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What do we get from navigation in primary THA?

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- Navigation in primary total hip arthroplasty has a history of over 20 years. During this process, imageless computer navigation can be particularly helpful in optimally restoring the hip's biomechanics. This involves the accurate placement of the acetabular component with the determination of the anteversion and abduction, whereby the navigated femur-first technique also allows for a calculation of the combined anteversion. Additional critical parameters such as the reconstruction of the rotation centre, as well as the femoral and acetabular offset, can also be optimally adjusted. Last but not least, an intra-operative evaluation and equalisation of the leg length is possible.

- Nonetheless, the disadvantages of this surgical technique in terms of the high costs in the acquisition and preservation of the necessary devices, as well as the longer operation time, must be taken into account. However, economic aspects are not the only thing preventing widespread use of the navigation technique. Determining the plane of reference (APP) for the optimal orientation of the implants is based on palpation of the bony landmarks – and this is influenced by the thickness of the soft tissue layer. Furthermore, the experience of the surgeon constitutes a variable that influences the accuracy of navigation.

- In summary, hip navigation certainly offers an interesting technique for the optimisation of total hip arthroplasty with reconstruction of proper biomechanics. At the same time, there is currently a lack of high-quality randomised controlled long-term trials that evaluate the clinical advantage for the patients, together with cost utility and survival rates.

Introduction

The short- and long-term success of primary total hip arthroplasty (THA) is associated with the correct reconstruction of the hip biomechanics. This includes the reconstruction of the rotation centre and offset, the correct positioning of the cup and shaft (anteversion, inclination and antetorsion) and the equalisation of leg length. Deviations in these parameters arising through planning errors and intra-operative misinterpretation can lead to a higher rate of complications such as reduced range of motion (ROM), and can raise the risk of impingement of the components, which in turn leads to increased wear, inlay breakage and dislocation.[1] These complications result in higher revision rates, a shortening of the implant service life and, not least, dissatisfied patients.[2-4]

For the use of the conventional freehand technique, both precise pre-operative planning and intra-operative re-evaluation are essential for correct implant positioning and optimal function. Simple methods include marking the implants on printed radiograph images with the help of planning films or intra-operative fluoroscopy.[5,6] However, this requires excellent three-dimensional thinking on the part of the surgeon and is obviously dependent on the surgeon's experience.[7,8] Earlier studies were nevertheless able to show that even experienced surgeons only seldom managed to achieve a reliable and reproducible implant position using the conventional freehand technique. For example, an acetabular cup position outside the target zone recommended by Lewinnek et al[9] was observed in 50% of cases, even where experienced surgeons were involved.[10]

Navigation, on the other hand, promises an accurate reconstruction of the aforementioned biomechanical parameters, while decreasing the number of outliers.[11]

The first clinical use of a CT-assisted surgical robot for femoral canal preparation took place in 1992.[12] In subsequent years, the technique progressed to the use of passive navigation systems, which were initially image-based, specifically in computerised tomography or fluoroscopy. The navigation system currently most in use is based on infrared wave communication and is referred to as an 'imageless' navigation system.[13-15] It uses optical tracking arrays that, for example, are fixed on the ipsilateral iliac crest and serve as a reference point throughout the entire surgery.

The anterior pelvic plane (APP), which is determined by both the anterior superior Iliac spine and the symphysis, serves as the reference plane for the abduction and anteversion of the socket. The femoral antetorsion can, depending on the navigation system, be intra-operatively referenced over the epicondylar axis or the most dorsal points of the femoral condyles. In the case of imageless navigation systems, these points are read with a blunt tracker over the soft

tissue. Thus, the accuracy of the navigation systems depends on the accurate acquisition of these planes.

Criticisms of navigation include: the increased operation time, an inaccurate reading of the anatomical landmarks especially in overweight patients, high acquisition costs and the potential danger of an electronic malfunction.

This review provides a consolidated overview of the advantages and disadvantages of navigation in primary THA and, last but not least, recommendations regarding further use.

Component positioning

Acetabular component positioning

Lewinnek et al[9] describe the so-called 'safe zone' for acetabular components having an abduction of between 30° and 50°, and an anteversion between 5° and 25 degrees. Dislocation of cups implanted outside this zone was four times more likely. There are now differing recommendations;[16] nonetheless, component placement plays a decisive role in the wear and stability of the THA.[17]

Studies show an improved positioning of the acetabular components with the use of navigation.[18-20] Lass et al[14] compared freehand positioning and imageless computer navigation in a prospective randomised study. They were able to observe higher accuracy with the navigation system and a significant difference concerning anteversion. No difference was observed for abduction.

The comparison of different guidance methods in 1980 total hip arthroplasties showed a significantly higher rate of acetabular components within Lewinnek's safe zone when using robotic- and navigation-guided techniques.[21] A prospective, randomised, controlled study comparing cup position showed a placement of the acetabular components within the zone suggested by Lewinnek et al[9] of 90% with imageless navigation and 80% with conventional placement (p = 0.661).[15]

Kalteis et al[20] also reported that 53% of the cups (16 of 30) implanted with the freehand technique were outside the safe zone, compared to 7% (two of 30) implanted using an imageless navigation system. In a prospective randomised study, Parratte and Argenson[19] were able to observe an outlier rate of 57% using the freehand technique and 20% with the use of an imageless navigation system. The use of this imageless navigation system indeed led to a marked improvement, but showed significant errors for overweight patients with a BMI ⩾ 27.

The high prevalence of incorrect socket position is surprising when one considers the results of an imageless navigation validation experiment. In such an experiment, an average precision of 1° for abduction and 1.3° for anteversion were proven for an imageless navigation system.[22] In this study, the landmarks were read *ex vivo* without the error-inducing soft tissue, which explains the high accuracy. Spencer et al observed a large intra- and inter-individual variation as well as

significant errors during APP-landmark acquisition by means of an imageless navigation system in a cadaver model.[23] In a similar model, Parratte et al[24] were then able to observe that the imageless navigation system is influenced by the thickness of the tissue over the bony APP landmarks. Richolt and Rittmeister[25] demonstrated with the aid of an ultrasound examination that the fatty layer is three times thicker over the symphysis in comparison to the anterior superior iliac spine. In contrast to the anterior superior iliac spine, the fat over the symphysis is not moveable, but can only be compressed by the blunt registration pointer. A direct reading of the bony landmarks over the symphysis is theoretically only possible with extremely slender patients. A nearly correct reading of both anterior superior iliac spine and the resulting errors in the registration of the symphysis creates a reference plane that does not correspond to the bony APP. Parratte et al also referred to the resulting plane as a 'cutaneous Lewinnek plane'.[24] It is through these registration errors that the significant versioning errors arise in the study discussed above.[24] Wolf et al developed a mathematical model which can calculate the resulting errors in the anteversion and abduction from registration errors of the APP.[26] Thus, a total error in the APP registration of only 4 mm can result in an error of 7° in the anteversion and 2° in the abduction.[26] In order to avoid these errors and enable an exact positioning, ultrasound was integrated into the navigation workflow. In the meantime, the advantage of this technique in comparison to imageless navigation was proven in *ex-vivo* and clinical studies.

In a cadaver study, the integration of the 2D-B mode ultrasound in the navigation algorithm allows for a very exact and reproducible registration of the APP.[27] This exact registration causes only a minor error in the acetabular cup position as shown by the navigation system and in the actual post-operative result. In this case, less experience on the part of the surgeon and a higher BMI in the cadaver do not result in a clinically relevant error. It was shown in a prospective randomised study that the ultrasound-based navigation has an outlier rate of 25% compared with 30% in the imageless navigation group.[28]

Femoral component positioning

A malposition of the femoral component can also lead to complications after THA. For a positioning of the acetabular cup within the safe zone according to Lewinnek, an antetorsion of 15° is recommended for the femoral component. This corresponds to the native femoral antetorsion attested by Toennis and Heinicke.[29]

The conventional implantation of the femoral components, in comparison to the acetabular components, shows a large variation of up to 44° in range. Due to the individual anatomy of the proximal femur, this can lead to rotatory and sagittal malalignment, even with cement-free implants. Consequently, it is difficult to achieve an antetorsion of 15° in every case. This fact clearly demonstrates the disadvantages of the respective target zones for the shaft

and socket. It is not possible to compensate for the incorrect positioning of one component by the modification of another during surgery.

It should be emphasised, therefore, that the concept of combined anteversion of the acetabular and femoral components,[30] which in a finite element and mathematical model attains a value of 37.7°, theoretically enables an impingement-free range of motion for the THA and, simultaneously, a higher stability.[31] The navigated femur-first technique offers the possibility of achieving an optimised combined anteversion.[32,33] For the shaft navigation, the dorsal femoral condyles are consulted as reference points. Dorr et al achieved an accuracy of 4.8° with respect to the femoral component positioning using imageless navigation,[32] though with a similarly large variability compared to the freehand technique.[7] The antetorsion of the shaft, especially with surgical approaches that allow for a good view of the femur, appears to be easily identifiable by experienced surgeons. However, an exact measurement allows for the optimisation and adjustment of the combined anteversion in context with the position of the acetabular cup. One of the latest studies on potential impingement-free range of movement after THA showed a better result with the navigated femur-first technique, in comparison to the conventional minimally invasive implantation.[34]

Leg length equalisation

Leg length difference after THA varies on average between 1 mm and 15.9 mm according to current literature.[35,36] Lengthening of over 6 mm and shortening of over 10 mm are perceived by the patients. Nonetheless, this is one of the most frequent reasons for court claims from patients and is crucial to post-operative satisfaction.

Without navigation, leg length is difficult to evaluate directly during surgery, as an exact measurement is hardly possible given the obstacles of the patient's position, pelvic tilt and sterile covering. Intra-operative fluoroscopy shows no significant difference in comparison to a control group with regard to leg length, yet leads to a marked increase in surgery time.[37]

In a matched-pair study, Manzotti et al[38] showed a significantly better restored leg length six months after THA in patients operated on with computer-assisted navigation. The number of patients with a significant leg length difference of over 10 mm was also smaller in this group. In another study, post-operative leg length difference averaging 3 mm was very rare (computer-assisted). However, there was no significant difference from the results of conventional methods.[39] In the study by Ellapparadja et al,[40] over 96% of the patients operated on had a leg length difference of under 6 mm. In other studies, the residual leg length difference even fell under 5 mm for 93% of patients.[13]

Acetabular and femoral offset

The reconstruction of the femoral and acetabular offset is essential for an adequate function of the THA.[41-43] A reduction of the offset can lead to a decrease in both the lever arm and in abductor strength. This can in turn lead to a THA impingement, to bone-to-bone impingement and even to the patient limping.[44] Furthermore, reduction of the offset can lead to an increase in the forces in the area of the bearing surface which may result in increased wear.[45]

In a recent study, 95.39% of the navigated hips had a similar offset (within 6 mm) to the opposite side.[40] The same was seen in another study, in which the global or femoral offset was able to be reconstructed within 8 mm in 98% of cases.[13]

Limitations and criticisms of navigation

The introduction of new surgical methods, especially in cases where the standard methods already achieve a good to very good outcome, has in particular to be evaluated with respect to its advantages and disadvantages.

One disadvantage of navigation in primary THA is the longer surgery time.[15,20,38] Kalteis et al[20] report a lengthening of OR time of 8 minutes, or as much as 10 minutes depending on the steps necessary for the registration process. Manzotti et al[38] recorded a surgery time of 73.17 minutes (range 48–116) in the control group, and 89.39 minutes (range 77–122) in the navigated group and therefore a significant difference ($p < 0.01$). A prolonged operation time can be associated with an increased risk of complications. As operation time in the studies mentioned is only increased within the range of a few minutes, it is debatable whether this short period of time has a significant impact. Nonetheless, it must be taken into consideration that the surgery time may be longer during the surgeon's initial mastery of the learning curve involved.

An additional criticism regards the increased costs. These comprise the acquisition costs for the system and the costs for disposables such as reflective markers, as well as the increased surgery time already mentioned. The acquisition of a navigation system therefore appears economically sensible only for high volume clinics,[46] although cost-effectiveness studies are lacking here.

Furthermore, the intra-operative determination of the anatomical reference plane can lead to errors in the socket positioning. Spencer et al[23] showed this in a cadaver study in which eight surgeons had to determine the anterior pelvic plane using pointer-based navigation. The abduction and anteversion of the socket theoretically implanted on the basis of the set landmarks did show significant differences (anteversion SD 9.6°, abduction SD 6.3°) and may be especially difficult in the case of overweight patients.[47] However, the study by Gupta et al[48] showed no difference in cup abduction and anteversion in patients with an elevated body mass index in the case

of robotic-guided navigation. The integration of ultrasound into the navigation algorithm has also led to an improvement in the landmark acquisition and positioning of the implant. Which technique wins through in the future depends above all on the practicability of the technique for the majority of surgeons, beyond its acceptance at highly specialised centres.

Finally, imageless computer navigation claims to be able to achieve a more accurate placement of the components as compared with the conventional implantation of a THA. In this context, the question arises of the existence of a safe zone for the acetabular components. Lewinnek et al[9] and McCollum et al[16] recommend different target areas. Other authors see no correlation between incidence of dislocation and a placement of the acetabular component in the safe zone.[49,50] Rather, they see an individual approach to the particular anatomy of the patient as being meaningful.

In view of the current lack of large, randomised controlled studies on navigation in primary THA with long-term follow-up, the above-mentioned advantages – while they can certainly be documented – are not yet relevant for daily clinical practice. Gurgel et al[15] showed no significant difference with respect to the absolute values of the abduction and anteversion in a prospective randomised controlled study with 20 THAs in each case (freehand placement *versus* imageless navigation). Most studies that entail a comparison to conventional implantation show similar values with respect to leg length equalisation and the reconstruction of the offset.[13] Meta-analyses comparing navigation and freehand positioning were only able to show an improved accuracy of the implant positioning and a reduction in the number of outliers.[51, 52] In the debate about the practicality of navigation in primary total hip arthroplasty, it is not only purely biomechanical sophistication with statistically significant differences that needs to be discussed – its significance in terms of clinical outcome as well as subjective patient satisfaction is more critical.[38] For example, one study showed a significant difference in the Harris hip score between navigated and conventionally implanted hips six weeks after surgery, but not six months or one year afterwards.[34] One of the first mid-term follow-up studies comparing navigated and conventional implantation found no differences in clinical outcome, bone density and polyethylene wear between five and seven years post-surgery.[53]

When working with navigation in practice, it must be remembered that every surgeon must also be able to perform the surgery using the conventional method, given that, due to electronic error, a failure of the navigation technique is possible at any time.

Conclusions

Computer navigation in primary hip arthroplasty seems to be a valuable tool to achieve exact positioning of the components and an equal leg length. Studies have shown

how to improve the measurement of the anatomical landmarks using ultrasound. Nevertheless, navigation has disadvantages that may hinder its widespread use, including high costs, longer surgery time and a current failure to completely satisfy the determination of the APP as the reference plane. Randomised controlled studies with long-term follow-up will have to prove the clinical relevance of navigation techniques in primary THA in the future.

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