Hip Navigation Using the OrthoPilot® System

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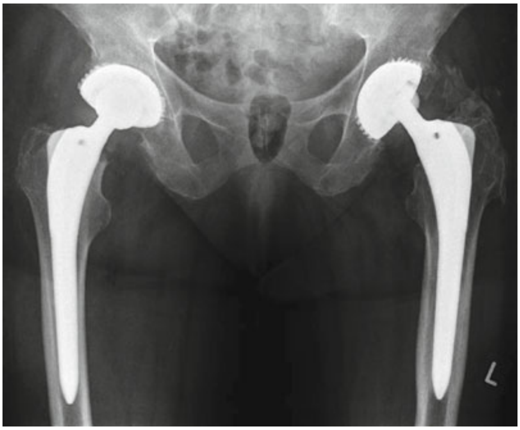
Total hip arthroplasty (THA) is one of the most successful orthopedic surgeries performed worldwide. More than 200,000 THAs are implanted in Germany each year. Critical to the success of these surgeries is the accurate positioning of the components. The orientation of the cup positioning affects directly the success and survival of the THA and may have an influence on the patient's functional outcome.

13.1 Importance of Cup Positioning

Malpositioning of the implant components is the major cause for early joint dislocation, limited range of motion due to femoroacetabular impingement, and early implant wear due to edge loading and leg length discrepancies (Kennedy et al. 1998; McCollum and Gray 1990; Schmalzried et al. 1994; Turner 1994; Williamson and Reckling 1978) (▣ Fig. 13.1). An increased anteversion or inclination of the cup may result in a higher risk of dislocation and mechanical wear due to edge loading (▣ Fig. 13.2a,b). The consequence of malpositioning depends among other things on the bearing materials used. The risk of mechanical wear is increased with polyethylene inlays (▣ Fig. 13.3). For modern hard-on-hard bearing surfaces, such as ceramic-on-ceramic and metal-on-metal, an exact orientation of the cup is important to prevent ceramic fracture, squeaking, or increased metal ion release in metal-on-metal bearings (Clarke et al. 2003; Gonzalez et al. 2011; Jacobs et al. 2003; Vendittoli et al. 2010). A decreased inclination and anteversion may lead to femoroacetabular impingement and thus to a limitation in range of motion. Therefore, new ways to improve the longevity of THA are becoming increasingly important.

The importance of cup orientation was mentioned by Lewinnek and colleagues as early as 1978. They defined a safe zone for cup orientation concerning inclination and anteversion to minimize the previously mentioned complications (inclination: 40°±10°; anteversion: 15°±10°) (Lewinnek et al. 1978). In a series of 300 total hip replacements, they determined a dislocation rate of 1.5% for cup positioning within the »safe zone« compared to 6.1% for cups positioned outside the safe zone. In addition, different studies report on a very high rate of revision (one third of all revisions) within the first 5 years after THA following recurrent dislocations (DiGioia III et al. 2003; Dobzyniak et al. 2006; Yuan and Shih 1999). Besides lowering the risk of complications, accurate positioning of the implants is important for reconstructing the offset, the limb length, and thus the biomechanics of the physiological hip. Recently, Widmer and Zurfluh introduced the concept of the »femur-first« method (Widmer and Zurfluh 2004). This concept of combined anteversion for THA proposes a relationship between the acetabular and femoral components that theoretically maximizes the postoperative range of motion and minimizes the risk for impingement of the joint. Using computer-assisted navigation tools, an anteversion angle of the cup component can be made to be dependent on the antetorsion angle of the stem component (or vice versa). Widmer proposed a combined anteversion of 37.3°, whereas the femoral antetorsion should be only 70% (anteversion of cup + 70% of antetorsion of the stem = 37.3°). Sendtner and coworkers conducted a prospective study on this concept and concluded that the combined anteversion concept results in a cup position with more anteversion when compared to the traditional cup placement according to the Lewinnek safe zone (Sendtner et al. 2010). In this context, they believe that modern navigation techniques open a new frontier for an optimized component position, because placing the acetabular and femoral component in relation to the anteversion for both compo-



▣ **Fig. 13.1** X-ray of a pelvis in anteroposterior view with different positioning of the cups: a small inclination of the right hip and a large inclination of the left hip

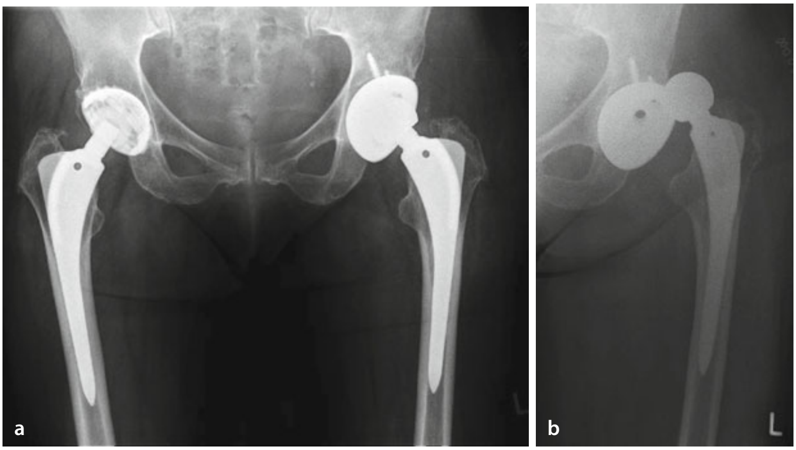


Fig. 13.2a,b X-ray of a pelvis in anteroposterior view with an increased inclination of the left cup (**a**) and the associated complication of hip dislocation (**b**)

nents allows patient-specific biomechanics to be considered.

13.2 Navigation for Correct Implant Orientation

Traditionally, correct component alignment depends on the surgeon referencing from the position of the patient on the table and the anatomical landmarks (Punwar et al. 2011). However, this may result in a wide variability in component positioning. Factors such as pelvic tilt are sometimes difficult to determine intraoperatively and they have an effect on cup positioning (Lin et al. 2011). Nishikubo and colleagues evaluated the preoperative errors in the pelvic tilt of 249 hips before THA using fluoroscopic imaging while the patients were in the lateral decubitus position (Nishikubo et al. 2011). The mean absolute value errors of the pelvic tilt were 2.94° (SD, 2.92°), 2.49° (SD, 2.68°), and 5.92° (SD, 5.20°) in the coronal, transverse, and sagittal planes, respectively. Thus, they regard such preoperative errors in the pelvic tilt as contributing to malpositioning of the acetabular component, since it is frequently observed on postoperative radiographs. Furthermore, in case of congenital deformities or deviations in anatomy due to previous reorientation surgery, as in patients with dysplasia, the intraoperative orientation according to anatomic landmarks may be misleading. Therefore, intraoperative radiography is one option for confirming the correct positioning of the components.

Fig. 13.3 Wear and destruction of a polyethylene inlay and a revision cup as a possible complication of edge loading

Navigation represents an alternative tool for this task. Computer navigation systems were introduced in the past to provide surgeons with data on acetabular and femoral positioning so that leg length, femoral offset, and range of motion are determined before the definite implantation of the components (Dastane et al. 2011). The surgeon is able to view lines, angles, and measurements for the implantation of THA in order to align and orient the components more precisely. Thus, navigation assists and optimizes cup positioning and simultaneously avoids radiation exposure. Two different concepts of navigation exist: image-based navigation and image-free navigation. Image-based navigation is based on a preoperative computed tomography scan. This concept has advantages for patients with anatomic deformities, such as coxarthrosis due to dysplasia or trauma. However, it is associated with a high radiation exposure. Because of this and the higher expenditures regarding time and money, today image-free navigation represents the gold standard. In the past, many companies developed mechanical guides for cup and stem positioning such as the OrthoPilot® (Aesculap Orthopaedics, Tuttlingen, Germany) as a tool for the precise execution of surgical interventions. OrthoPilot® is a computer-aided, image-free navigation system. The navigation system consists of infrared optics and tracking software continually monitoring the position and mechanical alignment of the components relative to the patient's individual anatomy. Minimally invasive smart wireless instruments send data to a computer, which analyzes these data and provides the angles, lines, and measurements needed to best align the components of the THA. The surgeon is able to change the positioning in real time. OrthoPilot® uses passive trackers to register the orientation of the pelvis intraoperatively with the registration of bony landmarks. Definition of the bony landmarks is important for the final accuracy of the positioning (Parratte and Argenson 2007; Renkawitz et al. 2009). The first experiments in kinematic navigation using OrthoPilot® were conducted as early as 1994. In the following years, further developments took place and a multicenter study was conducted (Aesculap 2012). The first clinical application and first publication dates back to 1997. Since its introduction in the market in 2001, more than 15,000 THAs have been implanted using this device.

13.3 Evidence of Benefits Using Navigation

In the last decade there was a tendency toward minimally invasive or less invasive surgery. During these interventions there is often a limited view of the operative field, which often makes perfect implant positioning very complicated (DiGioia III et al. 2003; Nogler 2004). Especially in these cases, special tools or landmarks for component positioning, such as computer navigation technology, can support the surgeon despite the lack of direct visualization of anatomical landmarks (DiGioia III et al. 2002; Sotereanos et al. 2006). Gebel et al. analyzed their new concept of using the minimally invasive direct anterior approach (DAA) in total hip replacement (THR) in combination with a leg positioner (Rotextable®) and a modified retractor system (Condor, Salzkotten, Germany). All surgeries were performed using hip navigation. Radiological analysis illustrated an average cup inclination of 43° and a leg length discrepancy in the range of ±5 mm in 99% of cases, showing the benefit of the navigation tool (Gebel et al. 2012). Confalonieri and coworkers performed a match-pair study between computer-assisted and freehand techniques using a short modular femoral stem (Confalonieri et al. 2008). They assessed surgical time, clinical outcome, dislocation rate, limb length, and offset in 44 patients and concluded that computer-assisted techniques allowed for easier management of limb length discrepancy and offset restoring. The postoperative leg length discrepancy was 4.1 mm for the navigated implantation and 7.9 mm for the conventional technique, while the preoperative leg length discrepancy was similar for both groups. In addition, Kreuzer and Leffers conducted a retrospective study comparing a consecutive series of 150 computer-navigated THAs with a consecutive series of 150 nonnavigated hips (Kreuzer and Leffers 2011). The two groups were similarly matched by age, gender, and body mass index. The navigation group mean cup inclination was 41° (range, 32°–54°), compared to 36° (range, 19°–52°) for the nonnavigated group. The authors concluded that the accuracy and precision of cup angle placement is comparable to the nonnavigated method but appears to be slightly improved with computer navigation. The high accuracy of the navigation tool was also confirmed in several other studies (Beckmann et al. 2009; Hohmann et al. 2011b, 2011c; Lin et al. 2011; Moskal and Capps 2011; Snyder et al. 2012). Snyder and colleagues evaluated the accuracy of a particular imageless computer navigation system in determining cup position (Snyder et al. 2012). After assessment of 39 patients, they determined a high specificity for navigation when assessing cup abduction and anteversion (specificity >90%). However, the system was not very effective in detecting suboptimal cup position (sensitivity: abduction, 50%; anteversion, 33%). Hohmann et al. compared acetabular component positioning using an imageless system with a matched control group using conventional techniques (Hohmann et al. 2011c). They demonstrated a significant increase in the accuracy of placement of acetabular cups within the desired position and safe zone using imageless navigation. In another study by Hohmann et al., the authors assessed and validated intraoperative placement values for both inclination and anteversion as displayed by an imageless navigation system compared to postoperative measurement of cup position using high-resolution CT scans (Hohmann et al. 2011b). Their findings determined a possible introduction of systematic error. Even though the acquisition of anatomic landmarks is simple, they must be acquired with great precision. An error of 1 cm can result in a mean anteversion error of 6° and an inclination error of 2.5°. Despite possible errors, navigation seems to offer a possible patient benefit from the resulting tighter control of the component position. This is also the conclusion of a meta-analysis reviewing published studies in order to investigate the claim of the increased precision of acetabular component placement in navigated THA compared to conventional, nonnavigated THA. In this review, 1,479 procedures were included. Moskal and Capps determined a statistically significant difference in the incidence of acetabular component placement in the »safe zone«, with navigation having significantly more »safe placements« than procedures without navigation, regardless of the chosen safe zone (Moskal and Capps 2011). In addition, navigated THAs had significantly fewer dislocations than nonnavigated THAs. Another meta-analysis published by Beckmann et al. confirmed navigation as being a reliable tool for optimizing cup placement and minimizing outliers (Beckmann et al. 2009).

A cadaveric study also determined a reduced variability in cup positioning for navigated versus manual THAs by measuring the inclination and anteversion using CT scans (Nogler et al. 2008). Thus, navigation systems in general seem to have a high accuracy. However, to achieve a high accuracy and avoid errors with navigation methods, the exact determination of anatomic landmarks is important. It was proven that some of the existing mechanical guides had a poor precision and accuracy (DiGioia et al. 1998), and surgeons have to be familiar with the use of this additional tool in order to avoid errors. Wassilew and colleagues conducted a prospective randomized controlled study of two groups of 40 patients each (Wassilew et al. 2012). They compared the results achieved using an ultrasound-based navigation system with the ones using an imageless navigation system with surface registration. They concluded that there was an improvement in cup positioning using ultrasound-based navigation compared to imageless navigation systems by reducing the outliers and achieving a higher accuracy of anteversion. In the first group, cup positioning was assisted by an ultrasound-based navigation system, and in the second group, the cup was assisted by an imageless navigation system with surface registration. However, these guides require an exact knowledge of patient orientation on the operating table. This is more complicated in patients in lateral decubitus position rather than in supine position. Furthermore, surgeons have to rely on their experience to modify the guides intraoperatively so as to avoid a malalignment of the cup. Especially in obese patients, the orientation for an adequate positioning of the acetabular cup is often very difficult and may lead to a suboptimal implant orientation. This may result in a wide discrepancy between the planned implant positioning and the final orientation (DiGioia III et al. 2002). Hasart et al. investigated the influence of body mass index (BMI) and the thickness of the soft tissue on the postoperative cup position and accuracy in the application of an ultrasound-based and a pointer-based navigation system (Hasart et al. 2010). According to their data, the accuracy of the ultrasound-based and pointer-based navigation systems is influenced by the BMI and the thickness of the soft tissue layer above the symphysis. However, ultrasound-based navigation seems to have certain advantages with thicker soft tissue layers, as seen in overweight and obese patients. The fact that obesity has a negative influence on the accuracy of imageless navigation was confirmed by Tsukada and

Wakui (Tsukada and Wakui 2010). They divided patients into obese (BMI ≥25) and nonobese (BMI <25) groups. The error in anteversion was significantly higher in the obese group (4.8°±2.5°) than in the nonobese group (3.2°±2.6°; *p*=0.01). Hohmann et al. investigated acetabular component position after THA in correlation to anteversion and inclination to anterior pelvic soft tissue thickness (Hohmann et al. 2011a). Thirty patients were operated on via an anterolateral approach in supine position using an imageless navigation system. The data did not reveal any significant relationships between BMI, soft tissue thickness, and final intraoperative or postoperative cup position. In addition, Fukui et al. also did not determine factors potentially affecting the accuracy of the intraoperative assessment, such as BMI and soft tissue thickness using the imageless navigation system OrthoPilot® (Fukui et al. 2010).

Critics of navigation systems in THA argue that the use of navigation systems is associated with additional costs, prolonged surgical time, and a learning curve for the usage of these devices, and point out that the cup can be positioned adequately without computer navigation.

The literature on the influence of navigation in THA on prolongation of surgery shows varying results. Thorey et al. found a prolongation of the operative time to be 4.8±3.8 min after the learning curve (Thorey et al. 2009). Similar results were presented by Kreuzer and Leffers (Kreuzer and Leffers 2011). They determined a mean surgical time for the navigation group of 56 min (range, 34–91 min) and 61 min (range, 33–119 min) for the nonnavigated group.

13.4 Conclusion

In conclusion, navigation tools (e.g., OrthoPilot®) provide surgeons with data on acetabular and femoral positioning such that leg length, femoral offset, and range of motion can be optimized in order to avoid malpositioning of the components and thereby reduce complication such as early joint dislocation, limited range of motion due to femoroacetabular impingement, and early implant wear due to edge loading and leg length discrepancies. However, surgeons have to be familiar with this tool and they should also be aware of the possible errors.

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