Introduction

As described in an earlier chapter, the direct anterior approach is a single-incision approach. The skin incision is made two fingerbreadths distal to the anterior superior iliac spine at the ventral border of the tensor fasciae latae muscle. The surgical portal lies between the lateral border comprised of the tensor muscle and the sartorius and rectus femoris muscle medially. The entire length of the incision will vary slightly depending on body habitus, but 8 cm is the typical incision length in our patient population. Special retractors developed for this procedure allow for excellent access to the acetabulum. With angulated reamer handles and cup introducers, acetabular preparation and cup implantation can be accomplished without the need for a larger incision. Femoral preparation and implantation are facilitated using special retractors that elevate the femur to a position that permits satisfactory access for stem preparation and using instruments with an anterior offset.

When utilizing the small incision for a minimally invasive surgery approach, visualization of the operative field is decreased as compared to the traditional approach. More importantly, the instruments have angulated or curved handles that give the surgeon less intuitive information on the axis of the instrument. To date, the potential for positioning error using non-axial instruments has not been evaluated. The use of an electronic navigation system would negate or significantly decrease any potential positioning error. Such a system calculates the position of an instrument irrespective of the handle configuration and can direct the surgeon’s efforts during preparation and implantation. The value of navigation for cup placement and orientation has been proven in multiple studies [1-4]. In a study by the authors’ group, conventional cup implantation was compared to navigated cup implantation with the Hip Navigation System (Stryker-Leibinger, Freiburg, Germany). In this study, no preoperative or perioperative imaging study was necessary and the 90th percentile for inclination and anteverision of the conventionally operated group (15.7° inclination - 18.5° anteverision) demonstrated a significantly larger range of results than the navigated group (4.3° inclination - 7.1° anteverision). It was also shown that leg-length change could be minimized (<0.3 mm median leg-length change). These findings indicate that the use of navigation systems in total hip arthroplasty can positively impact the accuracy of implant position.

Implant-design and material combinations are consistent topics in hip arthroplasty, but recent advances have focused the current discussion on minimally invasive approach and the navigation systems. These recent developments will re-focus the implant design and material discussion such that implant designs specific to MIS will be forthcoming. The early results from our institution indicate that the combination of the direct anterior approach and the Stryker hip-navigation system has been successful in permitting accurate implantation of the total hip components and earlier mobilization of the patient.

The Imageless Concept

A surgical navigation system translates a patient’s anatomy into a visual display of the implant position and orientation relative to that anatomy throughout the surgical procedure. There are currently two major navigation paradigms with regard to the acquisition of the relevant patient anatomy. The patient’s anatomic structures can be defined either through pre-operatively (MRI, CT) or intra-operatively (fluoroscopy) acquired images or intra-operative digitization of anatomical landmarks that is not
dependent on image acquisition. Such intra-operative digitization is performed with tactile probes percutaneously or through the open approach placing the probes directly at the anatomic point of interest. These navigation systems are known as imageless systems. Attempts to digitize bony landmarks with ultrasound probes have been made but are not yet clinically relevant [5-7].

An imageless navigation system that enables the surgeon to intra-operatively define anatomic landmarks and control instrument and implant position has several advantages:

1. No additional pre- or intra-operative radiation (an additional "invasiveness" that is not necessary),
2. All reference frames are acquired intra-operatively and can be checked and changed intra-operatively,
3. Pre-operatively preparation time is not increased waiting for the imaging study.

**Tracking**

Tracking of anatomic structures is the navigation system's responsibility and is done such that all bones are tracked independently. Currently, tracking is performed by all navigation systems with rigidly fixed bodies, that are either passive or active devices, such as those used with the Stryker Hip Navigation System. The trackers are fixed to the bone, using either screws or wires. The active devices are battery-powered electronic devices that are visible to the navigation system's cameras. Although fixation of these trackers can affect the minimally invasive nature of the approach we anticipate that solutions will eventually be found which permit non-invasive tracking. At the present, attaching the trackers should be undertaken using as minimally invasive an approach as possible.

**Orientation and Landmarks**

The orientation of the acetabular and femoral implants is based on intra-operatively determined landmarks and consecutively calculated reference frames that are updated in real-time. With the hip-navigation system (Stryker-Leibinger, Freiburg, Germany), these landmarks are acquired either percutaneously or – as in the case of the acetabular points – through the incision. Figure 12.1 gives an overview of the reference frames that are constructed intra-operatively by the system's software:

1. Acetabular component orientation is navigated, based on a pelvic reference frame defined by the two anterior or superior iliac spines and a midpoint between the two pubic tubercles. Alternatively, a single point, the pubic symphysis, can be chosen. These points are digitized by the surgeon percutaneously with the pistol-grip pointer. The system calculates the cup position relative to the pelvic reference plane (PRP) according to DiGioia's definition of a "surgical alignment" [2]. Coordinates of these points are recorded relative to the pelvic tracker pin. The distance between the two pubic tubercles and the midpoint is calculated.
2. The orientation of the femoral component is determined relative to a femoral reference plane which is defined by the entry point of the anatomic femoral axes, the popliteal fossa, and the Achilles tendon midpoint, thus resembling the figure-of-four position of the leg.
3. Acetabular landmarks consist of the fovea – with the deepest point giving an estimation of the desired cup-placement depth –, the articular surface and the acetabular rim. Additionally, the articular surface points that are collected provide a graphical representation of the acetabulum during reaming and subsequent implantation.
4. The proximal shaft axes are measured intramedullarly for varus-valgus alignment of the stem. The center of rotation of the hip is determined kinematically by moving the leg through a circumducted range of motion. New centers of rotation are defined later in the procedure after cup implantation and final reduction.
System and Surgical Setup

The Stryker Hip Navigation System is equipped with up to three boom-mounted infrared cameras, which are able to track active, battery-powered instruments with LEDs communicating with the camera's localizing system. The system's software runs on a standard laptop (Fig. 12.2).

An active pistol-grip pointer is used as a software controller and to percutaneously digitize the anatomic landmarks. The specific geometric data of the instruments, such as length and configuration, and of the specific implants is known to the software through the user controls. The reaming process and implant impaction are navigated in real-time, showing the instrument's position and orientation on the screen as well as the numerical values of cup inclination and version.

For the direct anterior approach, the patient is placed in the supine position on the operative table and bilateral draping is performed such that both legs can be moved intra-operatively. One tracker is mounted on the screw which was percutaneously placed in the area of the ASIS. The distal screw is placed in the anterior aspect of the distal femur, approximately 15 cm proximally to the joint line of the knee. A device is available to use three K-wires instead of the distal screw, giving the same stability but offering better protection of the soft tissues (Fig. 12.3).

Navigation of the Femoral Neck Resection

In an open approach, resection of the femoral neck can be accomplished without the use of navigation. In the direct anterior approach, resection of the femoral neck is far more difficult due to the limited exposure of the proximal femur and the narrow workspace. Consequently, a resection-guidance module was implemented in the system that is based on the anatomic axes of the femur (Fig. 12.4). Current development work in our lab bases the resection model on digitized landmarks, such as the most distal point of the piriformis fossa as well as the border of the femoral neck.
Cup Navigation

Based on the digitized pelvic PRP, the process of acetabular preparation and cup implantation is navigated in real-time. In addition to orientation of the reamers and the final component, the depth of the acetabulum is a major issue. In systems that are not image-based there is no knowledge about the thickness of the acetabular floor. The image-free navigation system permits the user to digitize the fovea and takes the deepest point along the acetabular entrance axis as the bottom of the acetabulum. During the reaming process, this point is defined as zero point. After preparation of the bone, the system establishes a new definition of the deepest point, e.g. the point which the deepest point of the acetabular implant reaches during impaction. Distance to the defined zero point is displayed in real-time (Fig. 12.5).

As depicted in Fig. 12.5 for the reaming and implantation of the acetabular component is monitored by the navigation system. Cup inclination and anteverision are displayed relative to the pelvic reference plane. After implantation, the final position of the acetabular component is recorded to define a new center of rotation. Throughout the process, the effects of the real-time cup position on leg length and offset are calculated and displayed on the screen. Results that are out of range are considered mal-placements and are displayed in red.

Stem Navigation

In order to define a femoral reference frame, a tracker screw or 3-wire fixation is placed in the distal femur. As discussed earlier in this chapter, both methods require additional incisions outside the surgical area. To date, however, no non-invasive alternatives are available. The anatomic reference frame is calculated based on the rotational center of the hip and the digitized landmarks. From these landmarks, the mechanical axis, anatomic shaft axes and a femoral reference plane (see Fig. 12.4) are calculated assuming that a normal vector of this plane directs to 0° of antversion on the femoral neck (see Fig. 12.1). As neither the mechanical axes nor the anatomic shaft axes provide a valid orientation for the varus/valgus alignment of the femoral component, an additional step measures the proximal shaft axes intra-medullarly. These proximal shaft axes confound the references axes to which broaches and implant are aligned. As in the case of cup positioning, the system supports the navigation of reaming, broaching and placement of trial and final implants. Real-time display of the varus/valgus angle, rotation and depth are visualized on screen, based on position information of the trackable instruments relative to the femur (Fig. 12.6).
Control over Leg Length and Offset

Equalizing a patient’s leg length is an important outcome parameter in THA. Using a navigation system, the real-time changes in leg length during the process of cup- and femur preparation are calculated and a visual evaluation offered to the surgeon. The real-time implant position is calculated in part, based on the configuration information for the implants chosen for the procedure and contained in the system’s database. In a traditional surgical approach, the surgeon is used to orienting the components in relation to anatomic landmarks such as the tip of the greater trochanter or the depth of the fossa. During a procedure with a limited view of the surgical field, the navigation system provides the surgeon with the data to precisely control these crucial parameters leading to optimal implant position and orientation.

After the trial implants have been implanted, the navigation system provides for a trial reduction and evaluation of leg length and resulting offset as compared to the values calculated during the surgery. Through changes in implant position and implant size or type – depending on the modularity of the implant design – the surgeon has the opportunity to address each of these parameters and evaluate the resulting range of motion and the stability and potential for impingement during a kinematic motion test (Fig. 12.7).

In our desire to provide our patients with the accelerated healing that is potential with a minimally invasive hip arthroplasty, we have focused our efforts on the direct anterior approach. As with all of the different anatomic routes to the hip joint, the initial results are encouraging, but long-term outcome studies will provide the validation that is ultimately needed. For the surgeon, the direct anterior approach has proven to be feasible when used with instruments that have been developed to facilitate the exposure while offering maximally soft-tissue protection. These instruments enable the surgeon to operate within a limited surgical field, limited only by the implant size (Fig. 12.8). The anatomic foundation of the direct anterior approach provides for minimizing damage to the muscular structures. The location and tracks of the vascular and neural structures in that field of the anterior approach have been extensively evaluated in our laboratory to determine the element of risk that may exist during the operative procedure (see earlier in this book). To date, the cosmetic results are impressive (see Fig. 12.8) and an ongoing prospective randomized study will demonstrate the level of benefit to our patients. For surgeons performing this approach in either the supine or later decubitus position – as in any MIS approach – it is more

Fig. 12.7. This screen shows the real-time measurements of the reduced hip, giving leg length and offset data as well as range of motion: red points indicate lift-off and dislocation

Fig. 12.8. Special retractors protect the soft tissue during cup impaction. The minimally invasive procedure produces scars that are small, typically 8 cm
demanding than a traditional procedure. The learning curves associated with the minimally invasive hip approaches have not been satisfactorily described and often run contradictory to the decades of experience of many arthroplasty surgeons. The intra-operative navigation systems that can assist the surgeon in optimizing implant position and orientation are a requirement for those approaches in which the operative field is limited. However, combining the minimally invasive approach with the use of a navigation system can present a significant challenge to many arthroplasty surgeons until the learning curve is overcome. Moreover, the navigation systems are associated with a slight increase in operative time for the intra-operative digitization process until the user gains significant experience. The imageless navigation system does offset this increased time to some extent as pre-operative imaging is not required. Our investigations have proven the system to be valuable in controlling and optimizing cup position, orientation and leg length, which should ultimately result in improved clinical outcomes. A navigated minimally invasive hip arthroplasty through the direct anterior approach can provide the patient with a viable alternative to the traditional approach. Further improvements in the navigation software will ensure optimal neck resection based on the anatomic landmarks of the proximal femur. Providing navigated instrumentation, such as the MIS saw used for neck resection, would provide the surgeon with real-time instrument position and orientation. Perfecting the use of anatomic reference points without the invasive placement of a wire or screw should also continue the development to the least invasive surgical approach for total hip arthroplasty.

References