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ORIGINAL PAPER

The direct anterior approach in hemiarthroplasty for displaced femoral neck fractures

Kerstin Schneider · Laurent Audigé · Stefanie-Peggy Kuehnel · Naeder Helmy

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Abstract
Purpose Hip replacement is the most common treatment for displaced femoral neck fractures in the elderly, and minimally invasive surgery is popular in the field of orthopaedic surgery. This study evaluated the outcome of monopolar hemiarthroplasty by the direct anterior approach over a postoperative period up to 2.5 years.
Methods A total of 86 patients with displaced femoral neck fractures were included (mean age of 86.5 years). Surviving patients were reviewed three months (retrospectively) and one to 2.5 years (prospectively) after surgery. One-year mortality was 36 %.
Results For all stems, implant positioning with respect to stem alignment, restoration of leg length and femoral offset was correct. Acetabular protrusion was observed in 55 % of the patients one to 2.5 years postoperatively. Subsidence and intraoperative periprosthetic fractures occurred in three patients (3 %) each. All revision stems for postoperative periprosthetic fractures could be implanted using the initial surgical technique without extension of the previous approach. The mean Harris hip score was 85 points at the one to 2.5-year follow-up; 85 % of the patients were satisfied with their hip and 57 % returned to their preoperative level of mobility.
Conclusion Based on these findings, hemiarthroplasty for hip fractures can be performed safely and effectively via the direct anterior approach with good functional outcome and high patient satisfaction.

K. Schneider (✉) · S.-P. Kuehnel · N. Helmy
Department of Orthopaedics and Traumatology,
Bürgerspital Solothurn,
Solothurn, Switzerland
e-mail: schneider.kerstin@gmx.ch

L. Audigé
AO Clinical Investigation and Documentation,
Davos, Switzerland

Introduction

Femoral neck fractures in the elderly are a significant health care problem. Affected patients frequently have multiple comorbidities, are often physiologically compromised, and should be immediately mobilised to prevent complications [1–3].

While nondisplaced femoral neck fractures can be treated conservatively, displaced fractures usually need surgical treatment. Arthroplasty is preferred to fracture reduction and internal fixation, especially in the elderly (over 65 years) due to better functional outcome and fewer reoperations [2–5]. Total hip replacement (THR) is recommended for the so-called active, healthy elderly patient [6]. Hemiarthroplasty (HA) should be performed in patients with poor health status and a low life expectancy [2, 3].

In general, hip fractures in the elderly are associated with a high one year-mortality up to 36 % [1]. Apart from choosing the proper treatment, optimising the surgical technique itself offers options to improve the outcome. Nowadays, minimally invasive surgery (MIS) is very popular in the field of orthopaedic surgery. In order to reduce soft tissue damage and gain quicker postoperative recovery and faster rehabilitation, various MIS techniques have been proposed [7–10]. The outcome of patients treated with these techniques has nevertheless been insufficiently documented [11].

This study evaluated the clinical and radiological outcomes of the direct anterior approach for unipolar head endoprosthetic hip replacement in patients with displaced femoral neck fractures over a follow-up period of up to 2.5 years.

Patients and methods

Patients and recruitment

Between January 2009 and December 2010, 91 patients underwent unipolar head endoprosthetic hip replacement for a femoral neck fracture using the direct anterior approach. Two patients had fractures affecting both hips; only the last side to be treated for each patient was included in the study population. Two patients presented with an undisplaced fracture during retrospective review of preoperative radiographs, two patients with a pathological fracture, and one patient with hemiparesis of the affected leg were excluded. Therefore, 86 patients with nonpathological, displaced femoral neck fractures were included in the analysis (Fig. 1). Among these 86 patients, there were 65 females and 21 males, with a median age of 86 years (range 70–100) at surgery (Table 1). There were 38 left and 48 right hips. Ninety-three percent of the fractures were Garden III and IV, 7 % were Garden II with Pauwels II or III. Ninety-five percent of the patients had no (Tönnis 0) or just slight (Tönnis 1) osteoarthritis in the affected hip. Simultaneous upper extremity fractures were documented in eight patients at the distal radius (n=5), proximal humerus (n=2) and clavicle (n=1). Eighty-five percent of the patients had an ASA score of III or IV.

Baseline evaluation

Preoperative radiographs and patient charts were reviewed by the primary author. Baseline characteristics including pre-injury use of walking aids, comorbidities likely to influence postoperative mobilisation, and the patients' physical status according to the American Society of Anesthesiologists (ASA) were recorded. The ASA classification system is a tool for assessment of the preoperative general health condition of a patient which is used to calculate the patient's surgical risk. An ASA score of I describes a normal healthy patient, an ASA score of V a moribund patient who is not expected to survive and in whom an orthopaedic surgery is usually not indicated. Fractures were classified according to Pauwels [12] and Garden [13]. Garden III and IV or the combination of Garden II with Pauwels II or III were defined as displaced fractures. Osteoarthritis in the affected hip was defined according to the Tönnis classification [14].

Surgical technique and implants

All patients were operated upon in a supine position using the AMIS® Mobile Leg Positioner (Medacta International SA, Castel San Pietro, Switzerland). In this technique, the 8-cm long skin incision starts about 2-cm lateral and inferior to the anterior superior iliac spine pointing distally to the head of the fibula. The deep intermuscular dissection is made between the tensor fasciae latae muscle and the sartorius and rectus femoris muscle, thus respecting a true internervous plane. After accurate ligation of the ascending branches of the medial femoral circumflex artery, a V-shaped capsulotomy of the anterior capsule is made to obtain a direct approach to the femoral neck and fracture site [9, 15, 16]. The anterior capsule can either be resected or closed after joint replacement; in our study, it was closed in all patients.

Every operation was performed by an AMIS® experienced surgeon or less experienced surgeon under expert supervision. An AMIS® experienced surgeon was defined as one with experience in at least 100 operations using this technique.

The implants used for our patient population included mainly cementless AMIStems or Quadra® stems (Medacta International SA, Castel San Pietro, Switzerland), with standard or lateral offset according to the patient's anatomy. In all cases, the unipolar, monobloc, high nitrogen stainless steel prosthetic femoral head, Medacta® Endo Head, was used.

Surgical data including the duration of surgery, amount of intraoperative blood loss, and mode of anaesthesia were recorded.

Follow-up evaluations

In addition to the routine examination at three months postoperatively, a one to 2.5-year follow-up examination (mean 18 months, range 8–30) was performed prospectively between July and August 2011 (Fig. 1); informed consent was obtained from all patients who were able to attend this last follow-up assessment.

Radiographs from the immediate postoperative and follow-up periods were evaluated for implant positioning and acetabular protrusion. Differences in leg length and femoral offset were measured in comparison to the contralateral hip based on the method of Ranawat et al. [17]. Stem alignment within 5° of valgus or varus angulation was considered for a correctly implanted prosthesis. Acetabular protrusion was measured from the prosthetic head tip to the ilioischiadic line. Relevant acetabular protrusion was defined as shortening of two millimetres or more medially or loss of joint space cranially.

All intra- and postoperative complications occurring up to the last follow-up examination were documented from all available patient medical charts and radiographs, analysed according to the classification system outlined by Audigé et al. [18]. Implant or bone complications included signs of loosening (based on the radiolucency zones defined by Gruen et al. [19]), periprosthetic fractures (according to the Vancouver classification [21]), subsidence or dislocations.

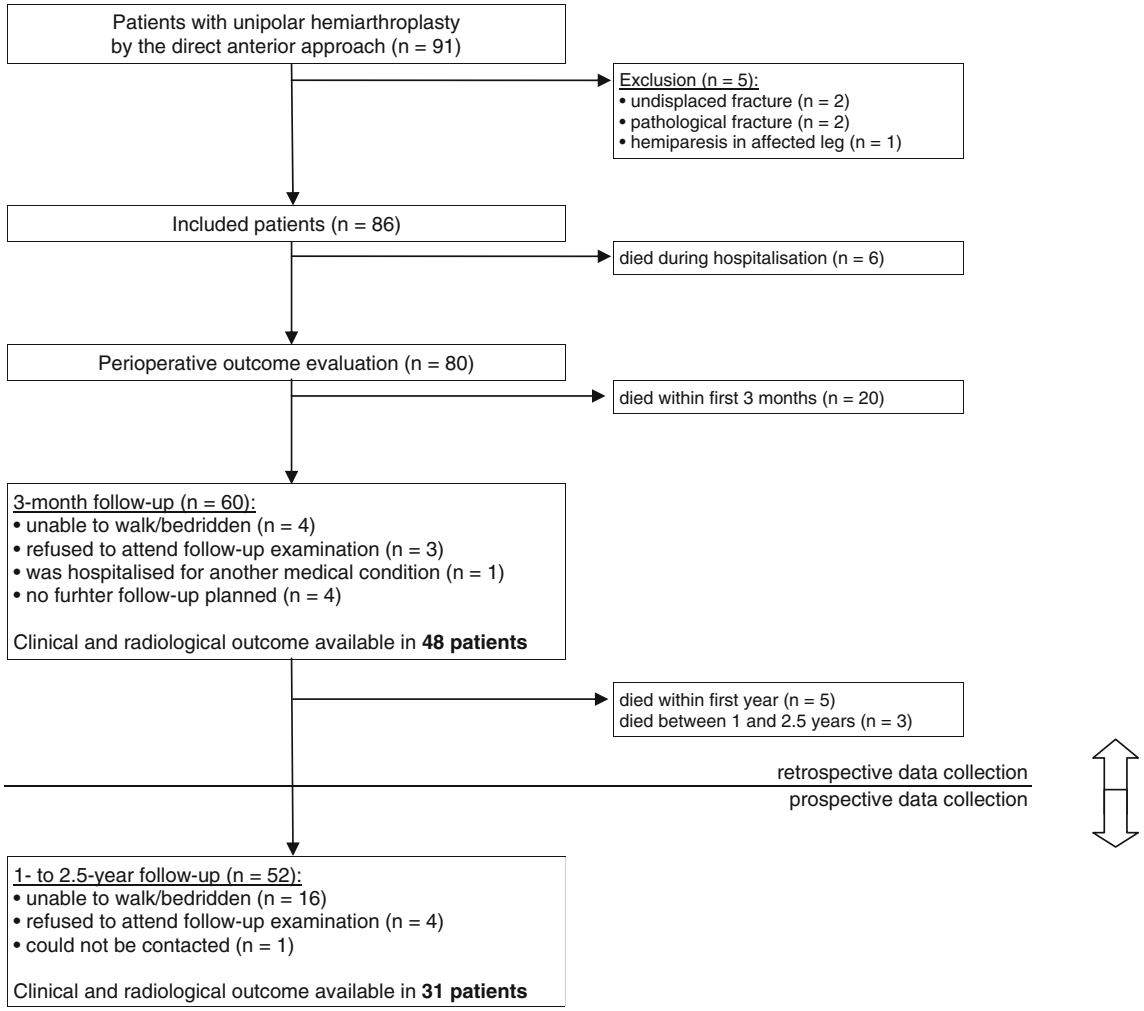

Fig. 1 Patient recruitment and follow-up flow chart

Subsidence was defined as 5 mm or greater vertical migration of the femoral component and was measured from fixed points on the prosthesis to any reproducible fixed landmark on the femur such as the lesser trochanter, the tip of the greater trochanter, or trochanteric wires [20]. Any soft tissue complications including superficial and deep infection, wound healing and haematoma were also documented.

The patient clinical examination included assessments of hip motion, the presence of the Trendelenburg sign in the operated hip as an indicator for insufficiency of the hip abductor muscles, and determination of functional status using the Harris hip score [22].

In addition, the level of mobility (use of walking aids) and patient satisfaction were documented from nondementia patients using a simple numeric rating scale where 'no support' and 'very satisfied' reflect best and 'wheelchair' and 'unsatisfied' lowest level of mobility and satisfaction, respectively.

Statistical analysis

All baseline and follow-up parameters were described with standard descriptive statistics.

Changes in continuous and categorical outcomes between follow-up examinations were evaluated using Wilcoxon signed-rank and symmetry tests, respectively. Ad hoc univariable group comparisons of continuous and categorical outcomes were examined using the Wilcoxon rank-sum test and Fisher's exact test, respectively. All analyses were explorative and performed using Stata 11 software (StataCorp LP, Texas, USA). P-values of <0.05 were considered significant.

Results

Follow-up data were available for 48 (56 %) patients at three months and 31 (36 %) patients at the one to 2.5-year

Table 1 Demographic and perioperative data

Characteristics	*n* (%)	Median (range)
Age at surgery (years)	86	86 (70–100)
Gender		
Male	21 (24 %)	
Female	65 (76 %)	
Comorbidities		
Parkinson's disease	6 (7 %)	
Severe dementia	29 (34 %)	
Relevant lower back pain	16 (19 %)	
Simultaneous injury of UE with or without surgery	8 (9 %)	
Previous surgery at contralateral hip	14 (16 %)	
ASA score		
II	13 (15 %)	
III	64 (74 %)	
IV	9 (11 %)	
Diagnosis/fracture classification		
Pauwels		
I	3 (4 %)	
II	54 (62 %)	
III	29 (34 %)	
Garden		
II	6 (7 %)	
III	41 (48 %)	
IV	39 (45 %)	
Fracture side		
Right	48 (56 %)	
Left	38 (44 %)	
Tönnis		
0	32 (37 %)	
1	50 (58 %)	
2	4 (5 %)	
Hospitalisation		
Duration of hospitalisation (days)	86	8 (2–15)
Time from admission to surgery (days)	86	0.5 (0–4)
Surgery		
Surgeon's experience		
Experienced	34 (40 %)	
Less experienced	52 (60 %)	
Duration of surgery (minutes)	85	80 (45–200)
Blood loss (ml)	29	300 (100–800)
Anaesthesia		
Spinal	65 (76 %)	
General	21 (24 %)	

UE upper extremity

examination (Fig. 1). A total of 34 patients died during the study period; 29 had an ASA score III and five patients an ASA score IV. The three-month mortality was 30 % (26/86) and 36 % (31/86) at one year. Fifty-nine percent (17/29) of the patients with severe dementia died within three months postoperatively. Additional patients were lost to follow-up because they had become bedridden, others refused to attend the follow-up examination or could not be contacted.

Hospitalisation and surgical data

The median delay between hospital admission and surgery was 0.5 days (range 0–4), with a median duration of hospital stay of eight days (range 2–15) (Table 1). About one-third (34/86) of the operations were performed by an AMIS® experienced surgeon.

The median duration of surgery was 80 minutes (range 45–200) with a borderline significantly shorter duration of five minutes for experienced surgeons ($p=0.046$).

The median volume of intraoperative blood loss was 300 ml (range 100–800) with no significant difference based on the surgeons' experience level ($p=0.341$).

Radiological results

Postoperative radiographs showed a median lengthening of the operated leg of five mm; femoral offset was restored with a median shortening of one mm (Table 2). There was no statistically significant change in leg length or femoral offset throughout the follow-up period ($p\geq0.152$). All femoral components were implanted within the range of 5° valgus and 5° varus angulation (median 0°), and stem alignment did not significantly change up to the last follow-up ($p=0.581$).

The proportion of patients with radiographically visible acetabular protrusion of the head component (Fig. 2) was 23 % (11/47) at three months, and significantly increased to 55 % (17/31) at one to 2.5 years ($p=0.001$). With a mean age of 85 years (range 80–95), this subgroup was about 2.5 years older than patients with no acetabular protrusion (range 74–93). Almost all of the 17 cases ($n=16$) had no or slight osteoarthritis (Tönnis 0 or 1).

Complications

Intraoperative periprosthetic fractures and subsidence were the most common surgeon- or technique-related complications, each with an overall risk of 3 % (3/86) (Table 3).

The three intraoperative periprosthetic fractures occurred as a result of the reposition manoeuvre. For the two Vancouver B.1 fractures, a cemented stem with tension wires was implanted, instead of the planned noncemented stem, using the same surgical approach (no extension was necessary) (Fig. 3). In one case, this led to the extreme lengthening of the leg of 23 mm (Table 2), with the patient dying

Table 2 Radiological results

Measurement	Postoperative		Three-month follow-up		One- to 2.5-year follow-up		*p*-value
	n (%)	Median (range)	*n* (%)	Median (range)	*n* (%)	Median (range)	
Difference in leg length (mm)[a]	79	5 (−14 to 23)	48	5 (−14 to 12)	30	3.5 (−10 to 12)	0.424[d]
Difference in femoral offset (mm)[b]	79	−1 (−11 to 15)	47	1 (−4 to 10)	29	1 (−5 to 10)	0.152[d]
Stem alignment (°)[c]	80	0 (−5 to 4)	47	0 (−3 to 5)	30	0.5 (−3 to 5)	0.581[d]
Acetabular protrusion			47		31		0.001[e]
Yes			11 (23 %)		17 (55 %)		
No			36 (77 %)		14 (45 %)		

[a] Negative value indicates that the operated leg is shorter than the contralateral leg

[b] Negative value indicates that the ipsilateral offset is shorter than the contralateral offset

[c] Negative and positive values indicate valgus and varus angulation, respectively

[d] Signed rank test between 3-month and 1- to 2.5-year follow-up

[e] Symmetry test between 3-month and 1- to 2.5-year follow-up

within three months postoperatively from nonsurgically related reasons.

The three cases of subsidence occurred in the early postoperative phase with no further vertical migration until the one to 2.5-year follow-up and no mechanical loosening of the prosthesis. In two cases, performed by a less experienced surgeon under supervision, a stem undersizing could be detected when comparing the radiographs to the preoperative planning. Analysing all operations performed by this surgeon, these two cases represented his first operations using this technique, with improvement of implant sizing and positioning over time.

Although subsidence ranged from five to 11 mm radiographically, there was no clinical relevant leg-length difference or hip abductor insufficiency detectable on patient examination.

All six postoperative periprosthetic fractures occurred following a new injury. In two cases, the revision surgery to exchange the stem (Vancouver B.2 fractures) could be performed using the previous surgical technique without extension of the approach. These two patients reported no pain and a general level of satisfaction with their outcome.

Clinical findings

The median flexion-extension and rotation angles reported for the operated hip at three months were 100° and 45°, respectively (Fig. 4). There was no significant change in the range of motion status up to the one to 2.5-year follow-up ($p \geq 0.424$); all patients examined had a minimum hip flexion of 90°.

The median Harris hip scores at the three-month and one to 2.5-year follow-up were 81 and 85 points, respectively ($p=1.000$) (Table 4). Fifty-seven percent of all patients who had at least one follow-up examination ($n=60$) returned to their preoperative level of mobility (based on the use of

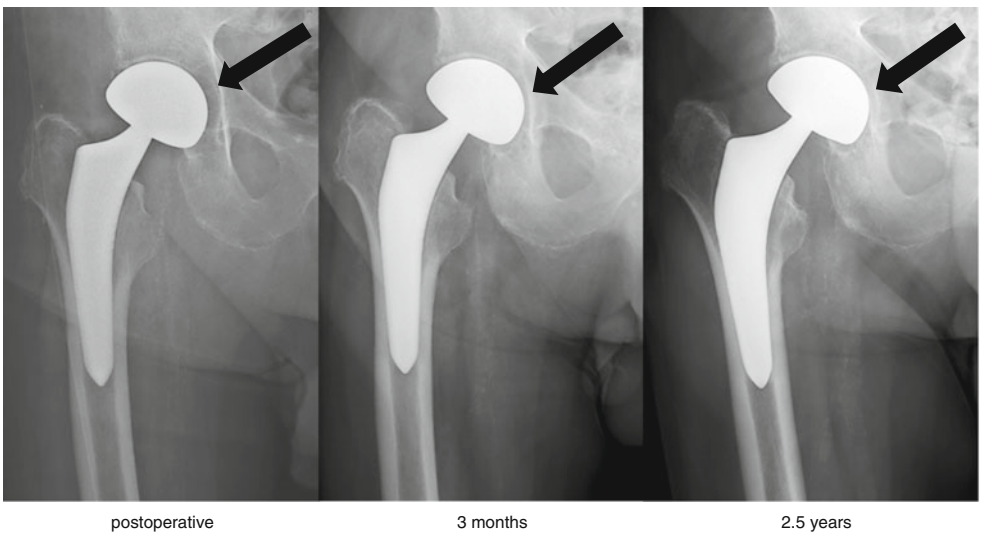

Fig. 2 Progression of acetabular protrusion up to the last follow-up

Table 3 Complications

Complications (n=86)	Grade	n (%)	95 %CI
Intraoperative complications		3 (3 %)	0.7–10
Periprosthetic fracture	Vancouver A	1 (1 %)	0–6
	Vancouver B.1	2 (2 %)	0.3–8
	Vancouver B.2	-	
	Vancouver B.3	-	
	Vancouver C	-	
Local postoperative complications		11 (13 %)	7–22
Implant/bone complications		9 (10 %)	5–19
Periprosthetic fracture	Vancouver A	2 (2 %)	0.3–8
	Vancouver B.1	2 (2 %)	0.3–8
	Vancouver B.2	2 (2 %)	0.3–8
	Vancouver B.3	-	
	Vancouver C	-	
Subsidence		3 (3 %)	0.7–10
Loosening		-	
Dislocation		-	
Soft tissue/wound		2 (2 %)	0.3–8
Superficial wound infection		1 (1 %)	0–6
Deep infection		-	
Haematoma		2 (2 %)	0.3–8

n is the number of patients with at least one complication, *%* indicates the number of patients with at least one complication divided by the total number of patients in the study, *95 %CI* is the95 % confidence interval

walking aids). Most of the patients (85 %) were (very) satisfied with their operated hip, with improving satisfaction up to the last follow-up (p=0.001).

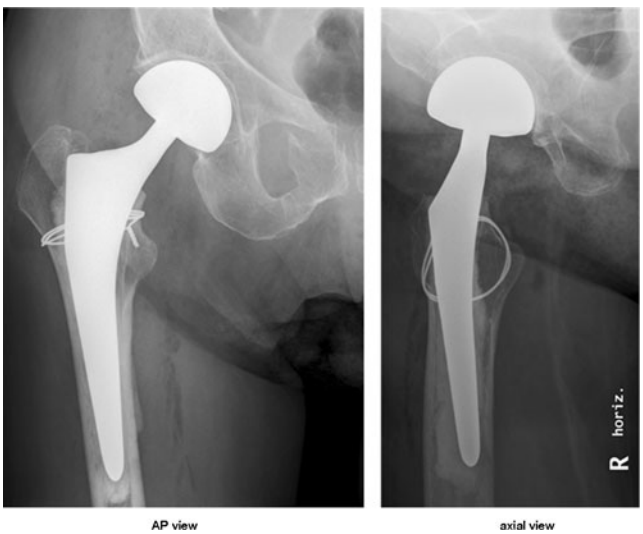

Fig. 3 After sustaining an intraoperative fracture a cemented stem with tension wires was implanted; no extension of the surgical approach was necessary

Discussion

This study presents the clinical and radiological outcome for patients with displaced femoral neck fractures treated using unipolar hemiarthroplasty by the direct anterior approach. Surviving patients can expect to achieve adequate range of motion with no indications of hip abductor muscle insufficiency and a Harris hip score of around 85 points which indicates some but close to no disability. Patients can also return to their preinjury level of mobility in more than half of the cases, with high satisfaction of overall hip function. On the other hand, well positioned implants can be expected, with acetabular protrusion occurring in half of the population at around one to 2.5 years after surgery. Periprosthetic fractures and subsidence are the most common problems. Nevertheless, this new technique is considered advantageous for patients suffering from a hip fracture, needing hip replacement.

Minimally invasive techniques in the field of orthopaedic surgery have been increasingly promoted in response to patients' demands and expectations [23]. The goal of such muscle-preserving implantation techniques is to minimise soft tissue trauma, so as to optimise postoperative rehabilitation and increase patient satisfaction [24, 25]. For the hip, various minimally invasive anterior or posterior, single- or two-incision approaches have been described, but only the direct anterior approach is the surgical approach "that truly uses intermuscular and internervous planes" [10]. It is nevertheless reported to be technically demanding [26, 27], and to be associated with a higher risk of implant malpositioning [25, 28] and intraoperative complications due to the limited visibility/overview. With regard to implant survivorship and long-lasting implant function, adequate positioning is critical [28, 29]. At our institution, it is a common approach performed during teaching operations, and by less experienced operators under expert supervision. We have achieved excellent results in implant positioning with respect to stem alignment, restoration of leg length and femoral offset regardless of the surgeon's experience level. Roy et al. [7] report of neutral stem alignment in just 74 % of their patients undergoing unipolar hip replacement via a minimally invasive posterior approach compared to 75 % in the standard posterior group. Preininger et al. [9] implanting bipolar HA over the direct anterior approach also achieved excellent results with regard to femoral offset (+1 mm) and leg length (– 0.5 mm) with a median varus malpositioning of the femoral component of 2.3 degrees.

Despite a relatively short observation period of around 2.5 years in our study, a radiographically visible acetabular protrusion of the head component occurred in 55 % of the patients, every one of them being pain free and mobilising well (75 % returned to their preoperative level of mobility). This subgroup suffered from poor general health with ASA

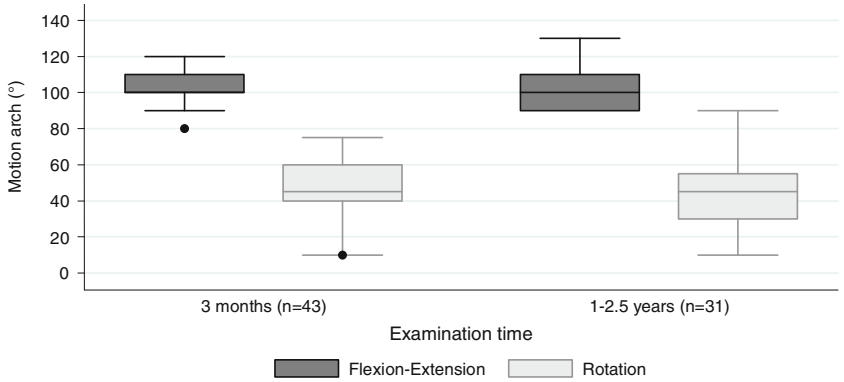

Fig. 4 Motion arches in the operated hip

scores of III or IV in 76 % of the cases, was about 2.5 years older than patients with no acetabular protrusion, and had no or a slight grade of osteoarthritis (94 %). Age, osteoporosis, activity level and length of follow-up are known to be associated with increased acetabular protrusion in HA [1, 2]. Based on the relatively high activity level status and shortness of the follow-up period, we believe the decision for THR should be considered more often in our institution. On the other hand, the patients' advanced age and general condition (ASA score) justify undertaking HA. The fact that acetabular protrusion occurred in hips without pre-existing osteoarthritis supports the reported suggestion that patient factors are more likely to influence the decision for performing THR or HA than the status of pre-existing osteoarthritis [1]. When considering HA, there is no clear consensus in current literature for uni- or bipolar head components. According to Kannan et al. [2] bipolar HA should mainly be used. But according to Leighton et al. [3], there is no superiority of bipolar over unipolar HA, because bipolar heads as unipolar implants over time.

In our opinion, as long as the patient remains pain free, a radiographically visible acetabular protrusion can be considered clinically irrelevant. And unipolar hip replacement is a valid treatment option for our elder, frail and low-demand patient population. But active, healthy patients with a life expectancy of more than five years should be carefully considered for THR.

From the viewpoint of cost effectiveness, it would be interesting to consider whether aged patients (i.e. ≥ 85 years) with a displaced femoral neck fracture and the combination of preoperatively documented severe dementia and good activity level could be treated with a similar outcome for their lifetime when using a less invasive method compared to arthroplasty, i.e. closed reduction and internal screw fixation. This issue should be considered in any future related study.

Table 4 Functional outcome and patient satisfaction

Parameter	Three-month follow-up		One- to 2.5-year follow-up		*p*-value
	n (%)	Median (range)	*n* (%)	Median (range)	
Range of motion					
Flexion-extension (°)	43	100 (80–120)	31	100 (90–130)	1.000[a]
Rotation (°)	43	45 (10–75)	31	45 (10–90)	0.424[a]
Harris hip score	38	81 (63–100)	27	85 (68–100)	1.000[a]
Use of walking aids	47		31		0.001[b]
No support	13 (28 %)		12 (39 %)		
One cane/walking stick	9 (19 %)		5 (16 %)		
Two crutches	5 (11 %)		1 (3 %)		
Walking frame	17 (36 %)		11 (35 %)		
Wheelchair	3 (6 %)		2 (7 %)		
Patient satisfaction	36		27		0.001[b]
Very satisfied	11 (30 %)		13 (48 %)		
Satisfied	20 (55 %)		10 (37 %)		
Not so satisfied	5 (15 %)		3 (11 %)		
Unsatisfied	-		1 (4 %)		

[a] Signed rank test

[b] Symmetry test

In our study, the overall risk for patients experiencing a surgeon or technique related complication was 6 %. That is not higher than that reported using other surgical techniques such as other minimally invasive approaches (i.e. modified Watson-Jones) or comparative conventional approaches (i.e. transgluteal), with a range of 2.6–8 % for intraoperative fractures [7, 8, 15]. All our intraoperative fractures were reported for patients whose operations were undertaken by an experienced surgeon; the surgeon's experience level was not a preventive factor in our study. Interestingly, all revision operations for postoperative Vancouver B.2 fractures could be performed using the initial surgical technique without extension of the approach. This is a new observation and to our knowledge, has not been reported in the literature.

The median Harris hip score of around 85 points represents a comparable outcome to the current literature, where scores ranging from 66 to 84 points have been reported [7, 15]. Similar satisfactory results were also obtained for the duration of hospital stay, duration of surgery and intraoperative blood loss (Table 1). In the current literature, duration of hospitalisation varies from seven to 15.2 days [7, 28, 29], duration of surgery from 57 to 93 minutes [7, 8, 15, 28, 30], and intraoperative blood loss from about 200 to 400 ml [7, 8, 28].

Our study was limited by the non-comparative and retrospective study design associated with unavoidable missing data points related to some study variables. Follow-up rates were low with 56 % at the three-month and 36 % at the one to 2.5-year follow-up. This was essentially due to the high mortality of our old and frail patient population. Furthermore, of our surviving patients, 16 became bedridden and could not attend the last follow-up examination.

We could not show that the overall survival of a displaced femoral neck fracture can be improved using the direct anterior approach, but with the described technique we could reach a high level of patient satisfaction (85 %), with 57 % of the patients returning to their preoperative level of mobility.

In conclusion, we could show that hemiarthroplasty for displaced femoral neck fractures can be done safely and effectively by the direct anterior approach, both in the hands of experienced and less experienced surgeons. In certain cases, revision surgery can be done without extension of the surgical approach.

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Conflict of interest The authors declare that they have no conflict of interest.

References

1. Antapur P, Mahomed N, Gandhi R (2011) Fractures in the elderly: when is hip replacement a necessity? Clin Interv Aging 6:1–7
2. Kannan A, Kancherla R, McMahon S et al (2012) Arthroplasty options in femoral-neck fracture: answers from the national registries. Int Orthop 36(1):1–8
3. Leighton RK, Schmidt AH, Collier P, Trask K (2007) Advances in the treatment of intracapsular hip fractures in the elderly. Injury 38 (suppl 3):24–34
4. Bhandari M, Devereaux PJ, Tornetta P 3rd et al (2005) Operative management of displaced femoral neck fractures in elderly patients. An international survey. J Bone Joint Surg Am 87:2122–2130
5. Frihagen F, Nordsletten L, Madsen JE (2007) Hemiarthroplasty or internal fixation for intracapsular displaced femoral neck fractures: randomised controlled trial. BMJ 335:1251–1254
6. Blomfeldt R, Törnkvist H, Eriksson K et al (2007) A randomised controlled trial comparing bipolar hemiarthroplasty with total hip replacement for displaced intracapsular fractures of the femoral neck in elderly patients. J Bone Joint Surg Br 89:160–165
7. Roy L, Laflamme GY, Carrier M et al (2010) A randomised clinical trial comparing minimally invasive surgery to conventional approach for endoprosthesis in elderly patients with hip fractures. Injury 41:365–369
8. Tsukada S, Wakui M (2010) Minimally invasive intermuscular approach does not improve outcomes in bipolar hemiarthroplasty for femoral neck fracture. J Orthop Sci 15:753–757
9. Preininger B, Jesacher M, Fabsits E, Winkler T (2011) Earlier postoperative mobilization with minimally invasive hip hemiarthroplasty [in German]. Unfallchirurg 114:333–339
10. Lovell TP (2008) Single-incision direct anterior approach for total hip arthroplasty using a standard operating table. J Arthroplast 23 (suppl 7):64–68
11. Butler M, Forte ML, Joglekar SB et al (2011) Evidence summary: systematic review of surgical treatments for geriatric hip fractures. J Bone Joint Surg Am 93:1104–1115
12. Pauwels F (1935) Der Schenkelhalsbruch. Ein mechanisches Problem. Ferdinand Enke Verlag, Stuttgart
13. Garden RS (1964) Stability and union in subcapital fractures of the femur. J Bone Joint Surg Br 46:630–647
14. Tönnis D (1984) Die angeborene Hüftdyplasie und Hüftluxation. Springer Berlin, Heidelberg
15. Auffarth A, Resch H, Lederer S et al (2011) Does the choice of approach for hip hemiarthroplasty in geriatric patients significantly influence early postoperative outcomes? a randomized-controlled trial comparing the modified Smith-Peterson and Hardinge approaches. J Trauma 70:1257–1262
16. Paillard P (2007) Hip replacement by a minimal anterior approach. Int Orthop 31(suppl 1):13–15
17. Ranawat CS, Dorr LD, Inglis AE (1980) Total hip arthroplasty in protrusio acetabuli of rheumatoid arthritis. J Bone Joint Surg Am 62:1059–1065
18. Audigé L, Goldhahn S, Daigl M et al (2011) How to document and report orthopaedic complications in clinical studies? A proposal for standardization. Arch Orthop Trauma Surg. doi:10.1007/s00402-011-1384-4
19. Gruen TA, McNeice GM, Amstutz HC (1979) "Modes of failure" of cemented stem-type femoral components: a radiographic analysis of loosening. Clin Orthop Relat Res 141:17–27

20. Weiss RJ, Beckman MO, Enocson A et al (2011) Minimum 5-year follow-up of a cementless, modular, tapered stem in hip revision arthroplasty. J Arthroplast 26:16–23
21. Duncan CP, Masri BA (1995) Fractures of the femur after hip replacement. Instr Course Lect 44:293–304
22. Harris WH (1969) Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. J Bone Joint Surg Am 51:737–753
23. Foucher KC, Wimmer MA, Moisio KC et al (2011) Time course and extent of functional recovery during the first postoperative year after minimally invasive total hip arthroplasty with two different surgical approaches — a randomized controlled trial. J Biomech 44:372–378
24. Müller M, Tohtz S, Dewey M et al (2011) Muscle trauma in primary total hip arthroplasty depending on age, BMI, and surgical approach: minimally invasive anterolateral versus modified direct lateral approach [in German]. Orthopäde 40:217–223
25. Smith TO, Blake V, Hing CB (2011) Minimally invasive versus conventional exposure for total hip arthroplasty: a systematic review and meta-analysis of clinical and radiological outcomes. Int Orthop 35:173–184
26. Kreuzer S, Leffers K, Kumar S (2011) Direct anterior approach for hip resurfacing: surgical technique and complications. Clin Orthop Relat Res 469:1574–1581
27. Matta JM, Shahrdar C, Ferguson T (2005) Single-incision anterior approach for total hip arthroplasty on an orthopaedic table. Clin Orthop Relat Res 441:115–124
28. Mouilhade F, Matsoukis J, Oger P et al (2011) Component positioning in primary total hip replacement: a prospective comparative study of two anterolateral approaches, minimally invasive versus gluteus medius hemimyotomy. Orthop Traumatol Surg Res 97:14–21
29. Pospischill M, Kranzl A, Attwenger B, Knahr K (2010) Minimally invasive compared with traditional transgluteal approach for total hip arthroplasty. A comparative gait analysis. J Bone Joint Surg Am 92:328–337
30. Wohlrab D, Droege JW, Mendel T et al (2008) Minimally invasive vs. transgluteal total hip replacement. A 3-month follow-up of a prospective randomized clinical study [in German]. Orthopäde 37:1121–1126