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Computer-Guided Total Hip Arthroplasty

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Abstract

Computer-assisted surgery in total hip replacement has proven to be better technology for achieving precision for implant placement. Variables that may be improved include leg length determination, appropriate anatomical offset, pelvic tilt, and appropriate version of the implants. This guidance is valuable for use in robotic applications and with minimally invasive operations. Recent meta-analysis studies have demonstrated

these improvements over conventional methods relying on conventional instrumentation. Newer technologies include the use of accelerometers and intraoperative computed tomography for automated registration, which reduce drawbacks of inconvenience and complexity of the technology.

Keywords Computer assisted surgery (CAS) – Definition – Computer technology – Navigation issues – OrthoCompass – Robotic navigation – Surgical technique

Introduction

Computer assisted surgery (CAS) has been defined as the ability to use sophisticated computer algorithms to allow the surgeon to determine three-dimensional (3D) placement of total hip implants in situ. Surgeons have sought better technology for doing more difficult minimally invasive procedures and are attracted by the precision offered for getting the implants in safely and correctly positioned. Implant malposition in total hip replacement typically leads to impingement, wear, elevated blood metal ion levels, loosening, and revision. A rapid ongoing evolution of technical advances has allowed the ability to move from cumbersome systems requiring a preoperative computed tomography (CT) scan of the patient's hip joint to more elegant systems that use image-free registration, robotic systems, and ultimately the use of intraoperative 3D CT. In total hip replacement, several meta-analysis studies prove that navigation clearly offers greater precision with various parameters of implant insertion including acetabular component inclination and anteversion, femoral version, femoral offset, and leg length difference. An additional factor to consider is pelvic tilt that can be an important variable and requires compensation in the software of a navigation protocol. For the surgeon, the barriers to entry for this technology include costs, inconvenience of the technology, and inefficiency of the operative procedure with prolonged operating times. While these problems have not been completely resolved, experience has shown the technology will become more user-friendly and attractive. This chapter will update a large body of literature that has coalesced about this topic, explaining basic features of guided technology, the metrology of current systems, and various pitfalls and problems to be expected.

Literature Review

Computer Technology Issues

Computer technology for navigation has been around for over 30 years, and while the basic technology remains, there have been myriad improvements in software capabilities and applications. The basic methodology began with the ROBODOC in 1984, where Barger and others were trying to utilize technology pioneered by IBM for industrial processes [*1*]. An important innovation was the ability to create spatial orientation accuracy down to the level of the pixel that is about 17 μm. The robotic system then could be used to cut bone cavities down to this level of precision and custom prosthetic implants could be fabricated to

match the cavities. Perhaps the next major advance was the introduction of Northern Digital Inc. cameras that could track small LED signals extremely accurately down to the micron level. These digital inputs could be incorporated into a computer system that allowed three-dimensional instant motion capture allowing for a virtual tracking of the target device in space. These targets were termed dynamic reference bases and could include registered single anatomical structures such as the femur or pelvis, instruments, implants positioned on instruments, robotic arms, and even drills or saws. Under ideal circumstance, the surgeon would register the target devices into the computer system and then use the 3D visual output from the LED monitor to guide his surgical procedure.

As will be reviewed in the metrology discussion, a basic premise of the navigation method is that the targeted element remains a rigid body, and the tracker position or stability must remain rigidly fixed, lest the precision of the navigation monitoring degrades. This means that certain methods such as imageless navigation require the surgeon not only to secure the trackers to the patient correctly but make certain that these trackers are not bumped or altered from the registered position. Additionally, the surgeon must understand exactly the prescribed points of anatomy to register, for certain inputs. This requirement may be abrogated in circumstances where “morphing” or general point matching is done, for example, around the lip of the acetabulum. With the use of preoperative computed tomography, the navigation software captures and matches the anatomy of the CT with basic and numerous reference points placed by the surgeon of the targeted hip joint. While this CT image guided technique is more time consuming, it is substantially more accurate than the imageless methods. Another important issue is the effect of distance on the precision. With hip registration, this comes into play when trying to capture the anterior pelvic plane and an error of one centimeter from referencing the pubic tubercle, possible with the wide skin bridge in an obese patient, will lead to an error of at least 6°. Trigonometry also plays a role and the further way from the targeted structure, the greater the error.

Anatomical Issues

A basic understanding of the anatomical features that guide surgical technique are important for interpreting the literature in this field. Murtha et al. has shown that non-arthritic hips have average inclination of 57° in women and 55° in men, while cup anteversion was 24° in women and 19° in men [2]. The basic radiographic analysis comes from the classic work of Murray for defining the planes of measurement of the pelvis. The three independent assessments of the acetabular cup position include the anatomical plane, which measures against the transverse plane of the body; the operative plane, which measures against the sagittal plane of the pelvis; and the radiographic plane, which measures against the coronal plane of the pelvis. In recent years, the radiographic plane has become the most popular method for use, as it is easily identified on a CT scan image. The operative plane basically replicates the method of a freehand mechanical cup guide where the guide references the sagittal plane of the body and the surgeon rotates the guide anteriorly against this plane. The anatomical method captures the position of the acetabulum in relation to the pelvis and is easier to use in the

dissection of an anatomical specimen. Murray defined nomograms that demonstrated the significant numerical differences of measurements reflected by the different trigonometry of each method [3]. For example, operative inclination of 40° and anteversion of 20° translates into 38.3° of radiographic inclination and 12.7° anteversion.

Lewinnek over 30 years ago defined the anterior pelvic plane for measurement of the position of an acetabular component, stating that the cup should be oriented against the fixed pelvic reference frame that is parallel to the coronal plane of the human body [4]. The anterior pelvic plane (APP) was a plane through both the anterior superior iliac spines and the pubic tubercle. Lewinnek stated that optimal cup position using the radiographic postoperative assessment should be 40° +/– 10° of abduction or inclination and 15° +/– 10° of anteversion.

Philippot et al. studied the relationship of the pelvic plane to the Lewinnek reference in the sagittal planes of supine, sitting, and standing positions [5]. They note that Legaye et al. define pelvic incidence as a constant feature equal to the sum of sacral slope and pelvic version [6]. They created the pelvic axis which was a line drawn for the center of the middle of the sacral plateau to the femoral head. Pelvic version was determined from the angle formed by a line from the femoral head to the center of the S1 sacral plateau and a vertical line from the femoral head dorsally. Sacral slope was a tangent from a horizontal line drawn through the top of the sacral plateau. The pelvic incidence remained constant through the positions of supine, sitting, and standing. The pelvic version on the other hand moved an average of 22° from seated to standing or seated to supine. Similarly, the sacral slope moved 22° from seated to standing or supine but was the same for standing or supine. The APP moved from about 4° posterior tilt in the standing and supine position to 25° of posterior tilt in the seated position. The authors noted their results were similar to seven other anatomical studies for pelvic incidence, pelvic version, and sacral slope. Finally, they observe the trend for posterior pelvic tilt to increase with age, noting that each 1° of pelvic retroversion leads to 0.7° of “hyperanteversion” of the cup, and from standing to sitting the cup could increase anteversion by 15°.

As we have learned, the pelvic plane is quite variable and can become particularly challenging in severe deformities such as development dysplasia, where there is marked anterior (“forward”) or posterior (backward) tilt of the superior pelvis in relation to the APP. This confounds the computer navigation as most systems have not incorporated the factor of pelvic tilt which can differ from supine, to sitting, to standing, requiring adjustments in order to reach the target cup anteversion. Murphy et al. found that supine pelvic tilt ranged from 21° anterior to –8° posterior. Standing tilt ranged from 13° anterior to 13° posterior [7]. Babisch et al. have shown that the mean supine pelvic tilt of a group of patients was anterior by 10° in the supine position and this decreased to 5° in standing but was not altered by a total hip replacement [8]. They created a nomogram for defining the adjustment of cup version needed when pelvic tilt exceeded 10°, which may occur in up to 16 % of patients, and this adjustment added about 0.7° for each degree of pelvic tilt difference for cup version from the neutral APP to compensate for the difference. Lembeck and Dorr have found similar

compensations, though there is limited literature supporting this clinical application [9]. Sugano has suggested using the supine functional plane, which is the plane parallel to the table as opposed the APP as the reference line with high degrees of pelvic tilt [10]. In general, the supine pelvic tilt position closely defines the problem, and Murphy has stated that this position does not change significantly after total hip replacement. It is expected that CT scans and intraoperative 3D CT scans will lead to software tools that will compensate for this issue.

Leg length, offset, and femoral version are other elements of the navigation problem, and recent systems have focused on the ability to assess these measurements. The cup center of rotation (COR) is a common landmark for assessing the initial position of the hip joint and may easily be captured with the kinematic rotation method of registration. Preparation of the acetabular cavity may change the COR which may move superior, medial, or lateral. If this movement is superior by more than 5 mm, there is a risk of implant wear and gluteal weakness due to shortening of the abductor lever arm. Offset measures the distance from a fixed point on the pelvis to a fixed point on the proximal femur and should not be varied in either direction by more than 6 mm, lest another factor of increased wear is created. Leg length can be assessed by a variety of software parameters, but navigation typically assesses the difference of the knee center or a fiducial marker on the proximal femur to the bilateral ASIS line, or some other point. This should not be increased more than 6 mm and can be noted by the patient if increased by more than 3 mm. Femoral version has been a challenging landmark to register into the software system and relies on a number of landmarks, for example, the shaft of the distal femur, which may require point registration through a small puncture hole, with the registration probe. That stated, a variety of methods determine femoral version creating the condylar axis which is the version of the femoral neck in relation to the posterior femoral condyles at the knee joint or the condylar twist angle which assesses the femoral version against the transepicondylar axis of the knee joint.

One more issue that must be considered with this technology is the problem burdens of increased operating time, increased radiation, surgical site complications, and problems created from additional bone pin insertions, etc. The time problem has been a serious detraction for surgeons and has persisted for applications such as CT guided navigation and robotic surgery, but technology evolution has solved many of those issues. Live fluoroscopy has been replaced by imageless navigation and CT, with a large reduction in x-ray exposure. The typical CT scan acquisition would compare to that of an abdominal CT. Sugano has stated that the 3 mm slice scans when combined with 1 mm image reconstruction technology is a satisfactory compromise for image quality [10]. Pin placement can be problematic and there are numerous case reports of soft tissue morbidity, infection, and stress fracture.

Metrology Considerations

An important consideration for the surgeon is just how accurate this technology is in the operating room and what are the variables that degrade the precision. The currently available digital cameras utilized can measure down nearly to the micron level but when combined with trackers and other elements resolve to 300–500 μm.

I have assessed the basic precision of the point registration of the imageless acquisition and find it to be less than 500 μm [*11*]. However, this is the best possible capability, and the surgeon must understand that the precision degrades for every possibility after that point. Tracker movement, spinning of the reflective balls, numbers of reflective balls, parallax of the line of site of the reflected trackers, inaccuracy of the registration points, etc., are just some of the myriad sources of error. That stated, when the surgical technique such as offset measurement or angular assessment has “safe zone” of 5–10 mm or degrees, this can be considered an incremental improvement, when considered against most “freehand” or conventional surgical methods. However, for the surgeon to avoid outliers and in some cases surgical mishaps, there must be early training, adequate attention to detail, and constant practice to make this technology work properly.

Takao et al. performed an accuracy study of a fluoroscopic 3D C-arm that used a flat panel detector to assess the metrology capability [*12*]. They found the mean target registration error was 0.7 mm (range: 0.1–1.5 mm). This error increased significantly when the distance from the imaging center increased up to 5 cm. For a dry bone study the mean target registration error was 0.9 mm (range: 0.7–1.5 mm) over the acetabulum and 1.0 mm (range: 0.5–1.4) over the femur. The Iso-C3D system had a 12-cm field of view but created the possibility of accurate 3D fluoroscopic navigation.

Tsukada et al. assessed the imageless navigation error in a variety of clinical scenarios comparing the final navigated screen output with a postoperative CT measure [*13*]. For all cases, the mean navigation error was 2.4° +/– 2.0° (range 0–9.3°) for inclination and 3.7° +/– 2.3° (range 0–13.9°) for anteversion. For obese patients (BMI > 25), the mean navigation error was 2.7° +/– 2.3° (range 0.8–9.3°) and 4.8° +/– 2.5° for anteversion. In the acetabular dysplasia group, the mean navigation error was 2.1° +/– 2.4° (range 0–8.3°) for inclination and 3.9° +/– 3.3° (range 0.1–13.9°) for anteversion. These errors are similar to those described by Jenny, of 2° for inclination and 4° for anteversion. The primary problem for the obese patient is the registration error for establishing the APP.

Kitada et al. assessed the accuracy of CT navigation for stem orientation and leg length discrepancy comparing the navigated record with the postoperative CT to calculate clinical accuracy [*14*]. For cup anteversion, the difference was 1.4° +/– 5.6° and for inclination it was –1.5° +/– 3.5°. For leg length discrepancy, the navigated to post CT difference was –3.4 mm +/–2.4 mm. The authors conclude that the navigation system did not reach target accuracy of 1° or 1 mm, probably based on the lack of registration points and the distances between the registration sites. I could cite several more assessments of accuracy of these systems, but the reader must understand that the navigated values are not uniformly “perfect” and there is always a degree of error. The surgeon must understand where that error comes from and what circumstances are more prone to it.

Literature Review of Outcomes

Over the past 10 years, there have been many case studies and now a substantial number of cadaver and clinical randomized control trials that have shown computer navigation offers statistical improvement in

implant positioning over conventional methods. Xu et al. note in a meta-analysis study that cups placed outside of the Lewinnek “safe zone” had a fourfold increased risk of dislocation. In addition, 8 % of navigated cups were outside of the “safe zone” as opposed to 28 % with conventional technique [*15*]. Operative time, however, increased a mean difference of 8–23 min. The other obvious conclusion is that CT-based navigation is significantly better for cup orientation. This is not surprising, comparing the metrology studies of CT versus imageless in the laboratory setting.

Patient obesity has been shown to be a risk factor for implant malposition and early complications. Barrack et al. demonstrated in large retrospective clinical series (1549) that a BMI > 30 was a factor for cup malposition, noting the odds ratio increased (>0.2) for each increase of 5 Kg/M ^{2} BMI [*16*]. Gupta et al. evaluated the outcome of the MAKO robotic system using the posterior approach finding no statistical difference in obese patients [*17*]. Numerous authors have cited the problem of imageless referencing of the pubic tubercle in morbidly obese patients. This may be improved by using a sharp probe that can puncture the skin.

A method gaining popularity with navigation is the ability to perform the femoral stem insertion first followed by acetabular component position adjustment, such that the combined anteversion of the stem and the cup total 35–37° with a range of 25–50°.

Widmer’s formula combined cup anteversion with 0.75 stem anteversion resulting in Widmer’s angle of 37.3° +/– 5° [*18*]. Fukunishi et al. was able to place 92 % of components in the range with stem first opposed to 42 % with cup first. [*19*] Dorr et al. was able to place 96 % of his stem first implantations in the safe zone of 25–50° [*20*].

Sugano et al. used a collision detection technique for 3D objects using CAD models to determine post implant impingement in various positions [*10*]. The method compares navigated range of motion against the benchmark activities of daily living range of motion: >110° flexion, 30° extension, 45° external rotation at 0° flexion, 30° internal rotation at 90° flexion, 50° abduction, and 30° adduction. In general, the post implant range of motion exceeded the model for impingement, and motion was not affected by changes from sitting to standing pelvic tilt. Renkawitz et al. used a similar method to find that 84 % of navigated hips could reach this range of motion using femoral first insertion compared with 65 % conventional technique hips [*21*]. Impingement is most importantly related to errors of prosthetic position, as opposed to other relevant factors that may include soft tissue tension, prosthetic design, and surgical approach. Leg length and offset can be precisely controlled with imageless navigation. Ellapardgja et al. found that in total hips, 96 % had femoral offset and 96 % leg length within 6 mm of the normal contralateral side [*22*]. Dastane et al. noted that postoperative femoral offset was 1.4 mm +/– 6.4 mm with 78 of 82 hips within the 6 mm difference from the opposite side. Leg length in the same study was within 2.5 mm of the normal leg, and the difference was less than 6 mm in 99 % of the cases [*23*].

Kalteis et al. performed a carefully designed randomized control trial comparing freehand conventional

guided technique with either imageless or CT-based navigation guided technique in 90 patients [24]. The outcome was that only 14 of 30 with the freehand method were within the Lewinnek “safe zone.” With navigation there were 25/30 with CT based and 28/30 with imageless navigation, and no significant difference with the navigated group ($p = 0.23$). Nogler et al. performed a cadaver analysis of navigation of the minimally invasive direct anterior approach to the hip using imageless navigation finding that the variation of inclination and anteversion was significantly smaller with the navigated cases [25]. The homogeneity based on median of variance showed a highly significant outcome ($p < 0.001$). Nogler in 2004 had performed a similar classic study using an open surgical approach finding similar results of navigation versus conventional methods [26].

CT-Based Navigation: Surgical Technique

CT-based navigation utilizes a preoperative CT scan taken from the pelvis to the knee joint that is transferred into the planning module of the computer. Typically 20 reference points are chose including the bilateral anterior superior iliac spines, bilateral pubic tubercles, the most distal point of bilateral ischium, mid pubic symphysis, sacral midplane, piriformis fossa, posterior point of the proximal femur, bilateral posterior condyles, and the knee center. The computer semiautomatically segments the pelvis into appropriate views. Planning of the femoral stem placement considers stem anteversion, valgus angle, and the shaft axis. It is possible to consider fit and fill of the proximal femoral canal. Cup orientation and adjusted according the femoral stem anteversion angle to acquire the best range of motion. Finally, leg length and femoral offset may be adjusted considering stem size, head offset, and the cup position.

With the operative procedure, the patient may be positioned according to the planned surgical approach, and a pelvic tracker is fixed to the ipsilateral ilium (Fig. 1). After the initial surgical approach, a femoral tracker may be fixed to a plate that has been fixed to the greater trochanter with 2.0 mm screws. Registration of the femur and pelvis is then done by digitizing multiple points on the proximal femur and the pelvis, as noted above with the preoperative planning phase. A verification point may be selected on the posterior superior acetabulum which may be checked during the procedure.

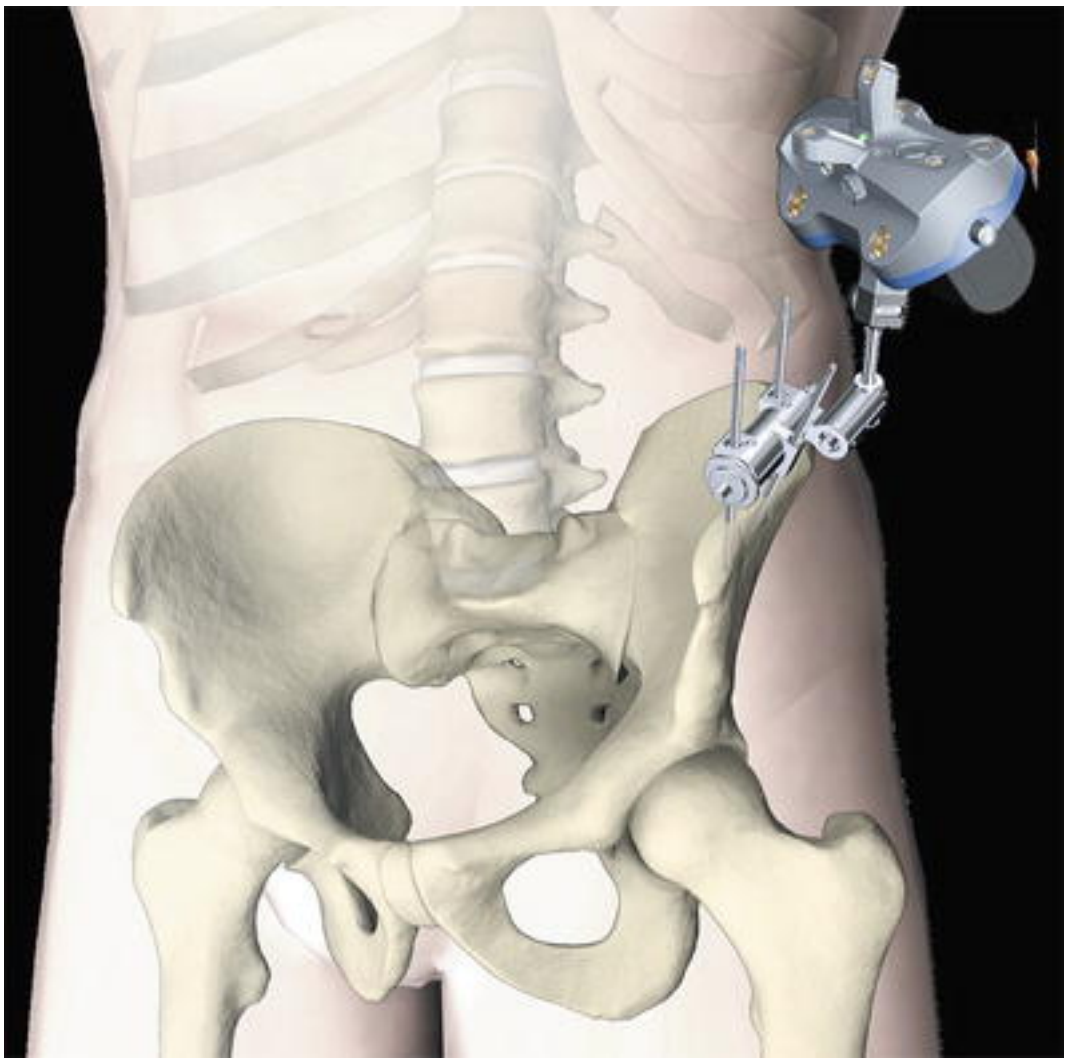

Fig. 1

Typical reference tracker is fixed to the iliac crest

After reaming of the acetabulum with navigation, the trial or final acetabular component may be placed with final cup inclination and anteversion recorded. Femoral preparation may be done by rasping and inserting the femoral trial controlling stem anteversion, valgus angle, and leg length. Leg length can be finally adjusted after femoral stem insertion by changing the neck length of the femoral head. Final checking of the verification points and the implant position parameters can be recorded.

Imageless Navigation: Surgical Technique

Typical imageless navigation systems have a PC computer data analysis, a camera system with two or three cameras that track the target “dynamic reference bases,” which can be active LED light emitters or passive reflective ball guides. The cameras transfer data of the moving targets in real time in 3D space portraying a visual rendering of the subjects on the computer screen. The surgeon can manipulate the instruments in relation to the anatomical targets, thus creating the guided or navigated surgical intervention. Modern systems have programs that allow the surgeon to customize the workflow, with multiple choices of targets, steps, and specific characterization of the anatomical features. In the total hip navigation, one may choose the reference of the standard anatomical frontal plane defined by registering the ASIS points and the public tubercle, the functional pelvic plane which normalizes the coronal plane of the standing patient with the position of the pelvis creating a perpendicular pelvic plane, or the patient/table registration which defines points the surgeon

determines to be in the “coronal plane” of the supine patient. Referencing the longitudinal body axis attempts to define the coronal plane of the patient, creating a “patient specific pelvic tilt” adjusting for out of plane tilt of the pelvis. A pelvic tracker is placed securely in the superior ilium with the tracking device attached. The camera system must be placed appropriately to visualize the position of the pelvic tracker and other instrumented devices. Positioning the patient is critical as the registration of the tracker assumes that the ASIS is perpendicular to the table, and the patient’s body is parallel to the axis of the operating table (Fig. 2). Registration considers the depth of the acetabular fovea, the articular surface of the acetabulum, the tip of the greater trochanter, and a distal point on the outside of the leg which may be an EKG lead. Other registration points may include the position of the transverse acetabular ligament and the anatomical hip center of the acetabulum obtained by the use of a dedicated reamer that bests fits the acetabulum.

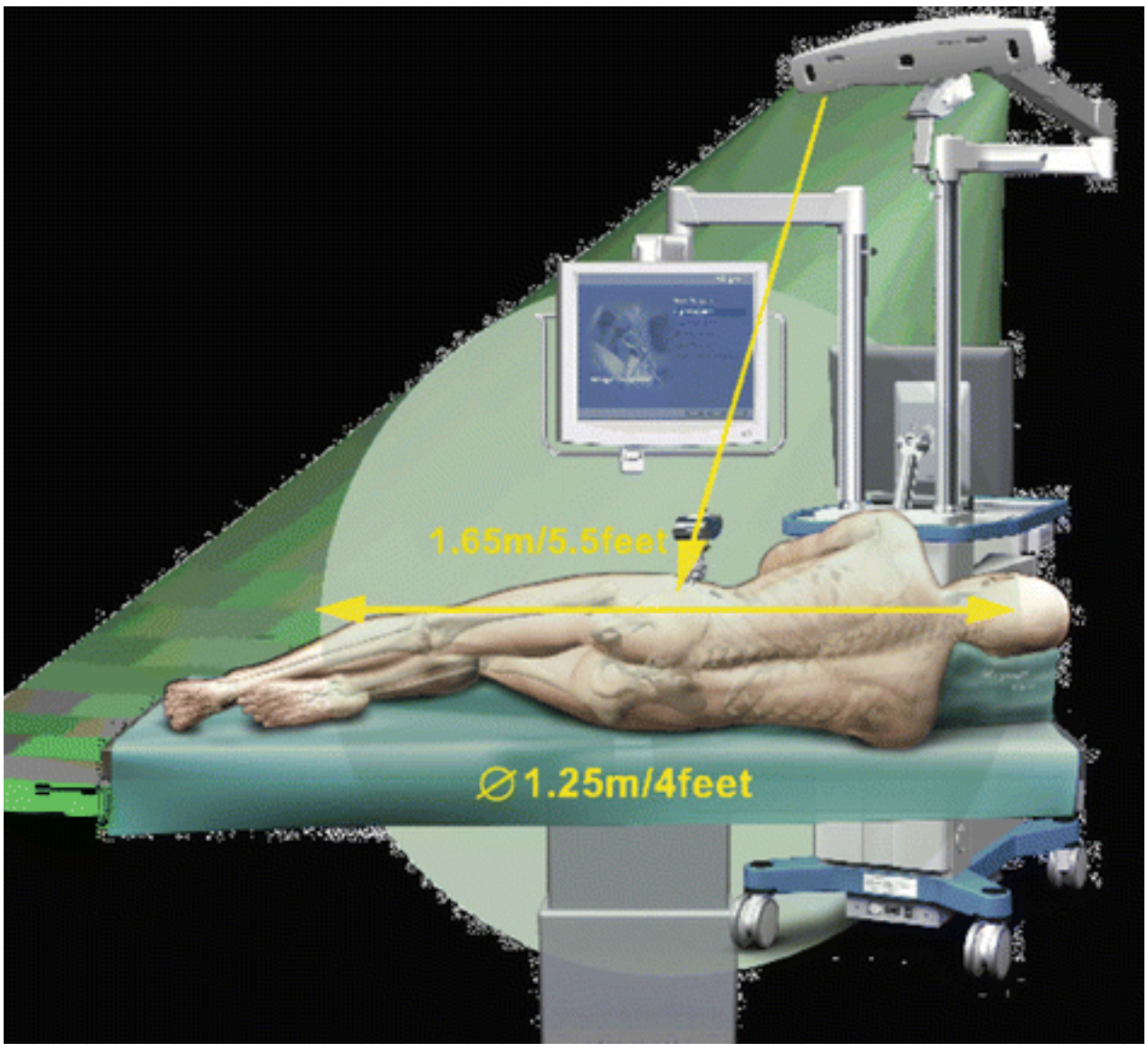

Fig. 2

For imagless navigation, body is place in the longitudinal plane allowing for dynamic referencing of the body plane. Note position of camera and reference tracker

Cup position must be defined by the exact planes selected and may consider the anatomical, radiographic, or the surgical definition (Fig. 3). This will be determined by the preference of the manufacturer. The various navigated features include movement of the cup center in medial/lateral, superior/inferior, and anterior/posterior directions. Femoral stem navigation considers navigation of the anatomical femur axis and

version of the stem that may be determined by the knee posterior condylar axis or the knee transepicondylar axis. Finally, leg length, offset, and femoral head medicalization/lateralization are other parameters that can be measured (Fig. 4).

Fig. 3

Screen shot for acetabular component navigation shows anteversion, inclination, and position of the cup to the floor of the acetabulum

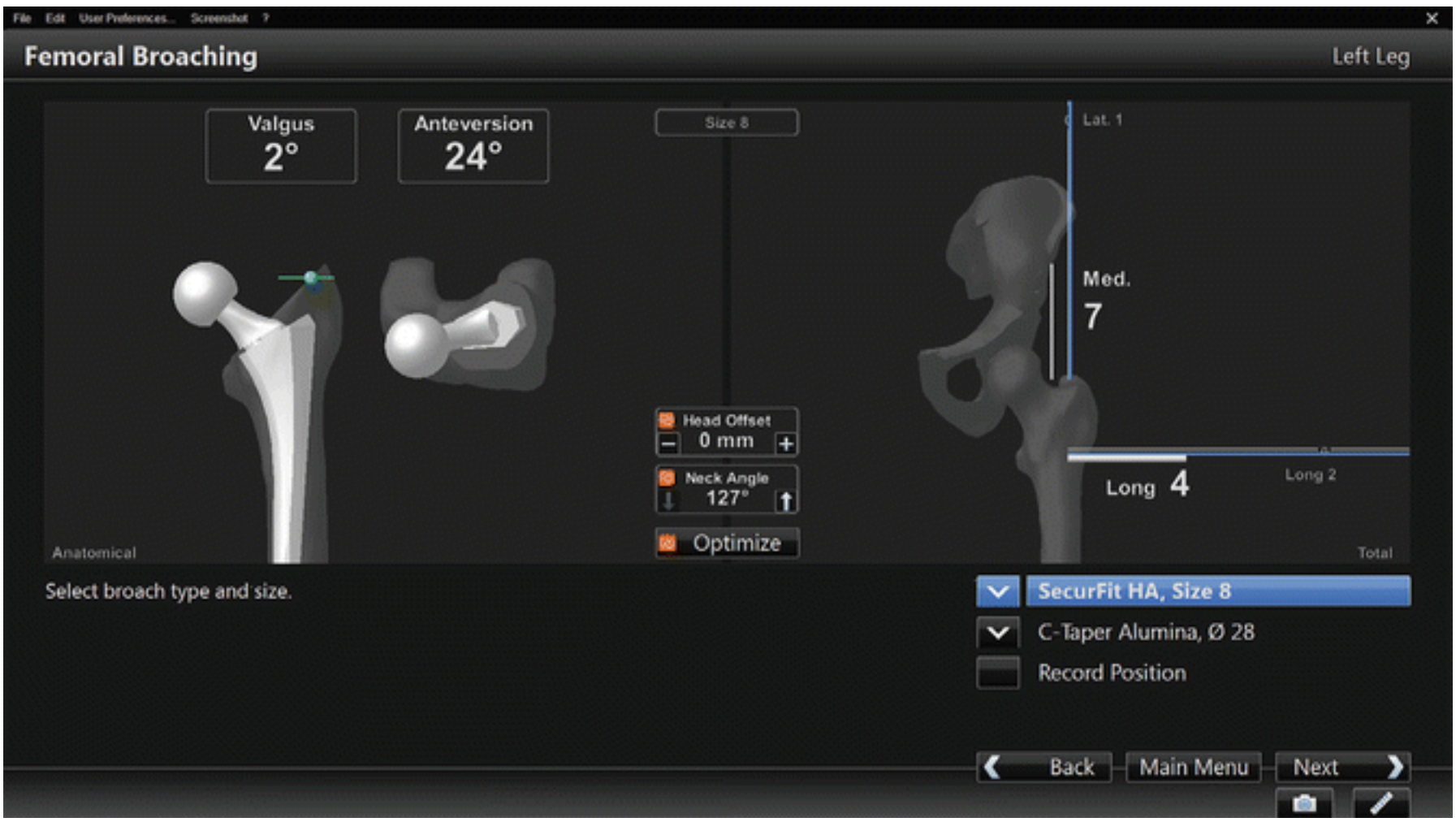

Fig. 4

Screen shot of the femoral component navigation shows femoral version, leg length, and offset

Robotic Navigation: Surgical Technique

Robotic computer-guided instrumentation has been developed to improve acetabular cup navigation by eliminating errors of manual reaming and cup implantation. The robotic instrumentation allows the surgeon to work within a haptic tunnel, creating a failsafe if the reamer exceeds the planned bone preparation in any plane by more than 2 mm. Cup impaction is also done through this haptic constraint to improve accuracy of inclination, anteversion, and the center of rotation. One such system is the MAKO robotic system (MAKO

Rio Robot, Ft Lauderdale, FL).

The technique described for the MAKO system may be done in a number of methods, but typically the patient is placed in the lateral position and a posterior-lateral approach is done. The pelvic tracker with reflective markers is placed in the pelvic rim. In addition, a 4.5-mm screw is placed in the posterior superior pelvic bone for confirmation of the robotic readings. Surface registration is then done for 32 points in the acetabulum including the rim. These positions are then matched to a 3D pelvis constructed from a preoperative CT scan with an acceptable registration error of 0.5 mm. That scan had been obtained under specific conditions and sent to MAKO for incorporation into the robotic software for the surgical procedure. Precise reaming is controlled by the stereotactic interface which restricts the reamers to a predefined volume of reaming with a fail-safe stop mechanism if the reamer exceeds 2 mm of the desired position. The cup impaction is within 1 mm of the desired outcome. The system allows for an error of 5° for inclination and anteversion.

A recent study by Kanawade et al. assessed this system evaluating 38 patients with postoperative CT scans. The planned inclination was 39.9° +/– 0.8° with the robotically guided placement of 38.0° +/– 1.6° and no outliers over 5°. For anteversion of the proximal femur, planned was 21.2° +/– 2.4° and intraoperative guidance was 20.7° +/– 2.4° with no outliers of 5°. On the postoperative CT evaluation, there were seven outliers. Center or rotation was superior by 0.9° +/– 4.2° and medial by 2.7° +/– 2.9 mm. For the overall precision, inclination was 88 %, anteversion 85 %, and center of cup rotation 81.5 %. The compares to literature studies where 40–78 % of implants may be outside of the desired range of error. The authors were able to achieve similar precision using bone models for comparison (Fig. 5).

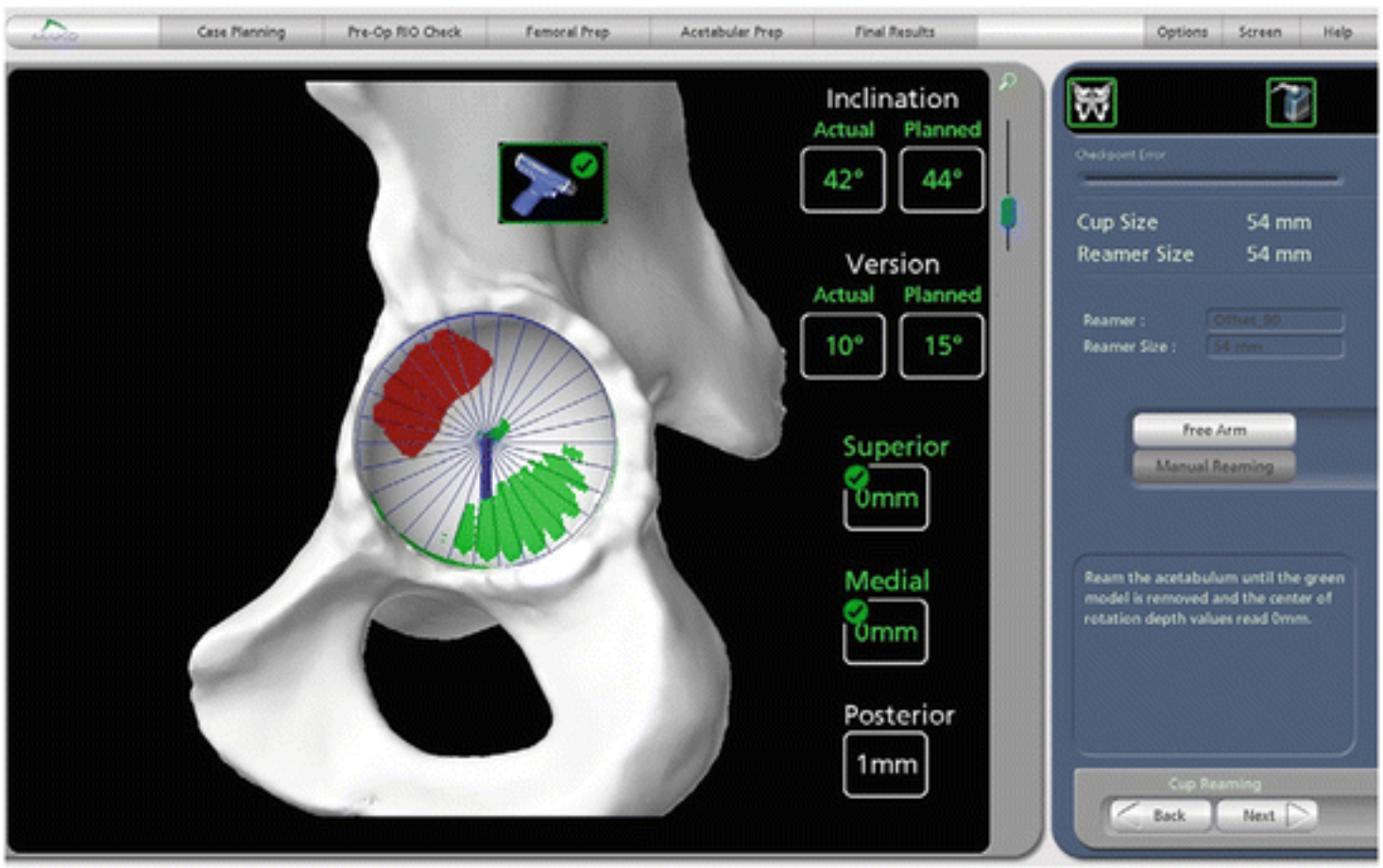

Fig. 5

Note image of the computer screen during the planning phase, with green being the bone to be reamed, white shows the correct depth of reaming, and red shows reaming beyond the appropriate depth

New Evolutionary Technology: OrthoCompass

The OrthoCompass is a new pre FDA approved system that demonstrates the future application of one of the many common technologies that is found in a large number of everyday products, namely accelerometers (Fig. 6). One of the easiest to recognize is the “gizmo” inside of a cellular telephone that allows gravity to reposition the image on the screen if the phone is upside down. The OrthoCompass is a “leg” with a “hip joint” attached to the computer platform that has a spherical coder for the ball and socket joint, a “knee joint” that has an angular sensor recording the angle of the articulation, and an “ankle” joint that attaches to the cup inserter. The cup inserter is a normal rod with the cup attached distally for insertion. The data input from the OrthoCompass is angular and positional information from the spherical encoder that attaches the proximal “leg” to the computer platform, and an angular sensor that measures angular displacements of the “knee” when moved in space. These two inputs then define the precise position of the distal fitting that captures the acetabular cup.

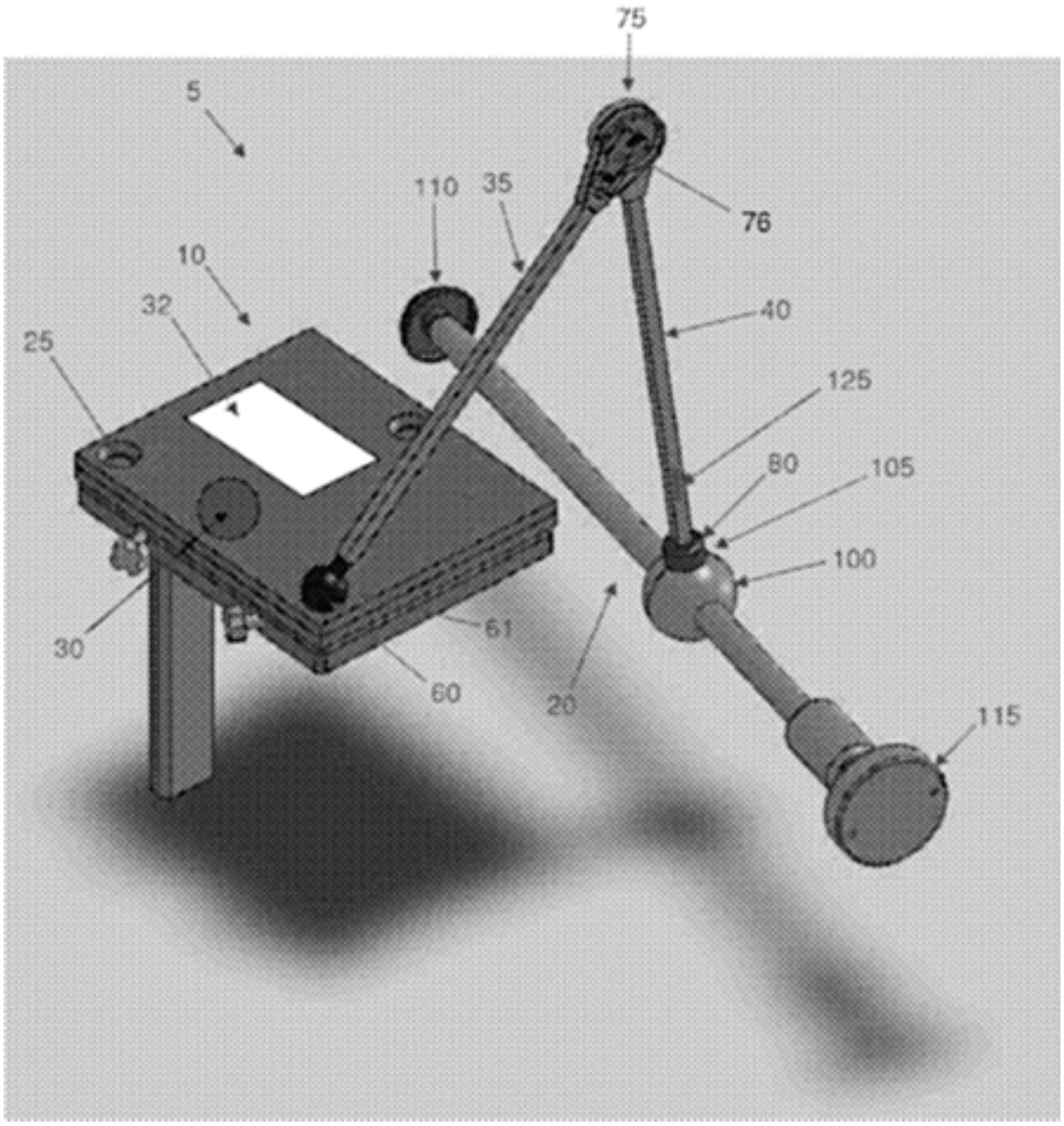

Fig. 6

Illustration of the OrthoCompass shows the device anchored to the table and the simple arm that directs position of the cup insertion for appropriate anteversion and inclination

Other information needed for registering the hip joint into the computer come from determining the anatomical center of the target hip joint. This is performed by the well-known kinematic method, which is done by moving the hip joint in a circular motion. The superior iliac spines are also registered by the typical touch-pointing method. This data registration creates the hip center superior spine (HCAPP) plane which is the anatomical relationship of the hip center to a line created by the two anterior superior iliac spines. As this angle is a known anatomical feature with limited variability, this feature can then be used to calculate the anterior pelvic plane which is the coronal plane projection connecting the anterior superior iliac spines and the pubic tubercles in space.

Computer guidance allows the two jointed articulation to place the acetabular impactor in the exact alignment in space to drive the acetabular component into the acetabulum with the desired amount of anteversion and inclination in relation to the HCAPP and the calculated APP. Another important element is the need to control the position of the ASIS during the procedure, as the patient may move slightly changing the relation to the system computer platform. This compensation is performed by two ultrasound devices placed in pads over the anterior superior iliac spines that constantly assess and adjust for the movement of the ASIS during the procedure. While the system remains experimental, the prototype demonstrates the potential of simple highly accurate positional devices to measure anatomical landmarks and to create directional guidance.

Conclusion

Computer navigation in total hip replacement offers several important inputs to the surgeon for accurate placement of implants. Older technologies have proved to be precise enough to improve cup position, leg length and offset determination, and innovative ideas such as the femur first implant placement. However, there has been little innovation of image acquisition, registration, and overall simplicity for the past 10 years, and my demonstration examples such as CT based and imageless navigation protocols are virtually identical to that presented in the first edition. However, there are lots of technology advances on the horizon. The Orthocompass, MAKO robotic system, and the use of intraoperative 3D CT are to name just a few innovations that will change the playing field for the community surgeon and enable dramatic improvements in the downside issues of cost, complexity, and efficiency.

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