39 Navigation Technologies for the Anterior Approach in Total Hip Arthroplasty

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As many clinicians know, hip arthroplasty is a very successful surgical intervention to improve the function and satisfaction of those with hip pathologies. While surgeon experience and skill can certainly maximize successful outcomes, outliers can exist across the spectrum of surgeon acumen and approaches. This success can be tempered by functional issues related to implant position including cup position, proper leg length, and offset restoration. The importance of cup position for successful outcome during hip arthroplasty has been well studied. Safe zones of acetabular cup position have been described in several studies. Lewinnek et al. determined a safe zone as 30° to 50° of abduction and 5° to 25° of anteversion noting increased dislocation rates outside these zones [1]. Barrack et al. determined the safe zone to be 35° to 50° abduction and 10° to 30° of anteversion to mitigate dislocation [2]. Despite surgeon familiarity with these safe zones reliably attaining them during total hip arthroplasty is less than assured.

Interestingly, surgeon experience has been found to not always assure cup and stem position by visual intraoperative estimation during standard and minimally invasive approaches [3, 4]. Callahan et al. reported experienced surgeons using visual clues alone in 1823 cups studied only half were found to be within the combined target zones of 30° to 45° abduction and 5° to 25° anteversion [4]. Implant positioning can also influence complications such as dislocation [1, 2, 5–7], accelerated bearing surface wear and reduced implant longevity [5, 8–12], impingement with resultant limited range of motion [13], and even catastrophic failure [14–16].

Computer-assisted orthopedic surgery technologies in total hip arthroplasty have been developed to assist the surgeon in optimizing implant positioning and promoting improved patient satisfaction and outcomes. The introduction of intraoperative fluoroscopy was a significant advancement in total hip arthroplasty, enabling guidance of implant placement. Fluoroscopy can be used to facilitate decision making and provide real-time qualitative information on implant positioning including estimation of comparative leg length and offset. Beamer et al. have found fluoroscopy to improve the odds of placing the cup into the surgeon's safe zone abduction 30° to 45° and anteversion of 5° to 25° using different approaches during primary, conversion, and revision total hip arthroplasty [17].

The supine position in direct anterior approach allows surgeons to adopt fluoroscopy into their workflow. Intraoperative fluoroscopy is a readily available, affordable, and facile enabling technology in direct anterior approach and predated the

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computer-assisted orthopedic surgery systems of today. J. Martin et al. compared anatomic component positioning in 100 patients using posterior approach without fluoroscopy to 100 direct anterior approach patients with fluoroscopy [18]. Direct anterior approach provided more accurate restoration of leg length, femoral offset, and total offset than imageless posterior approach. Direct anterior approach also provided more ideal cup abduction and anteversion than posterior approach [18].

Rathod et al. compared direct anterior approach with fluoroscopy to posterior approach without fluoroscopy including those cases considered during the learning curve of direct anterior approach [19]. They reported reduced variances in cup inclination and anteversion were significantly lower than the direct anterior approach group with target inclination and anteversion achieved more reliably (98% and 97% respectively) compared to the posterior approach group (86% and 77% respectively). Even during the learning curve of direct anterior approach, target inclination was attained in 95% and anteversion 91% of cases reviewed [19]. While fluoroscopy was readily accepted as a qualitative tool into the direct anterior approach surgeon's workflow, it lacked granular, quantitative data for optimizing intraoperative decision making. The need for more quantitative data delivery systems around the readily available fluoroscopy left opportunities for innovation in total hip arthroplasty.

Computer-assisted orthopedic surgery has rapidly expanded over the past three decades to include four basic technologies (Fig. 39.1):

- Computer-assisted preoperative planning
- Computer-assisted navigation
- Robotics
- Patient-specific surgical templates

Many of proprietary systems available today incorporate two or more of these technologies to minimize inaccuracies while attempting to optimize efficiency during hip arthroplasty. Navigation platforms typically incorporate computer-assisted preoperative planning into their workflows whereas robotics require computer-assisted preoperative planning and navigation to direct the action of the robotic device.

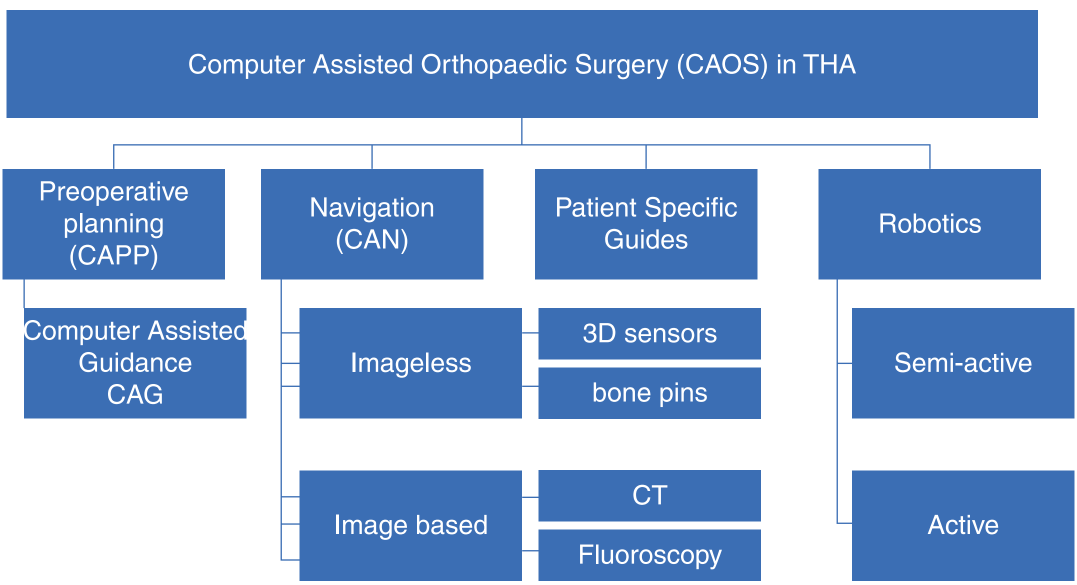

Fig. 39.1 Computer-assisted orthopedic surgery (CAOS) in total hip arthroplasty comprises four basic technologies

Computer-Assisted Preoperative Planning

Preoperative planning with acetate film has long been supplanted by digital and computer-assisted preoperative planning. Most arthroplasty surgeons are versed in the many computer-assisted preoperative planning platforms. These platforms allowed more capable computer-assisted guidance technologies to evolve. Computer-assisted guidance aims to augment fluoroscopy providing more detailed and robust qualitative guidance experience for the surgeon. In general terms, guidance is providing information aimed at resolving a problem or question and maybe considered more qualitative in nature. Conversely, navigation requires detailed quantitative information to afford an objective. Preoperative planning allows guidance, as does intraoperative fluoroscopy, but typically lack the accurate data computer-assisted navigation systems provide.

Computer-Assisted Navigation

Computer-assisted navigation for hip arthroplasty developed in the 1990s with advancements in three-dimensional sensor technology. In general terms, navigation is considered a process of accurately ascertaining position and then planning to execute a planned route. Prior to computer-assisted navigation, acquiring accurate acetabular and femoral positions for implant placement lacked quantitative data in millimeters and degrees. Computer-assisted navigation technologies germinated and evolved quickly in the early 2000s to help address the quantitative deficiencies with conventional visual, mechanical, and fluoroscopic techniques. Computer-assisted navigation systems strived to allow surgeons to accurately plan and place implants to the level of millimeters and degrees not previously attainable with conventional techniques and mitigate the potential for radiographic outliers.

Computer-assisted navigation and computer-assisted guidance systems are considered passive technologies which provide information to guide surgeon decisions and actions using conventional tools. Computer-assisted navigation and computer-assisted guidance do not physically control the surgeon's actions as robotic systems do. Computer-assisted navigation systems are typically image-based or imageless in the way the surgeon acquires the data for intraoperative decision making. Image-based systems rely on either preoperative computed tomography (CT) scans or intraoperative fluoroscopic images. Image-based systems may be considered noninvasive, taking indirect measurements of the relevant bony anatomy (Fig. 39.2).

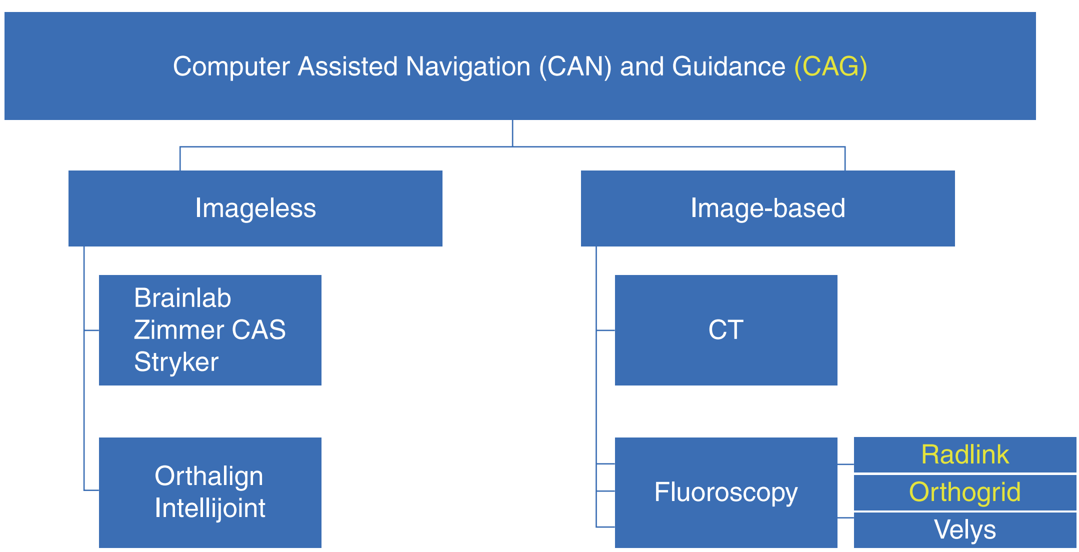

Fig. 39.2 Computer-assisted navigation and guidance systems

Image-based systems may be considered more favorable to surgeons as they take indirect radiographic measurements instead of direct measurements from reference arrays requiring placement of invasive anatomical reference pins in the pelvis and femur. The amount of time it takes to register the bony anatomy using either imageless or image-based computer-assisted navigation systems seems highly variable between technologies and may impose significant learning curves for the surgical team.

Imageless Navigation

Imageless navigation systems first on the market, such as Zimmer Computer-Assisted Surgery (CAS) (Zimmer Biomet, Warsaw, IN), Stryker OrthoMap Navigation (Stryker, Kalamazoo, MI, USA), and BrainLab Navigation (BrainLab, Munich, Germany) required drilling of pins into the pelvis and sometimes femur, to place passive optical trackers which are monitored by the three-dimensional active optic tracker station near the operative field. Accurate registration of acetabular and femoral landmarks are recorded with an optically tracked probe. The registration of landmarks and stability of the anatomic trackers is of the paramount importance in accuracy and success of these procedures. Cup position, notably inclination and anteversion, as well and changes in leg length and often offset, are displayed in real-time to the surgeon with these imageless systems.

The value of these technologies would be based on the accuracy of the data and the precision and efficiency of the input of the registration steps. With careful registration, data could be reliable, providing real-time feedback to the surgeon to make data-driven decisions on implant position and functional metrics. Continual advancements in computers, optics, and tracker technology hope to provide improved accuracy and efficiency over older systems. Some imageless computer-assisted navigation systems are universal with any implants, and some had to be used for optimal data capture with a specific implant company. With the infrequency of intraoperative imaging being used in approaches like posterolateral, lateral, and anterolateral when the patient is placed in the lateral decubitus position, the appeal of this data was to compliment the standard techniques which relied heavily on surgeon experience and skill. Surgeons and approaches which found fluoroscopy cumbersome were the beneficiaries of imageless navigation system development. These systems reinforced the desire to minimize the use of ionizing radiation for certain approaches and surgeons.

The efficacy and accuracy of imageless computer-assisted navigation systems to reduce outliers and improve implant position, including cup position and leg length discrepancy, when compared to standard techniques has been reported [20–22]. While in general, these systems are effective, accurate, and reliable when registration is realized they rarely improve efficiency and reduce operative times [21]. To the contrary, Kruezer et al. reported minor operative time reductions with imageless computer-assisted navigation versus conventional direct anterior approach theorizing the supine positioning allows a less cumbersome registration process than lateral positioned approaches [23]. Despite these radiographic, safety, and potential efficiencies benefits, significant improvements in clinical outcomes have yet to be realized for imageless computer-assisted navigation systems [20, 21].

The navigation systems were somewhat agnostic to the approach and could be used for anterior approach as well as the more common approaches when these products were introduced. As the percentage of anterior approach total hip arthroplasty cases increased, these products become more frequently used in settings which were less common on their initial release. With anterior approach, some advantages to registration were seen, as the anterior superior iliac spine (ASIS), for example, access to both sides was more readily available.

Certain cup analytics, such as defining cup position off of the anterior pelvic plane, became easier with patients in the supine position. These registration points could be done as well on the lateral decubitus position, but often needed to be registered prior to this positioning. This could create a workflow disruption, as some level of sterility was needed as the pins would need to be drilled into the pelvis for this portion of the registration prior to final positioning. Often, surgeons would forgo this registration and the applicable data when using this technology in the lateral decubitus position and would register functional plane of the pelvis.

The advantage of the registration of both ASIS during supine positioning was partly offset by the disadvantage of having the pelvic tracker on the ilium during femoral preparation. During anterior approach surgery, femoral exposure and broaching would often compete with the same real estate as the tracker on the same side of the ilium. Any distortion of the pins in the pelvis during femoral preparation would cause error in data, most notably leg length and offset. Smaller trackers with the newer navigation systems would help this problem somewhat as well as placing the tracker on the contralateral ilium. This could provide some workflow challenges, but navigation systems are successfully used in anterior approach total hip arthroplasty.

The adoption of this technology among surgeons was based on the upside of the data output of the navigation system versus the downside of potential time to the case, change in surgeon workflow, and most often large cost to the hospital system for the additional capital, software, and disposable costs. Additional navigation systems, such as Intellijoint HIP ® (Intellijoint Surgical, Inc., Kitchener, ON, Canada) (Fig. 39.3) and HipAlign® (OrthAlign, Inc., Aliso Viejo, CA, USA) attempted to address some of the cost concerns, portability, and potentially improved ease of use. Although these systems still required registration steps and pins to be drilled for data, they attempted to appeal to a larger user population by addressing some of the concerns of the initial product offerings.

Fig. 39.3 Intellijoint HIP mini navigation system as depicted in Bradley et al. [24]

Image-Based Navigation

Image-based navigation systems have evolved in parallel to the imageless systems. Similarly, to imageless systems, image-based navigation has advantages and disadvantages. Image-based systems in orthopedic surgery are comprised of volumetric imaging including magnetic resonance imaging (MRI), CT, and even new ultrasound technologies and nonvolumetric imaging like two-dimensional and three-dimensional fluoroscopy. CT-based and two-dimensional fluoroscopic-based systems have been the focus of most imaged-based navigation systems in total hip arthroplasty. CT and fluoroscopic platforms expose the patient to ionizing radiation whereas the use of fluoroscopy alone exposes the surgeon, patient, and surgical team. The exposure to surgeon and patient during direct anterior arthroplasty has been recently studied [25–27].

McNabb et al. reported fluoroscopy use during direct anterior hip arthroplasty does not pose undue radiation exposure risk to the patient or surgeon [25]. Curtin et al. reported during a direct anterior approach using fluoroscopy the total radiation exposure was nearly identical to previous published values for a screening mammography (3 m Gy) and four times less than a standard chest CT (13 m Gy) [26]. They concluded while it is difficult to ascertain the exact patient-absorbed radiation, their data suggest a one-time exposure during the approach is likely negligible. Pomeroy et al. concluded a surgeon would need to perform greater than 300,000 direct anterior approach total hip arthroplasty to exceed the 800 m Gy cataract threshold dose but leaving the decision to use protective glasses to surgeon discretion [27].

Increasing surgical time is a concern for patients and surgeons alike. The use of many technologies requiring data acquisition increases surgical times for the advantage of more accurate surgical execution and improved patient outcome. A comparative study by Hube et al. reported both CT and fluoroscopy-based systems increased surgical time over manual techniques with CT-based requiring significant preoperative planning with less intraoperative time and fluoroscopic-based requiring no preoperative planning but more intraoperative time for setup and analysis [28]. Both technologies provided similar accuracy in the mean variation of postoperative abduction angle with preoperative planning. CT-based systems had the advantage of three-dimensional feedback on landmarks but required time-consuming preoperative planning. Hube et al. concluded fluoroscopy-based method may be utilized for routine cases with normal anatomy and lesser deformities while there may be advantages to utilizing CT-based methods for complex deformities [28].

CT-based navigation was first used by Digiola et al. in 1998 to improve accuracy of acetabular component placement in total hip arthroplasty [29]. CT-based navigation yields improved accuracy over conventionally placed acetabular components while also being effective in both anterior and posterior approaches [30, 31]. Sugano et al. in a long-term follow-up study found reduced dislocation and impingement related mechanical complications resulting in revision of cementless total hip arthroplasty and ceramic bearing surfaces [31]. Barriers to CT-based navigation have included time-consuming CT preoperative planning, increased time, cost, and logistical planning with the added radiation exposure [32].

Fluoroscopy-based navigation is a recent evolution in computer-assisted navigation. Historically, invasive navigation systems were infrequently used with anterior approach due to the prevalence of fluoroscopy adoption. More commonly, surgeons performing anterior approach total hip arthroplasty would use fluoroscopy to provide qualitative implant positioning data. The accuracy and need for fluoroscopy during direct anterior approach has been questioned by some authors [33] yet embraced by others [17]. Fluoroscopic images and their interpretation can be affected by patient size, positioning, and C-arm position. The initial setup of the C-arm and stable supine patient positioning is helpful to aid interpretation throughout the case as pelvic motion can confound decision making. Shah et al. reported intraoperative pelvic motion occurred during 86.4% (19/22) direct anterior approach total hip arthroplasty starting in a neutral position trending toward extension by cup impaction [34]. Rolling of the pelvis was also reported. They noted the predicted change in cup version of ≥5° due to changes in pelvic position was seen in 32% (7/22) patients. Shah concluded, "although minor, changes in pelvic position do occur during supine total hip arthroplasty which may affect acetabular orientation" [34].

A learning curve is typical for new adopters of fluoroscopic-assisted direct anterior approach total hip arthroplasty as complications decline with experience [35]. Difficulties with interpreting x-ray and fluoroscopic images led to even the most experienced pelvic surgeon like Jeff Mast, to described interpretation as "the misery of x-rays". X-ray images are shadows which can be distorted leading to misinterpretation, hence the misery for the orthopedic surgeons.

Jang et al. reported the accuracy of perceived cup anteversion and inclination to minor variations in C-arm tilt angles [36]. They noted with just 10° of caudal or cephalad C-arm tilt led to a 9° and 10° error and perceived cup anteversion and inclination respectively. James et al. found total hip arthroplasty relying on routine intraoperative fluoroscopic anteroposterior pelvic imaging utilizing the accepted coccyx to pubis distance resulted in 95% (39/41) hips being placed in unrecognized excess anteversion and inclination due to imaging the pelvis in extension [37]. They recommended positioning the C-arm so the size and shape of the obturator foramen matches the standing preoperative anteroposterior pelvis x-ray. James goes on to explain, "this technique will allow for the native standing pelvic tilt to be accounted for intraoperatively and will result in the least variation in intraoperative and postoperative standing acetabular component orientation” [37]. The dichotomy of opinions and concerns left opportunities to improve the guidance capabilities of fluoroscopy and spurred the need for more quantitative data acquisition to augment and aid in true surgical navigation of total hip arthroplasty.

At the time of writing this chapter, VELYS™ Hip Navigation (DePuy Synthes © West Chester, PA, USA) is the only navigation system using fluoroscopy during anterior approach hip arthroplasty surgery. Other technologies use the images to provide surgeon feedback on implant positioning and leg length and offset include OrthoGrid Hip (OrthoGrid Systems, Inc., Salt Lake City, UT, USA) and Radlink (Radlink, Inc., El Segundo, CA, USA). Surgeons would also use other techniques, not technology, to help interpret the images for feedback. These techniques have been described as printing out overlays, using measurement tools, and guide rods. The success of these techniques has not been widely described and are presumed to depend on the user experience in understanding their limitations. Additional description will follow on these technologies assimilate with fluoroscopy making them more relevant for anterior approach hip arthroplasty surgery.

OrthoGrid

OrthoGrid Hip is an intraoperative surgical application designed specifically for direct approach total hip arthroplasty. The technology may be best known for its ability to correct fluoroscopic distortion, which can easily go unrecognized. Image intensified C-arms, common in many operating rooms around the world, are subject to fluoroscopic distortion primarily as a result of electromagnetic interference. When unaccounted for, distortion may affect the interpretation of component positioning during direct approach total hip arthroplasty, resulting in limb-length discrepancies and undesirable patient outcomes” [38]. Figure 39.4 demonstrates OrthoGrid Hip distortion correction technology enabling more accurate image guidance during direct approach total hip arthroplasty (Fig. 39.4).

Along with distortion correction, OrthoGrid Hip provides key tools and templates that enable surgeons to objectively assess and accurately evaluate component positioning and restoration of hip mechanics, such as cup inclination, hip offset, and leg length. In a study comparing direct approach total hip arthroplastys performed using fluoroscopy with and without the use of OrthoGrid, acetabular inclination, limb length restoration, and hip offset restoration were all improved with the use of OrthoGrid [39]. A different study comparing the analog OrthoGrid Drone system to the digital system concluded that the OrthoGrid Hip digital gridding system “demonstrated an efficient method for consistent and accurate cup positioning and restoration of hip symmetry following direct approach total hip arthroplasty,” and showed lower overall surgical and fluoroscopy times compared to the analog system [40].

Radlink

Radlink was the first Picture Archive and Communication System (PACS) system to market provided data for the surgeon using intraoperative imaging. The company leveraged imaging being captured from flat plate technology as well as from a fluoroscopy C-arm, making the technology applicable for both supine and in the lateral decubitus position. The software/hardware company provided meaningful data for hip arthroplasty surgery, including guidance for cup position, leg length, and offset. The system has a tower and monitor allowing implant representatives and surgeons preoperative planning and intraoperative guidance. Radlink provides an intraoperative cup position ellipse for qualitative inclination and abduction estimates (Fig. 39.5).

Hamilton et al. utilized Radlink’s cup positioning ellipse and reported improved accuracy and precision of cup placement [41]. The system allowed the surgeon to target a preselected ellipse with 40° abduction and 20° anteversion

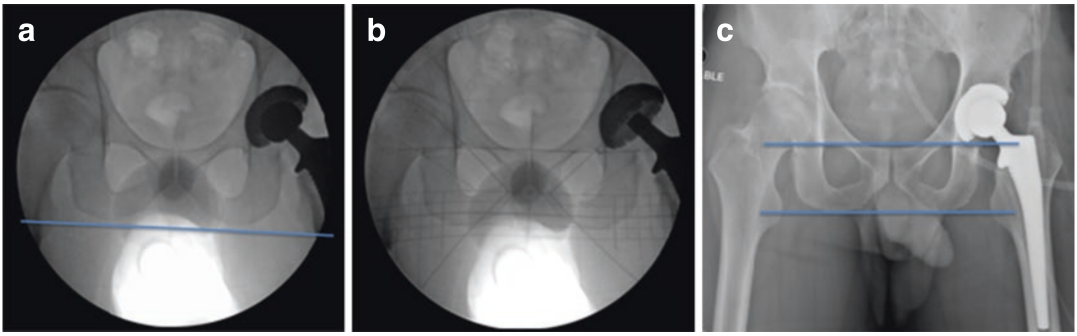

Fig. 39.4 (**a**) Distortion makes operative extremity appear short, (**b**) with distortion correction, the limb lengths are very close, and (**c**) this is confirmed on post-operative imaging

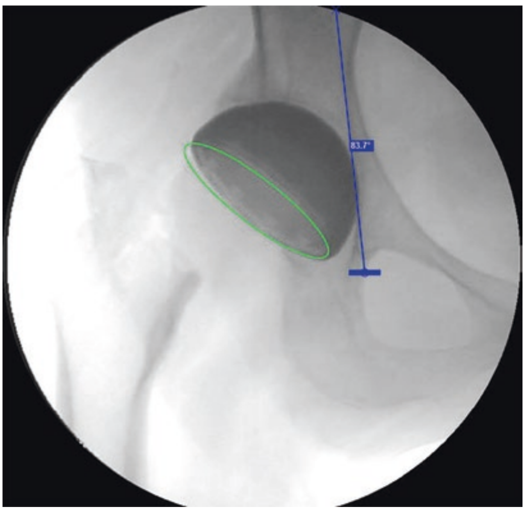

Fig. 39.5 Radlink anteversion and inclination ellipse

Fig. 39.6 Radlink digital overlay of intraoperative trials and contralateral hip anatomy

during cup impaction was measured for accuracy with postoperative radiographs. The mean abduction angle was 40.4° (range 32.7° to 51.1°) for the computer-guided group and 42.3° (range 33.7° to 51.1°) for the fluoroscopic group. The computer-guided cups were significantly closer to the predetermined targeted abduction angle of 40 ° ($P < 0.001$). They reported a modest increase in surgical and fluoroscopy times over their routine fluoroscopy alone techniques. Surgical time for the impaction of the cup increased from 4:58 minutes with fluoroscopy alone to 7:04 minutes with the computer-assisted guidance group ($P < 0.001$). Fluoroscopic times were increased slightly from 11.1 seconds to 12.9 with the guidance system ($P < 0.001$). Hamilton noted, "although both groups showed accurate and precise placement, and on-screen guide to assist with positioning may help a less experienced surgeon even more" [41].

The system also provides an overlay analysis which is a colored digital outline of the pelvic anatomy similar to the manual fluoroscopic printer acetate overlay technique direct anterior approach surgeons are historically familiar with (Fig. 39.6). Radlink's digital overlay technology allows the surgeon to appreciate relative resultant pelvic anatomies throughout the procedure. The technology helps guide surgeons in selecting the implant size and morphology after reduction of trial implants and allows comparison to both ipsilateral and contralateral hips.

At completion of the surgery and before wound closure, the surgeon can take five overlapping fluoroscopic spot images across the pelvis. The software then digitally stitches these images together providing the surgeon a panoramic view of the entirety of the pelvic anatomy analogous to taking an intraoperative low anterior-posterior (AP) pelvis flat plate x-ray (Fig. 39.7). The system is agnostic for implant vendors.

VELYS Hip Navigation

Described as the first and currently only technology described as fluoroscopic guided navigation for hip arthroplasty, VELYS Hip Navigation, formally JointPoint, incorporates images acquired during surgery and provides data on cup position, leg length, and offset. There are some notable differences to the aforementioned imageless navigation systems in this chapter.

The VELYS Hip Navigation system is noninvasive, as no pins are required to be placed in the pelvis and/or femur. Additionally, the registration steps are often performed by a consultant not in the surgical field. The technology is primarily software-based, as it runs on computers communicating with the fluoroscopic C-arm. This allows the surgical field to remain clear of excess tools and instruments. Both qualitative and quantitative data are displayed on a touch screen monitor (Fig. 39.8). Most computer-assisted guidance, computer-assisted navigation, and robotic systems have a monitor for surgeons to preoperatively plan and make intraoperative changes to surgical plan. Navigation and robotics allow for quantitative assessments using millimeters and degrees.

The monitor allows the industry representative and surgeon to manipulate and make measurements from the preoperative pelvic radiographs for templating and later fluoroscopic images obtained before, during, and after surgery (Fig. 39.9).

The leg length and offset data provided in VHN is displayed in a chart called OneTrial™ (DePuy Synthes Orthopaedics, Inc., Palm Beach Gardens, FL, USA) (Fig. 39.10). The purpose of this chart is to allow the surgeon to not only see the current leg length and offset situation with the

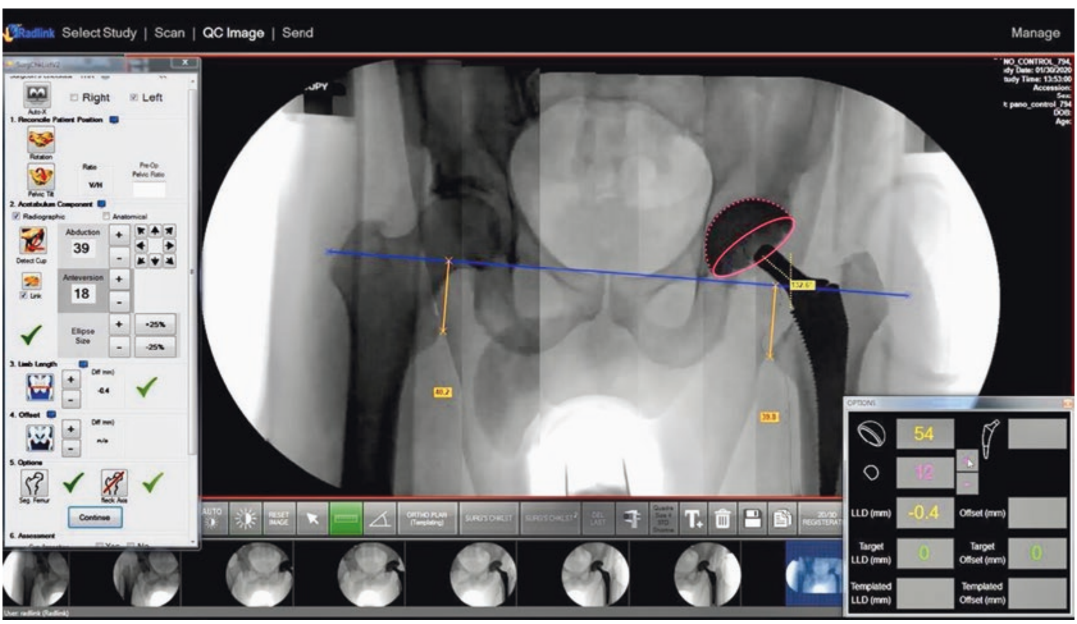

Fig. 39.7 Radlink Panoramic digitally stitched image allows a surgeon to appreciate the full pelvic anatomy prior to wound closure

Fig. 39.8 VELYS Hip Navigation system tower with touchscreen monitor

construct being trialed, but the leg length and offset change associated with other modular constructs specific to the stem being utilized. This requires the software to understand the options specific to the applicable stems used, as well as the geometry of the stem and how it would affect the trialing options. With the anterior approach, many surgeons find repetitive trialing, especially when on a special table, to be time-consuming and cumbersome. This technology was designed to address some specific concerns of the anterior approach and was a result of the large growth in this type of surgery.

Fluoroscopy use during anterior approach has been described as potentially time inefficient as well as introducing radiation exposure to the surgical personnel and patient. Accurate interpretation of intraoperative images often requires

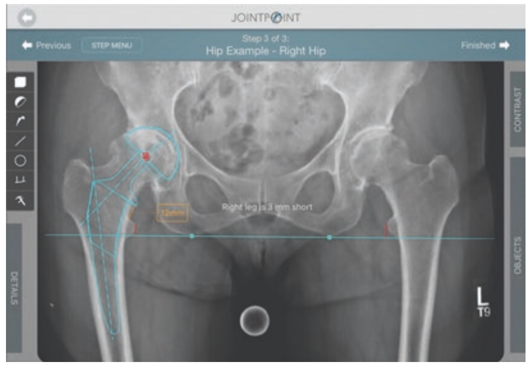

Fig. 39.9 VELYS Hip Navigation system is similar to other computer-assisted guidance and robotic systems which provide computer-assisted preoperative planning

significant amount of imaging time to address some of the variables affecting data conclusions. VELYS Hip Navigation uses the registration steps to address these variables, potentially reducing the need for repetitive imaging [42].

The importance of cup position for successful outcome during hip arthroplasty has been well studied previously. VELYS Hip Navigation uses a mathematically based ellipse to address cup anteversion and inclination with the use of fluoroscopy. Accurate cup data requires the user to analyze the acetabular component while the pelvis is level. Furthermore, the current technology does not yet account for functional changes in the pelvis that occur during sitting and standing. These tilt changes in the caudal and cephalad direction that occur functionally can be addressed with intraoperative fluoroscopy and preoperative images to assess cup position outside the supine position.

VELYS Hip Navigation has a focus on leg length and offset data in a user-friendly chart to help improve this important feature of successful hip arthroplasty surgery. Many surgeons felt the anterior approach could limit the ease of examining the hip for tension while on a special table, direct anterior approach tables with the operative extremity secured in a traction boot, requiring more emphasis on the imaging for this information. Without technology, existing techniques can be time-consuming and/or inaccurate. VELYS Hip Navigation had a primary focus on providing

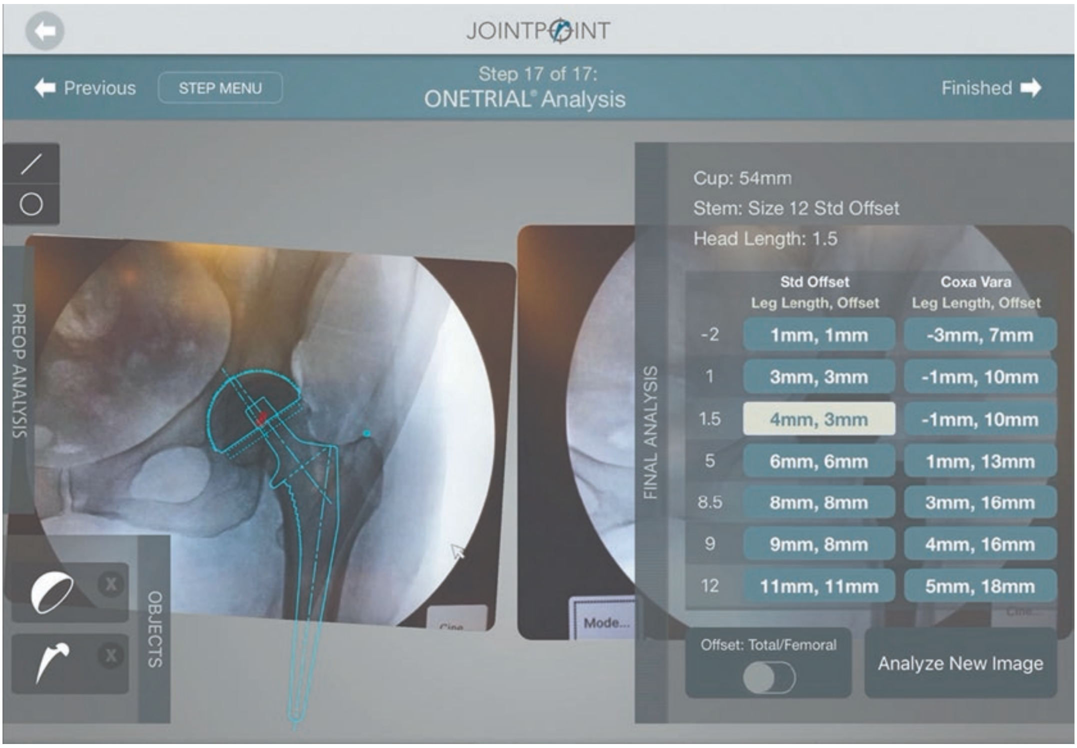

Fig. 39.10 The VELYS Hip Navigation system facilitates intraoperative navigation by calculating leg length and offset of different implant morphologies available to the surgeon to recreate the patient's specific anatomy while allowing comparison to the contralateral hip. Using OneTrial™ technology the surgeon can select the optimal final implant size and geometry from the first trial reduction of the stable broach, neck, and head construct

not only cup data, but leg length and offset data by comparing two images.

Future studies are required to better determine if VELYS Hip Navigation reduces outliers or improves outcomes over traditional techniques. Since VELYS Hip Navigation requires two images for cup position, and two images for leg length and offset, there is a potential for most surgeons to find a reduction in image requirements. Like other navigation systems studied with the posterior approach, data has shown to reduce outliers in cup position, leg length, and offset. Better functional outcomes will have to be researched to compare VELYS Hip Navigation to standard techniques to determine how much of a benefit it can have for patients. Furthermore, reduction in operating room time, fluoroscopy use and radiation exposure, by using VELYS Hip Navigation versus traditional techniques will likely continue to be described.

The previously discussed navigation and guidance technologies help fulfill a need for improved accuracy, precision, and reliability when implanting total hip arthroplasty components previously relied on confoundable human visual and tactile clues. Routine use of anatomical landmarks and mechanical alignment guides have been found to have varied reliability in assuring optimal cup positioning [43–45]. Most computer-assisted systems have been successful in improving cup positioning over conventional surgeon acumen but report the detriment of increased surgical time. Cost, portability, and reduced workflow efficiencies have been a concern for many of these technologies and allowed opportunities for new innovations.

Like most evolving, enabling technologies, costs decline, portability improve, and workflow efficiencies rise as technologies advance and surgical teams acquire experience with these systems. Studies on improved accuracy and precision in determining leg length and offset with these systems have been limited to date. Likewise, despite the radiographic, safety, and potential efficiency benefits, of computer-assisted systems significant improvements in clinical outcomes have yet to be realized. To date, the ideal combined cup angles for any patient's hip arthroplasty is unknown. Established radiologic safe zones reflect a static pelvis and uniform anatomies which are contrary to a dynamic reality. It is now appreciated pelvic and spine anatomy represent a dynamic relationship called spinopelvic mobility which can change from supine, standing, and sitting positions [46–48]. Spinopelvic alignment, balance, and mobility maybe an under-appreciated and misunderstood cause for complications like dislocation [49–51]. It follows to mitigate dynamic problems like dislocation, impingement, wear, and breakage a surgeon must account for the variability in each patient's fixed anatomy and spinopelvic mobility to target their optimal functional implant positions.

As computer-assisted guidance and navigation technologies evolve they will no doubt be an integral tool in elucidating, documenting, and understanding dynamic relationships of spinopelvic anatomy and patient-specific differences and promote accurate, reliable targeting of each patient's optimal, functional implant position mitigating potential adverse outcomes after total hip arthroplasty.

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