Developments in Imageless Computer Navigation for Acetabular Component Position in Total Hip Replacement

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Imageless computer navigation functions as a high-technology instrumentation for the positioning of the acetabular component in total hip replacement. Computer navigation provides quantitative and qualitative information for the surgeon during the preparation of the acetabulum and cup implantation. Previously, surgeons implanted the acetabular component based on experience and some anatomic landmarks such as the transverse acetabular ligament (or cortical edge of the cotyloid notch) plus the pubis\(^1\) and the sciatic notch.\(^2\) Errors occurred with any anatomic referencing because the surgeon did not know the tilt of the pelvis. The tilt of the pelvis influences the true position of the acetabular component, in reference to the pelvic anatomy and the longitudinal axis of the body, as compared with what the surgeon visually perceives the cup position to be.\(^3\) Knowledge of the tilt of the pelvis allows the surgeon to have an adjusted anteversion (and inclination) provided by the software to allow compensation of cup position for that tilt. For instance, if the pelvis has a posterior tilt of 12 degrees, the cup may have actual anteversion 10 degrees more than is visually apparent to the surgeon with just the anatomic landmarks available in the operative field.\(^4\) It is critical that the tilt be determined for the position of the patient during the operation, i.e. if the patient is to be operated supine the tilt should be determined in the supine position, whereas if the patient is to be operated in the lateral position the tilt needs to be determined in the lateral position. The determination of tilt prior to operative placement of the cup allows imageless computer navigation to be performed because no computer-generated image of the pelvis and acetabulum relationship is necessary for the software to recognize where the cup is being placed. The tilt is determined by registering the anteroposterior (AP) plane of the pelvis into the computer and then registering the longitudinal axis of the body. When the patient is operated in the lateral position the longitudinal axis can be determined from the posterior supports of the pelvis and the chest.\(^5\)

The imageless software that the authors use is that of Orthosoft, located in Montreal, Canada. With this software the intra-operative registration of the acetabulum is undertaken by registering 16 points from the bony acetabulum avoiding the cotyloid notch to determine the center of rotation of the acetabulum. Three or four points on the cotyloid notch are then marked to register the medial wall. During the process of reaming the computer can provide information to the surgeon as to the depth of the reaming (the change in the center of rotation both medially and cephalad). The average medialization for center of rotation for correct cup coverage is 6mm; the average cephalad displacement of the center of rotation is 4–5mm. Qualitatively, during reaming the surgeon knows the location of the medial wall by the image on the computer screen and can track the reamer as it approaches and contacts the medial wall. This prevents inadvertent reaming through the medial wall. In addition, the quantitative anterior–posterior number tells the surgeon whether the reaming is being performed eccentrically. This knowledge allows a precise preparation of the acetabulum so that a component can be covered by bone to prevent impingement of the metal neck against the metal edge of the cup, and so that this coverage can occur with an inclination that is below 45 degrees so as to prevent excessive wear.

The cup is also implanted with qualitative and quantitative knowledge of its position. The qualitative information is the same as with the reamer, i.e., the cup can be tracked as it is implanted to verify that the medial edge of the cup has contacted the medial wall of the bone and no gap remains. The inclination and anteversion of the cup is quantitatively provided on the computer screen. If a target number for anteversion, such as 20 degrees, is desired then the cup holder can be adjusted to achieve that numerical position. The depth of reaming allows inclination of less than 45 degrees to be achieved with coverage of the cup by bone. It is known that inclination of the cup of more than 45 degrees results in increased wear.\(^6\)\(^7\) The only reason that finite element studies ever suggested inclination above 45 degrees was beneficial was because in those studies that position prevented impingement.\(^8\)\(^9\) The weakness of these studies was that the bony center of rotation was never changed so that impingement could only be avoided by increasing inclination. When
the center of rotation is changed medially and cephalad with reaming, coverage of the cup to avoid impingement can be achieved while maintaining a target inclination of 40 degrees.\textsuperscript{13}

For these advantages to be helpful for the surgeon there must be accuracy with this computer instrumentation. The authors established the accuracy by obtaining postoperative computed tomography (CT) scans of the pelvis of 30 patients who had computer-assisted total hip replacement. In the comparison of the computer navigation position to the CT position for inclination and anteversion there was excellent correlation. There were no outliers with computer navigation of more than 5 degrees. The precision for inclination was 4.3 degrees and for anteversion was 4.1 degrees; the bias for inclination was 0.23 and for anteversion was 0.42. This data means that almost all cups were actually within 1 degree of the computer-designated position. This data could be compared to that of an experienced surgeon. The computer never had an outlier more than 5 degrees whereas the experienced surgeon had outliers of more than 5 degrees 33% of the time and had outliers of 10 degrees or more 6% of the time for inclination and 9% of the time for anteversion. Clearly, the computer prevents outliers. The prevention of outliers is important to help reduce instability of the hip and to eliminate outliers of excessive wear from incorrect cup positioning.

Many surgeons have the expectation that computer-assisted total hip replacement will eliminate dislocations. Computer-assisted total hip replacement is simply high-technology instrumentation. It will allow the surgeon to accurately position the acetabular component (and it can also allow the surgeon to know the combined anteversion because the anteversion of the femoral component can also be known). However, dislocation is a product of impingement. Impingement is a result of the metal neck impinging against the edge of the cup or the greater or lesser trochanter impinging against the pelvis. Therefore, the surgeon is still ultimately responsible for preventing dislocation. The computer will be of tremendous help to the surgeon by providing correct acetabular position and thereby providing good combined anteversion of the femur and acetabulum, and good depth of the acetabular component in the acetabular bone to prevent metal neck impingement against the cup. Impingement of the trochanter against the anterior–inferior spine in flexion or the lesser trochanter against the ischium in extension can still cause pain and instability. Therefore, the surgeon must be certain that this is not occurring by restoring the leg length and offset to the hip. Lastly, impingement is best avoided with the use of a large femoral head which increases the radius of motion. In patients that are very flexible, and usually in women, the threat of impingement may not be able to be completely eliminated, but it is critical in these patients that all possible sources of impingement be controlled. Therefore even in these patients the computer is of great benefit.

The authors’ prediction is that the use of computer navigation will become more common in the future because its benefits as a high-technology instrumentation will become recognized, the cost will be reduced, and there will be industry support of the use of the computer for implantation of their products.

References