metal-on-metal large heads, the consequence has been increased wear and cyst formation.10

During our operations, we cannot visualize the relationship of the acetabulum to the pelvis and to the functional axis of the body through its spinopelvic dynamics,12 nor can we visualize the inner contour of the femur that affects the anteversion of the cementless stem.13 The judgment errors made because of inaccurate information of anatomy may cause short-term complications such as dislocation and impingement pain, which cause feelings of failure for the surgeon, or later complications of wear and loosening, which are absolute failures for the patient. Today, every human endeavor that involves a device has used modern technology of computers to minimize the human errors. A computer can provide quantitative knowledge that changes qualitative judgment decisions to accurate and precise ones. This technology is the solution we surgeons can use to solve our intraoperative dilemmas.

Near 3 years ago, a surgeon research team comprising the authors of this article set out to design an intraoperative technique that used computer technology to provide the surgeon with intraoperative quantitative knowledge that would enable a predictable, reproducible operation with every THA. We worked with MAKO robotic-guided navigation (MAKO Surgical Corp, Ft Lauderdale, Florida) because of the accuracy of the technique and the fail-safe mechanism against manual errors of this technology (Figure 1). The operation could be personalized for each patient by a preoperative computed tomography (CT) scan (Figure 2) and intraoperative registration of the patient’s anatomy. The tilt of the pelvis can be measured from the CT scan, as can the anteversion of the femur bone. The known pelvic tilt permits adjustment of the cup anteversion to the functional coronal plane of the patient’s body.14 The known anteversion of the femur gives an indication of stem anteversion, but stem anteversion may be different because of how the stem fits inside the bone.13

Impingement of the hip replacement, either implant or bone, can be avoided in all but the most flexible hips (hips with flexible spinopelvic dynamics as revealed by high preoperative anterior tilt of the pelvis >15°) by correct combined anteversion of the stem and cup (safe zone 25°-45°, 50° for flexible hips) to avoid component impingement; and correct center of rotation of the hip to avoid bone-on-bone impingement.1 The center of rotation is known after preoperative planning and will be achieved at surgery because of the precision of the robotic navigation (Figure 2A). Knowing the center of rotation of the acetabulum allows the correct femur bony neck cut to reconstruct the desired leg length and offset (Figure 2B). In most hips, it is beneficial to increase the offset up to 5 mm for clearance of the hip throughout the range of motion because the prosthetic head always has a smaller diameter than the bony head.15,16 Accurate intraoperative quantitative knowledge of leg length and offset is immensely valuable to the surgeon.

Although radiographic measurement of leg-length difference can be up to 6 mm without patient complications, the clinical measurement cannot exceed 2.5 mm, the difference because of radiographic rotation and magnification.17

CONCLUSION

Improvement of human performance in THA is the most necessary innovation for this procedure. Improving human performance in surgery will be done by machines in the operating room just as it is in every other human endeavor outside of surgery. The MAKO robotic-guided navigation gives precision of bone preparation of the femur and acetabulum (Figure 3); it gives quantitative knowledge of component position and biomechanical reconstruction of leg length and offset; and it has a fail-safe mechanism for acetabular preparation and cup implantation. For these reasons, our surgical design team believes this technology is valuable innovation for THA.

REFERENCES
2. Callaghan JJ, Forest EE, Olejniczak JP, Goetz DD, Johnston RC. Charnley total hip arthro-
Figure 1: The acetabulum is reamed with robotic-guided navigation with the reamer constrained by a virtual haptic tunnel, which prevents the surgeon from going off-line or too deep. The reamer stops if human error is made. The computer screen shows the angle of the reamer, which only needs to be within 10° of desired numbers to create the correct hemisphere. The center of rotation superiorly, medially, and anteroposteriorly is defined, and when the reamer achieves the correct center of rotation, the robot stops reaming. The robot is seen on the right-hand side of the figure, and the surgeon’s hands hold the reamer (A). The cup is connected to the robot and directed to the correct inclination and anteverision through a virtual haptic tunnel created by the robot. The computer screen will give the numbers achieved for inclination and anteversion (B).

Figure 2: Preoperative planning of the acetabular cup position on the CT scan allows restoration of the center of rotation of the hip with the cup. Any difference between the center of rotation of the cup (green dot) and the native hip (magenta dot) can be factored into the reconstruction of the femur. The depth of reaming is determined to create the correct hemisphere. The acetabular anteversion can be adjusted after the femoral anteversion is known (femur is prepared first). The CT planned cup position is then superimposed on the radiograph as seen in the lower left corner. The acetabular bony geometry of the CT scan is confirmed intraoperatively by registration as seen in the lower right-hand corner (A). The cup is connected to the robot and directed to the correct inclination and anteverision through a virtual haptic tunnel created by the robot. The computer screen will give the numbers achieved for inclination and anteversion (B).


Figure 3: The final screen at completion of the reconstruction shows all the quantitative numbers for component position and biomechanical reconstruction with the final numbers compared to the preoperative plan.