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ORIGINAL PAPER

Computer-assisted placement technique in hip resurfacing arthroplasty: improvement in accuracy?

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Abstract Freehand positioning of the femoral drill guide is difficult during hip resurfacing and the surgeon is often unsure of the implant position achieved peroperatively. The purpose of this study was to find out whether, by using a navigation system, acetabular and femoral component positioning could be made easier and more precise. Eighteen patients operated on by the same surgeon were matched by sex, age, BMI, diagnosis and ASA score (nine patients with computer assistance, nine with the regular ancillary). Pre-operative planning was done on standard AP and axial radiographs with CT scan views for the computer-assisted operations. The final position of implants was evaluated by the same radiographs for all patients. The follow-up was at least 1 year. No difference between both groups in terms of femoral component position was observed ($p>0.05$). There was also no difference in femoral notching. A trend for a better cup position was observed for the navigated hips, especially for cup anteversion. There was no additional operating time for the navigated hips. Hip navigation for resurfacing surgery may allow improved visualisation and hip implant positioning, but its advantage probably will be more obvious with mini-incisions than with regular incision surgery.

Résumé La position du guide fémoral lors du resurfaçage de hanche peut être améliorée par l'utilisation d'un système de navigation. 18 patients comparables en termes de sexe, d'âge, de BMI, de diagnostic et de score ASA ont été opérés par le même chirurgien. 9 patients ont été traités avec l'aide d'un système de navigation et 9 avec le matériel ancillaire habituel sans navigation. L'analyse pré-opératoire et post-opératoire a consisté en une radiographie face profil et un scanner. Le suivi n'a pas été inférieur à un an. Il n'existe pas de différence entre les deux groupes en terme de position fémorale ($p>0.05$), il n'y a pas non plus de différence sur les incisions. Par contre, une meilleure position de la cupule a été observée sur les hanches naviguées surtout pour l'anteversion. Il n'y a pas eu d'augmentation du temps opératoire du fait de la navigation. En conclusion, la navigation de la hanche lors d'une intervention chirurgicale de type resurfaçage permet d'avoir une meilleure visualisation de la position des implants mais ces avantages sont plus importants lors d'une mini incision que lors d'une incision classique.

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Introduction

Since the first generation of hip resurfacing implants have been used [2, 14], current hip resurfacing implants represent a significant development in the evolution of hip arthroplasty [25]. Hip resurfacing arthroplasty (HRA) is an attractive method to treat coxarthrosis in young and/or high activity level patients. Theoretical advantages of HRA when compared with total hip replacement (THR) could be summarised as preserving femoral bone stock by less bone resection, approximating more similar to normal hip kinematics and joint stability [7, 9, 17, 20, 23, 24], giving good proprioceptive feedback, restoring normal anatomy, loading the femur normally, minimising the potential for post-operative leg-length discrepancy and stress-shielding of the proximal femur [4, 20, 24], reducing the risk of dislocation, and potentially providing easier revision since the femoral canal was not violated [3, 8, 24].

However, despite the attractive early clinical results and success [3, 8, 24], some complications in relation with the surgical technique that are unique to this procedure continue. The surgical technique is complex and demanding for the surgeon, often related to a sub-optimal femoral component placement or notching of the femoral neck. Femoral notching and varus placement of the resurfacing component have been demonstrated to increase the risk of post-operative femoral neck fracture [8, 20]. Computer-assisted navigation systems could be used to optimise the preparation of the femoral head and femoral placement of the guide pin and component. In this way complication rates should theoretically be decreased and the placement of components improved, resulting in an improved range of motion of the hip. Length of surgery could be shortened.

The aim of the study was to assess the effectiveness and improvement in accuracy of placement of metal-on-metal hip resurfacing arthroplasty implanted with the aid of a computer-navigation system compared with a standard placement technique. The purpose was to find out whether, the preparation of the acetabulum as well as the femoral head, and the cup positioning respective to the femoral component positioning, could be made easier and more precise, by using a navigation system. In addition, we looked at the consequences of both types of surgeries in terms of functional patient outcome.

Patients and methods

Study groups

All patients operated on by HRA are currently included in a prospective registry of the Orthopaedic Surgery Department of our Institution after informed consent. In 2005, the nine patients operated on with a Birmingham Hip Resurfacing Arthroplasty (BHR) by one senior surgeon (PYZ) using computer-assisted surgery (c.f., description below) were matched with nine patients who underwent a standard BHR procedure by the same surgeon during the same period, by gender, age, BMI, ASA score and diagnosis. The demographic characteristics of the patients are shown in Table 1. There were no statistically significant differences between both groups as expected: the mean patient age at surgery was 47 years (range, 22 to 60 years), the body mass index (BMI) averaged 26.7 kg/m^2 (22.3–33.2) and all patients were operated upon for hip osteoarthritis with a good American Society of Anaesthesiologists Classification of Physical Status (ASA) score of 1 or 2.

The average duration of follow-up was 18 months with a minimum of 1 year. All patients were invited to attend outpatient clinics, where they underwent the standard clinical and radiological examinations and completed a questionnaire recording complications of their hip arthroplasty as well as an outcome-evaluation using the Harris Hip Score [13], WOMAC score [5] and EQ-5D scale [1]. Patients were also asked specifically about running, jogging, sporting activities and heavy manual work. The medical notes were checked to ensure that no complications or revisions had been missed.

CAS system description

We designed a CAS system to transfer pre-operative plans to the operation theatre that included 3D planning and navigation software and a measurement arm with 6 degrees of freedom. Using the images generated from a CT scan provided in DICOM format, preliminary software is necessary for the segmentation of the femoro-acetabular area; a 3D model is then reconstructed and used as reference shape to plan the virtual surgery [18]. The planning software allows the surgeon to make quickly the necessary decisions regarding the selection and positioning of the implants in 3D. The anatomical and morphological criteria allow an automatic placement of the implant while preparing geometric information necessary for navigation. A range of motion simulation of the virtual prosthesis allows a study of the eventual bony impingement. During navigation, the surgeon was assisted and guided in making the gestures mapped by the planning software. This enabled the surgeon to concentrate totally on the adequate positioning of the implants of the prosthesis. The navigation instrument is a 6 degrees of freedom measurement arm, which is fixed directly onto the specific bone where the prosthesis element has to be positioned (i.e., the pelvis and the femur). This arrangement decreases the chain of uncertainty that arises using optical tracking systems. Extremely light and compact (about 600 g), the arm measures the position and orientation of the tools relative to the bone in a direct way. In addition to the advantages of control and precision, this technique allows a progressive reduction of the incision size, making the procedure less invasive [18].

Table 1 Patient characteristics

Characteristics	Conventional group	Navigation group	p-value
Sex (male:female)	5:4	5:4	1.0
Age [years]	48.2 (32–60)	46.4 (22–57)	0.71
BMI [kg/m2]	26.4 (22.3–30.5)	27.0 (20.3–33.2)	0.69
ASA score	1.6 (1–2)	1.3 (1–2)	0.37
Diagnosis	Hip osteoarthritis (all)	Hip osteoarthritis (all)	1.0

Surgical technique and hospital course

Pre-operative planning was done on standard AP and axial radiographs of the hip as well as CT scan views for the computer-assisted operations. All operations were performed using the postero-lateral approach of Moore with the details described by McMinn [21]. In all cases, the Birmingham hip resurfacing implants (Midland Medical Technologies, Birmingham, UK) were used.

All patients were managed similarly with prophylactic antibiotics for 1 day. Thromboprophylaxis comprised the use of sub-cutaneous low-molecular-weight heparins from day 1 to day 4, followed by low-dose of warfarin for a total length of 6 weeks. All patients were allowed partial weight bearing (20 kg) for 6 weeks. Walking was begun on the second postoperative day. Sports were generally permitted at 4 months postoperatively.

Standard radiographic analysis

Anteroposterior (AP) and lateral radiographs were taken and compared between the the pre- and post-operative time (24 h, 3 months and at follow-up) (Table 2). Changes around the femoral component of the hip resurfacing implants were described on the AP radiographs using the zones 1–3 of Amstutz [3] as well as on the lateral radiographs (assigned zones 4 to 6 from anterior to posterior). Changes around the acetabular component were described on the AP radiographs using the zones of DeLee and Charnley [10] and on the lateral radiographs from zones IV to VI from anterior to posterior. Implant positioning was analysed using the definitions of Jolles [16].

Statistical methods

The null hypothesis of this study was that there is no difference between computer-assisted navigational alignment and conventional alignment (freehand or using a mechanical guide) in terms of implant positioning as seen on X-rays. For statistical analysis the patient data were entered on a computer Excel® (Microsoft Office) sheet and subsequently analysed with the Stata™ 8.2 (Stata Corporation College Station, TX) software. Data were analysed as a whole and for each treatment group between baseline and follow-up times for each observation. Means, standard deviations, absolute and relative frequencies were analysed. The data was analysed by non-parametric tests using the Wilcoxon signed-rank test at the 0.05 level of significance.

Results

The only difference that was observed between both groups was a trend for a better cup position, especially for cup anteversion, in the navigated hips.

Radiographic results

There was no statistically significant difference between both groups in terms of femoral component position ($p > 0.05$) or in femoral notching (absent in both study groups).

A trend for a better cup position was observed for the navigated hips especially for cup anteversion: as for the conventional group, a mean value of 32 degrees (range 20–55) was noted compared to 23 degrees (range 15–35, $p = 0.09$) for the computer-navigated group.

Operative time results

There was no additional operating time for the hips implanted with the computer-navigation system: the conventional group had a mean operative time of 102 min (range 74–135) compared to 100 min (range 70–125, $p = 0.82$) for the computer-navigated group.

Outcome scores

There were no statistically significant differences between both groups neither between the Harris Hip Scores (HHS at 3 months: $p = 0.90$, at 1–2 years: $p = 1.00$) nor for the WOMAC scores (pre-operatively: $p = 0.72$, post-operatively: $p = 0.99$). The same results were achieved for the personal satisfaction questionnaires between the two groups of patients, as shown in Table 3.

Complications

In the conventional group, we observed one patient with a deep vein thrombosis (DVT). This patient was 54 years old (mean of the group 47), with a BMI of 28.7 kg/m^2 (mean of

Table 2 Radiographic variables examined using the definition of Gruen [12], De Lee and Charnley [10], Jolles [15] and Amstutz [3] (AP: antero-posterior, AMA: abductor moment arm, BMA: body moment arm) and results for both groups

Radiograph	Variable	Conventional group	Navigation group
Pre-operative AP pelvis	Neck-shaft angle	141.7 (135–150)	143.1 (135–150)
	Femoral offset	2.9 (1.9–2.7)	3.0 (2.4–3.7)
	Acetabular offset	2.7 (2.4–3.0)	2.2 (1.6–2.8)
	AMA abduction moment arm	3.8 (3.2–4.8)	3.3 (2.9–3.8)
	BMA body moment arm	6.5 (5.7–7.1)	6.2 (4.5–7.6)
	Presence of femoral head cysts	8× yes/1× no	7× yes/2× no
	Presence of acetabular cysts	8× yes/1× no	8× yes/1× no
Pre-operative lateral hip	Ante-/retroversion of femoral neck	20.6	11.7
	Presence of femoral head cysts	8× yes/1× no	7× yes/2× no
	Presence of acetabular cysts	8× yes/1× no	8× yes/1× no
Post-operative AP pelvis	Stem/shaft angle	142.6 (135–150)	143.1 (140–150)
	Stem offset	3.2 (2.3–4.1)	3.2 (2.6–4.1)
	Cup offset	2.3 (2.0–2.8)	2.1 (1.8–2.3)
	AMA abduction moment arm	3.6 (3.1–4.2)	3.6 (3.2–4.1)
	BMA body moment arm	6.2 (5.6–6.8)	6.7 (5.5–11.7)
	Cup abduction angle	40.0 (30–50)	43.9 (30–55)
	Varus/valgus of femoral component	0.9 (−7–15)	0.4 (−10–10)
	Notching of the femoral neck	No	No
	Uncovered reamed bone	5× no/4× yes	8× no/1× yes
Post-operative lateral hip	Ante-/retroversion of the stem	16.7 (−2–30)	15.1 (3–35)
	Notching of the femoral neck	No	No
	Uncovered reamed bone	5× no/4× yes	8× no/1× yes
Follow-up AP pelvis	Periprosthetic stem lucent lines (>1 mm)	No	No
	Periprosthetic cup lucent lines	3× no/6× zones I–III	5× no/4× zone II
	Implant migration	No	No
	Change in neck density of trabeculation	No	No
	Femoral neck cortical hypertrophy	No	No
Follow-up lateral hip	Periprosthetic stem lucent lines (>1 mm)	No	No
	Implant migration	No	No
	Change in neck density of trabeculation	No	No
	Femoral neck cortical hypertrophy	No	No

the group 26.4), an ASA score of 2 (mean 1.6), an operating time of 90 min (mean 102) and blood loss of 800 ml (mean 460). He was treated successfully with therapeutic anticoagulation for a 6-month period.

Otherwise, we did not have any other complications in our collectives, such as described in the specialised literature [e.g., fracture of the femoral neck, loosening, revision (stem/acetabulum), conversion to THA, dislocation, range of movement impaired compared to preoperative status, limb length discrepancy, wound dehiscence, infection (deep), nerve palsy or death].

Table 3 Outcome scores for both groups

Harris Hip Score (HHS)	3 months follow-up	1–2 years follow-up
Total (max. 100=best)		
Conventional hips	90.5 (68–100)	97 (93–100)
Navigated hips	91.1 (75–99)	97 (92–100)
Statistical difference	No, p=0.90	No, p=1.00
Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)	Pre-operatively	Post-operatively
Total (min. 0=best)		
Conventional hips	53.6 (41–61)	12.3 (3–26)
Navigated hips	57 (30–76)	12.2 (3–25)
Statistical difference	No, p=0.72	No, p=0.99

Table 4 Comparison of accuracy in cup positioning in studies using computer-assisted navigations systems for THA in vitro (by Jolles [15]) and in vivo for BHR (by DiGioia [11] and Krüger)

Accuracy (range)	Jolles 2004 (n=150)	DiGioia 2005 (n=38)	Krüger 2007 (n=18)
Anteversion (ideal position searched: 15°)			
Conventional hips	8.0 (5.5–10.5)		17 (5–40)
Navigated hips	1.5 (1.9–2.0)	3.7 (0–16.2)	8 (0–20)
Statistical difference	No, p≤0.0001		No, p=0.099
Abduction (ideal position searched: 45°)			
Conventional hips	4.0 (3.0–5.5)		7.2 (5–15)
Navigated hips	2.5 (2.0–3.5)	9.0 (0–18.4)	5.6 (0–15)
Statistical difference	No, p=0.866		No, p=0.44

Discussion

The concept of hip resurfacing arthroplasty has stimulated the development of new techniques to help surgeons achieve optimal cup orientation and exact positioning of the femoral component through guided drilling, guided reaming and mechanical acetabular alignment guides. However, poor results have been observed with their use [11, 19]. Computer-navigated concepts indicate that the precision of implant positioning could be improved and complications could be decreased, but the results obtained here for resurfacing hips did not show statistical differences between conventional and navigation methods of implant positioning.

Although this study has a relatively low number of patients, the pre-operative mandatory computer-tomography scan for the navigation group in a young adult population, and prospective data collection, the differences between both patient groups at baseline were minimised by matching cases. All operations were performed by a only hip specialist surgeon using the same approach for all patients, and the analysis was performed by an independent observer.

While comparing the results of studies that are looking for advantages of computer-navigation systems for THR, we found the same trend of positioning improvement in accuracy and presion for the acetabular component (Table 4) [6, 15]. In all three studies, the preoperative planning for cup placement using navigation systems was done from a computed tomography scan. Jolles [15] demonstrated that computer-assisted cup placement was an accurate and reproducible technique and that it was more accurate than traditional methods of cup positioning. The accuracy of cup abduction and anteversion was assessed with an electromagnetic system, which is more precise than angular measurements on radiographs used in clinics. The limitation of this study was inherent to the in vitro conditions. DiGioia [11] noted in his study the error of different measurement methods. He asks for more reliable tools to provide reproducible and accurate acetabular alignment. He found significant variation in cup alignment while only

Table 5 Comparison of HRA results in recent studies of hip resurfacing [3, 9, 22]

	De Smet (2002)	Amstutz (2004)	Pollard (2006)	Krüger (2007)
Number of hips	198	400	108	18
Age [years]	49.5 (16–75)	48.2 (15–77)	49.8 (18–67)	47 (22–57)
BMI [kg/m2]	27 (18.8–42.1)	27 (17.5–46.4)	26.4 (18.5–37.0)	27.0 (20.3–33.2)
Sex [m:f]	7:3	7.3:2.7	7.6:2.4	5:4
Blood loss [ml]	466 (250–1,500)	–	–	480 (200–960)
Operating time [min]	96 (45–240)	–	–	100 (70–125)
Cup abduction angle [°]	46.4 (29–61)	–	–	43.9 (30–55)
Migration of femoral component	–	3.9%	8%	0%
Complications	4.5%	5%	6%	5.5%
Revision	–	3%	6%	0%
Harris Hip Score	67% excellent 31% good	93.5 (41–100)	–	97 (92–100)
Follow-up [years]	1.01 (0.5–3.5)	3,5 (2–6)	5–7	1–2
Study characteristics	Case series No control group	Case series No control group	Mached pairs	Mached pairs
Used implants	BHR (MMT, Birmingham, UK)	Conserve Plus (Wright Medical Technology, Arlington, TN)	THA-BHR (MMT, Birmingham, UK)	BHR (MMT, Birmingham, UK)

using the mechanical guide that would have resulted in unacceptable acetabulum alignment.

Our results in terms of outcome scores are similar to those obtained by De Smet [9], Amstutz [3] and Pollard [22] in studies of resurfacing hips without navigation (Table 5). Patients had a high level of activities, including sports, in the age range values. In all of the studies more male patients were treated than female. This was probably due to the better bone stock and the incidence of less osteoporosis in men. Length of surgery and blood loss were only mentioned in De Smet's study, which was similar to the classical total hip arthroplasty procedure and also similar to our results. De Smet describes cup abduction angles similar to ours. Amstutz described radiological signs as radiolucent lines in over 25% and migration of femoral components in 3.9%. Pollard found a sclerotic line in 60% of femoral components and 10% of the femoral components with radiolucent lines had migrated. Complication rates were also similar to ours, and we have had no revisions. This may due to the patient selection, the number of patients and the experience of the surgeon. It is important to avoid notching the neck and to cover all of the reamed bone with the component, which was achieved in all of our cases.

De Smet and Amstutz described the functional outcome by the Harris Hip Score. De Smet did not report the exact score, but found 67% with excellent and 31% with good results. Amstutz demonstrated a mean Harris Hip Score of 93.5 points. In our study, the level was similar (97 of 100 points).

During the computer-navigated procedure there is always a risk of disconnection of the reference fixation zone or a risk of imprecise registration of the pelvis, while the femoral segmentation might be difficult. However, centering of the acetabulum component was found extremely precise (up to 2 mm) with an accurately positioned axis. In severe deformities, component positioning might be found more easily with a navigation system, therefore allowing smaller incisions (minimally invasive approach).

Conclusion

Computer-assisted placement technique was found to be an accurate and reproducible technique for hip resurfacing arthroplasty. The cup position was better achieved for the navigated hips than by the traditional method of positioning used in this study, even for the well-trained surgeon.

Hip navigation for resurfacing surgery may allow improved visualisation and cup positioning.

Its advantages would probably be more obvious in severe deformities or with mini-incisions than with regular incision surgery for femoral implant positioning.

Outcome-based research and long-term follow-up are necessary to assess the clinical and economic impact of a computer-navigated method for hip resurfacing.

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