Author: Embden, Daphne van
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Chapter 7

Fixation device related rotational influences in femoral neck and trochanteric fractures: a radio stereometric analysis

Daphne van Embden
Guido A.N.L. Stollenwerck
Lennard A.Koster
Bart L. Kaptein
Rob G.H.H. Nelissen
Inger B. Schipper

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ABSTRACT

The aim of this study was to quantify the stability of fracture-implant complex in fractures after fixation. A total of 15 patients with an undisplaced fracture of the femoral neck, treated with either a dynamic hip screw or three cannulated hip screws, and 16 patients with an AO31-A2 trochanteric fracture treated with a dynamic hip screw or a Gamma Nail, were included. Radiostereometric analysis was used at six weeks, four months and 12 months post-operatively to evaluate shortening and rotation.

Migration could be assessed in ten patients with a fracture of the femoral neck and seven with a trochanteric fracture. By four months post-operatively, a mean shortening of 5.4 mm (-0.04 to 16.1) had occurred in the fracture of the femoral neck group and 5.0 mm (-0.13 to 12.9) in the trochanteric fracture group. A wide range of rotation occurred in both types of fracture. Right-sided trochanteric fractures seem more rotationally stable than left-sided fractures.

This prospective study shows that migration at the fracture site occurs continuously during the first four post-operative months, after which stabilisation occurs. This information may allow the early recognition of patients at risk of failure of fixation.

INTRODUCTION

Undisplaced intracapsular fractures of the hip are often treated with either a sliding hip screw such as a Dynamic Hip Screw (DHS, DePuy Synthes, Oberdorf, Switzerland) or three cannulated screws (CS, DePuy Synthes). Extracapsular proximal femoral fractures or trochanteric fractures are most commonly treated with an extramedullary sliding hip screw device or an intramedullary (IM) nail, such as the Gamma Nail (GN, Gamma3 Trochanteric Nail 180, Stryker, Kiel, Germany). All these types of implants are associated with fixation-related complications, such as cut-out of the implant and delayed union. Fixation-related complications are reported in up to 30% of proximal femoral fractures. Complication rates vary depending on the type of fracture and the choice of treatment: 12% in undisplaced[1] and up to 30% in displaced fractures of the femoral neck.[2] In trochanteric fractures, failure of fixation is reported in between 2%[3] and 20%[4] of patients, and the incidence of fracture-related complications in transverse or reversed oblique trochanteric fractures (31-A3)[5] is 30% to 32%.[6, 7] Many of these complications relate to the biomechanical characteristics of both the fracture and the fixation device, and to the quality of the reduction and fixation.[8-10] Rotational instability of the fracture-implant complex is thought to be a significant cause of failure of fixation and may be a key predictor of the most common fixation-related complications.[11] However, the extent of rotational instability in hip fractures treated with modern implants has not been previously investigated in detail.

Rotational stability is difficult to assess using standard imaging techniques. However, movement between the fracture fragments can be accurately measured by radiostereometric analysis (RSA).[12] Therefore, the aim of this study was to use RSA to quantify the movement of proximal femoral fracture fragments after fixation with the most commonly used methods of osteosynthesis (GN, DHS and CS).

PATIENTS AND METHODS

Between April 2010 and April 2012, all patients aged over 60 years who were admitted to Leiden University Medical Center's departments of trauma and orthopaedic surgery with either an AO 31-B15 fracture of the femoral neck (Garden[13] grade 1 or 2, undisplaced intracapsular fracture) or an AO 31-A2 trochanteric fracture planned for osteosynthesis, were enrolled after providing written informed consent. Patients with severe arthritis of the involved hip, a pathological fracture, pre-existent immobility, or those who could not be reviewed post-operatively, were excluded. The study had approval from the local ethics committee of the Leiden University Medical Center.

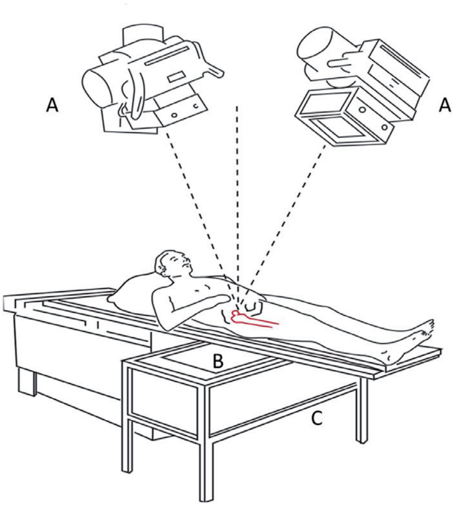


Figure 1

Diagram showing patient positioning in radiostereometric analysis (RSA) set-up. The RSA set-up consists of two synchronised x-ray tubes (A) and a calibration box (B). The x-ray films are positioned underneath this box (C). The hip is positioned at the intersection of the x-ray beams, so that a stereo image is created.

All operations were performed by or under the direct supervision of an orthopaedic or trauma surgeon within two days of admission. Patients with a fracture of the femoral neck were randomly assigned to treatment with either a DHS or CS. Those with a trochanteric fracture were randomly assigned to treatment with either a DHS or a GN.
Intra-operatively, after or during placement of the fixation device, between three and six spherical tantalum markers (1 mm diameter, Wennbergs Finmek AB, Gunnilse, Sweden) were inserted into each fragment at the medial and lateral side of the main fracture line, surrounding the implant. Micromotion of the fracture fragments along the three orthogonal axes (i.e., X, Y and Z) was tracked post-operatively. RSA radiographs were obtained within the first one to two days (T = 1), at six weeks (T = 2) (after full weight-bearing mobilisation was achieved), four months (T = 3) and one year post-operatively (T = 4). Figure 1 shows the positioning of the patient in an RSA setup.

Statistical analysis

The RSA images were analysed with Model-based RSA software (version 3.34; RSAcore, Department. of Orthopaedics, LUMC, Leiden, The Netherlands) by a trained technician. Migration was calculated using the largest fracture fragment marker set possible (mean error of rigid-body fitting (ME) max 0.5 mm; condition number (CN) below 150 m-1).[12]
The ME is a measure to assess the stability over time of markers in the rigid body, and the CN is a calculated number used to assess the distribution of markers in the rigid

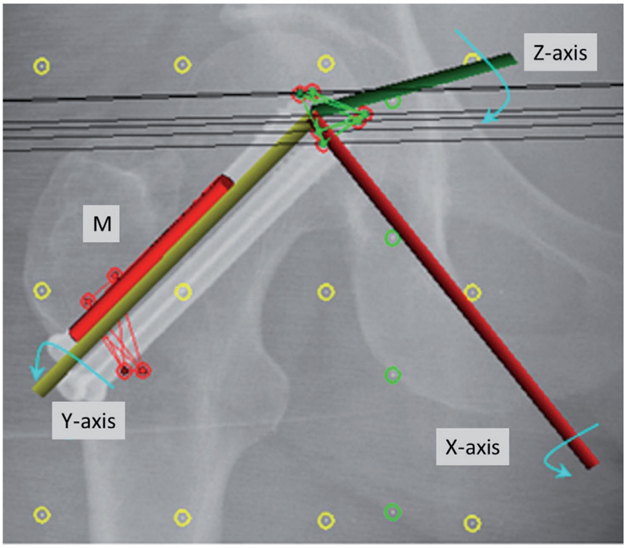


Figure 2

Radiostereometric analysis radiograph presenting head and shaft markers (red dots). The black lines are created by the computer program in order to correlate the markers with a second radiograph (not presented). The yellow and green markers in this radiograph are box markers. These are used, together with the second radiograph, which is taken simultaneously but from another angle, to calculate three-dimensional (3D) micromotion of the markers and the 3D orientation of the cylindrical model (M) that represents the position of the proximal cannulated screw.

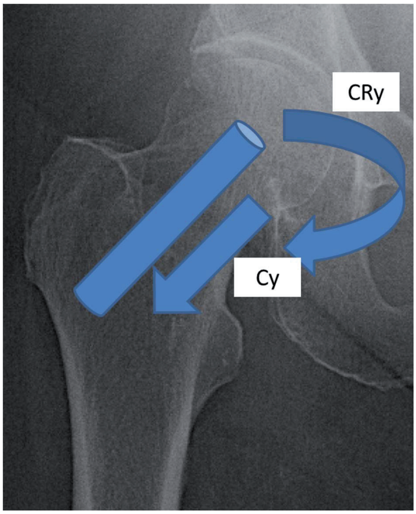


Figure 3

Schematic view of the migration model based on an implant head screw. CRy: rotation about y-axis; Cy: shortening along the y-axis.

body.[12] Measurements were made of translations along and rotations around the orthogonal axes. The axial system in which the migration is expressed was orientated such that the Y-axis was aligned with the longitudinal axis of the fixation material (i.e., parallel to the screw of the DHS/GN or to the most proximal CS) (Figure 2). The origin of this co-ordinate system was positioned in the centre of gravity of the markers in the femoral head. The migration calculations are given as translations and rotations of the femoral head with respect to the femoral shaft, using the immediate post-operative (T = 1) RSA acquisition as the baseline. This results in data representing rotation (CRy) and fracture shortening or collapse (Cy) (Figure 3).

Left-sided hips were transformed to right-sided in order to analyse the results as one group.[12] Descriptive statistics were used to present the results. Due to the limited sample size, formal group comparisons were not feasible.

RESULTS

In total, 31 patients were included: 15 consecutive patients with an undisplaced fracture of the femoral neck were treated with a DHS (n = 6) or a CS (n = 9), and 16 consecutive patients with a trochanteric fracture were treated with a DHS (n = 10) or a GN (n = 6) (Figure 4).

In those with an undisplaced fracture of the femoral neck, ten patients (3 DHS, 7 CS) had adequate RSA data for final analysis. Three (1 DHS and 2 CS) did not have sufficient markers to calculate rotation or shortening at the fracture site, mostly caused by absence of adequately positioned medial markers. Two patients (both DHS) only had post-operative RSA data and were lost to follow-up. Both withdrew from the study as they were unable to visit the hospital.

In those with a trochanteric fracture, seven (4 DHS, 3 GN) had adequate RSA data for analysis. In six patients, the markers in the fracture fragments were not sufficiently stable for the accurate analysis of migration (ME > 0.35 mm).[12] Two patients treated with a GN and one treated with a DHS had only one post-operative RSA examination and all three withdrew as they were unable to visit the hospital. The baseline characteristics of those with complete follow-up data are presented in Table 1.

In undisplaced fractures of the femoral neck, both CRy and Cy remain stable after an initial migration up to the four month follow-up. The mean CRy at four months was 5.5° (-3.6° to 14.0°). Although not statistically tested due to the small sample size, there did not seem to be obvious rotational differences between those treated with CS and DHS. A wide range of rotation, between -28.2° and 11.6° in the first four months (Table 2), was mainly caused by patient 6 (-28.2°) (Figure 5). This patient died six weeks post-operatively.

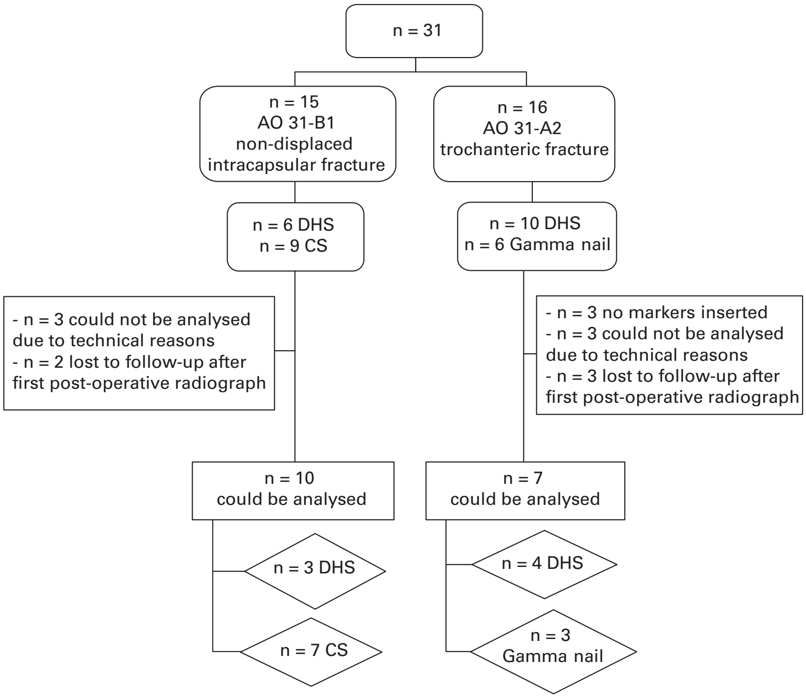


Figure 4

Overview of the included and analysed patients with proximal femoral hip fractures

Table 1

Patient characteristics

		Type of fracture	
		Femoral neck N=10	**Trochanteric N=7**
Mean age (range) in years		72 (62-88)	79 (63-92)
Sex (f/m)		6/4	5/2
Complications		1*	1**
Mortality		1	0
RSA radiographs			
	6 weeks	10	7
	4 months	7	4
	1 year	5	6

*delayed union and AVN reoperation after 6 months

**superficial wound infection

Table 2

Rotation and shortening This table presents the results of the rotation (CRy) and fracture shortening or collaps (Cy) as presented in Figure 3.

		Time	Time	Time
Parameter **Femoral neck fractures**		**6 weeks** **N=10**	**4 months** **N=7**	**1 year** **N=5**
Rotation (CRy)				
degree	Mean (S.D.)	0.1 (10.9)	5.5 (6.1)	3.4 (3.5)
	Minimum–maximum	-28.2 – 11.6	-3.6 – 14.0	-0.6 – 7.2
Shortening (Cy)				
mm	Mean (S.D.)	5.3 (4.5)	5.4 (5.8)	4.7 (3.4)
	Minimum–maximum	0.05 – 13.7	-0.04 – 16.1	0.8 – 7.7

		Time	Time	Time
Parameter Trochanteric fractures		**6 weeks** **N=7**	**4 months** **N=4**	**1 year** **N=6**
Rotation (CRy)				
degree	Mean (S.D.)	-4.7 (13.1)	-10.6 (15.8)	-6.6 (12.2)
	Minimum–maximum	-26.1 – 10.7	-28.1 – 6.1	-25.7 – 5.5
Shortening (Cy)				
mm	Mean (S.D.)	4.4 (3.9)	5.0 (6.0)	4.4 (5.0)
	Minimum–maximum	0.26 – 10.7	-0.13 – 12.9	-0.3 – 13.4

The mean shortening (Cy) in undisplaced fractures of the femoral neck at four months was 5.4 mm (-0.04 to 16.1). The mean rotation (Cry) in trochanteric fractures was 10.6° (-28.1° to 6.1°) at four months (Table 2). The mean shortening after four months was 5.0 mm (-0.13 to 12.9). Fractures treated with a DHS (n = 4) had a mean shortening 7.1 mm (4.6 to 10.7) after six weeks. Those treated with a GN (n = 3) had a mean shortening of 0.7 mm (0.3 to 1.3).

Figure 6a illustrates the migration profiles in trochanteric fractures; and there was a difference in rotational stability between right- and left-sided fractures (Figure 6b). For shortening in the fractures of the femoral neck, no differences between the sides were seen.

One patient (P1 in Figure 5) in the undisplaced fracture of the femoral neck group had delayed union and osteonecrosis (ON) of the femoral head that led to re-operation after 5.5 months. This patient had the most shortening compared with the other patients after both six weeks and four months and had rotation of the femoral head of > 10°

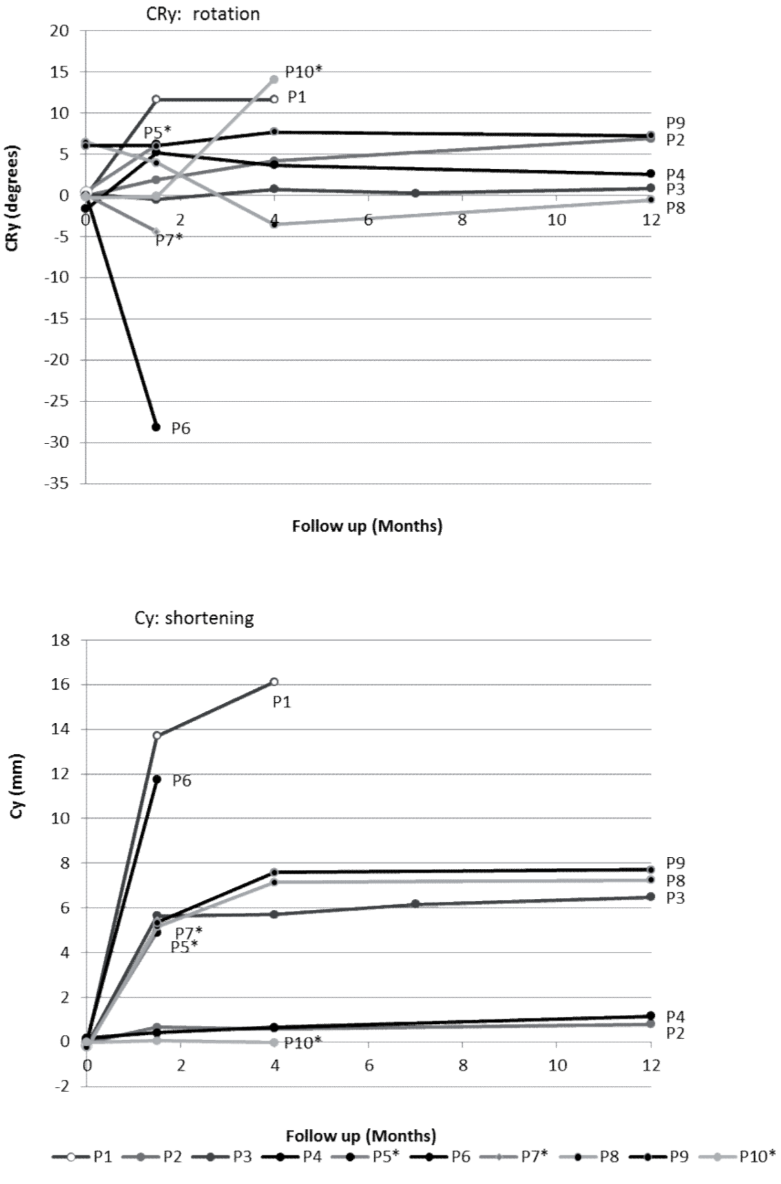


Figure 5

Graphs showing the migration profile of AO 31-B1 fractures of the femoral neck after fixation with cannulated screws or a dynamic hip screw. Treated with a DHS (*): P5, P7, P10. Treated with CS: P1, P2, P3, P4, P6, P8, P9. Patients P5, P6 and P7 only had two follow-up scans. P3 had one extra follow-up scan.

a

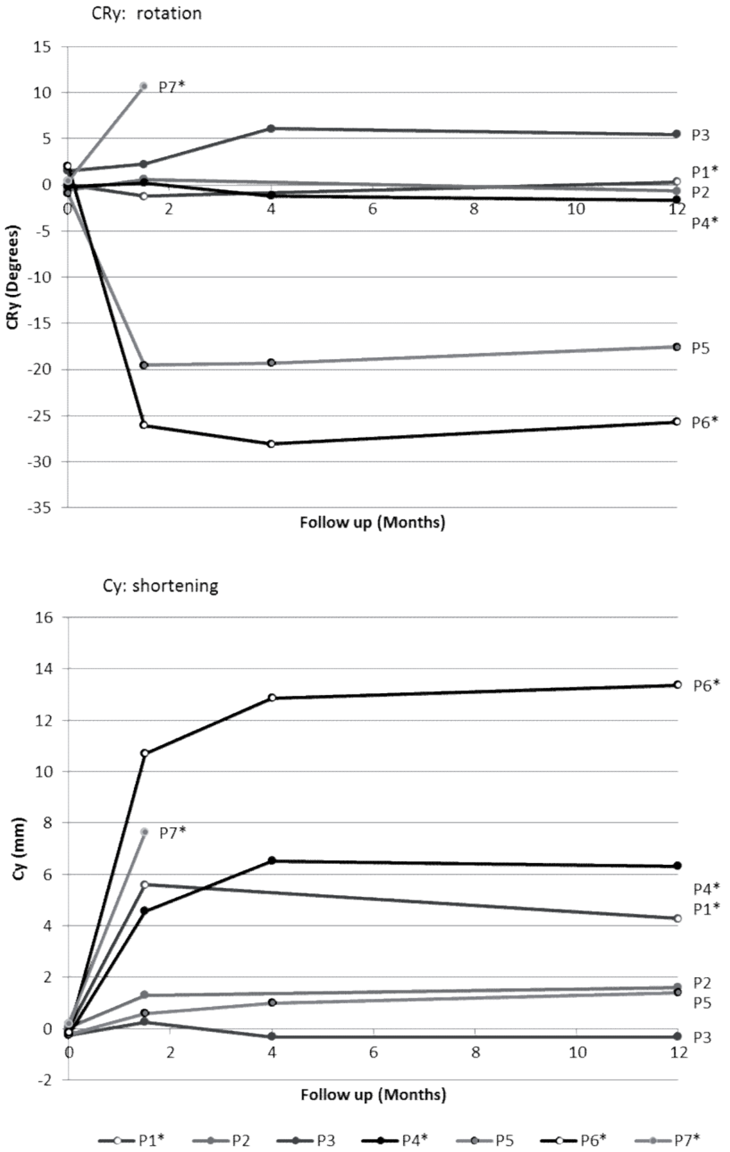
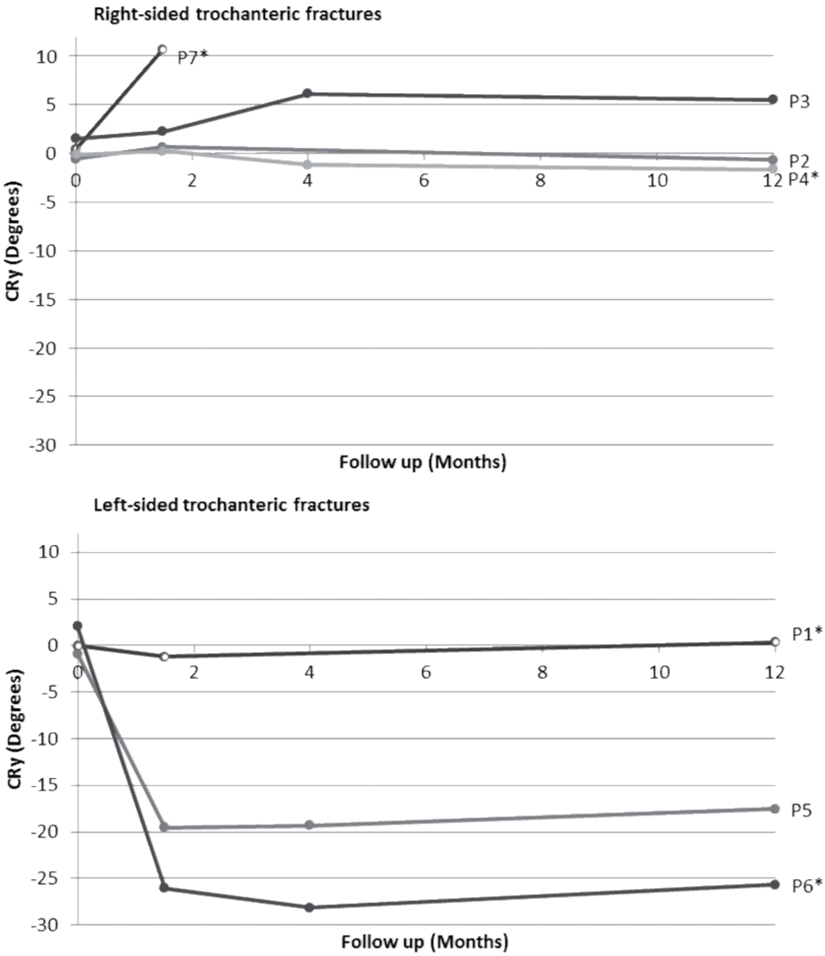


Figure 6[a] and Figure 6[b]

Graphs showing: a) the migration profile of AO 31-A2 trochanteric fracture after fracture fixation with DSH or Gamma Nail (GN). Treated with a DHS(*): P1, P4, P6 and P7. Treated with a GN: P2, P3 and P5. P7 only had two follow-up scans; and b) rotation of right-sided and left sided trochanteric fractures. Treated with a DHS (*): P1, P4, P6 and P7. Treated with a GN: P2, P3 and P5. P7 only had two follow-up scans.

b


Right-sided trochanteric fractures
10
5
0
-5
-10
-15
-20
-25
-30
0
2
4
6
8
10
12
P7*
P3
P2
P4*
CRy (Degrees)
Follow up (Months)
Left-sided trochanteric fractures
P1*
P5
P6*
CRy (Degrees)
Follow up (Months)

after six weeks. In another patient with a fracture of the femoral neck, it was suspected that two of the markers migrated into the articular cartilage of the hip but data from this patient could not be analysed for technical reasons. This patient had no symptoms related to this finding. In the trochanteric fracture group, one patient had a superficial wound infection. No other complications were encountered.

DISCUSSION

This is the first time that RSA migration profiles, including measurements of rotational stability and shortening, have been presented in patients with a fracture of the hip treated with the most commonly used modes of osteosynthesis. We found considerable rotational and axial instability in both undisplaced fractures of the femoral neck and AO-31 A2 trochanteric fractures treated in this way.

Our findings are relevant as rotation of the femoral head is believed to facilitate cut-out of the implant, as shown by Lustenberger et al.[11] Their assumption was supported by Baumgartner et al,[14] who showed the importance of optimal placement of the screw in the femoral head and emphasised the use of the tip-apex-distance (TAD). They showed that a TAD of > 20 mm to 25 mm predisposes to cut-out of the implant, which probably starts by rotation of the head around the screw.

The biomechanical aspects of rotational stability have been the subject of research and debate for many years, especially in patients with a trochanteric fracture.[8, 11] Two separate types of rotation may occur: rotation of the screw with the medial fragment in respect to the lateral fragment, or rotation of the medial fragment around the hip screw of the DHS or the GN. In this study, we could not differentiate between these types of rotation. However, both the DHS and the GN, together with many other implants, have some form of anti-rotational mechanism that prevents rotation of the screw in the implant. In these implants, only rotation of the medial fragment around the hip screw can occur. We may therefore provisionally deduce that rotation of the medial fragment in a 31-A2 trochanteric fracture as measured in our study results from rotation of the fragment around the hip screw. This highlights the importance of the use of hip screws designed to prevent the rotation. Additionally, the anti-rotational effect of cement augmentation could be considered.[15-17]

A remarkable finding in the results of this study was the difference in rotational stability of left and right-sided trochanteric fractures. No differences were found in the undisplaced fractures of the femoral neck as these were mainly treated with CSs. Mohan et al[18] described a higher rate of potentially unstable fixation in left-sided trochanteric fractures and explained this finding by the clockwise torque in the screw of the DHS. In unstable right sided-fractures the clockwise torque causes compression of the proximal fragment into the distal fragment. In left-sided fractures the buttress of the anterior spike (proximal fragment) does not occur, resulting in a potentially unstable fixation. Also, soft-tissue restraints such as the iliofemoral ligament will be tightened in right-sided trochanteric fractures due to the right-sided torque, which may result in increased tension of soft-tissue and subsequently less displacement of the fracture. Significantly higher complication rates of left-sided fractures have not been reported in clinical trials, therefore the extent of the relevance in daily clinical practice, is currently not known.

Shortening could be a sign of prolonged micromotion within a fracture, a first sign of nonunion or ON, or could be a predictor of cut-out of an implant.[19] The overall results of our study show a limited mean shortening (Table 2). (After four months: undisplaced fractures of the femoral neck 5.4 mm; -0.04 to 16.1 and trochanteric fractures 5.0 mm; -0.13 to 12.9). The only patient in this study suffering from delayed union and subsequent re-operation had a maximum shortening of 16 mm after four months, which was the highest value of all the patients. This patient also had a large amount of rotation compared with other patients. The other patient with a similar migration profile died six weeks post-operatively. Although no statistical conclusions can be drawn, it may be that a high migration profile in the first six to 16 weeks after fixation may indicate actual or future problems with the healing of the fracture.

For both migration parameters, shortening and rotation, a clear trend was displayed: regardless of the type of fracture or fixation, most migration happened within the first four months after operation, and primarily in the first six weeks. These results suggest that stabilisation of the fracture caused by consolidation starts after six weeks and will be completed for most patients within four months. Most fractures with uncomplicated healing show this same limited course of shortening and rotation. These findings are in-line with the assumption that continuous shortening after three months is a sign of nonunion.[19] Migration profiles, therefore, may help identify those at high risk for failure of fixation.

A study group has previously used RSA for the assessment of fractures of the hip, mainly displaced fracture of the femoral neck.[19-23] In one of their studies, three undisplaced fractures of the femoral neck were treated with two cannulated screws and, similar to our findings, limited rotation was seen.[20] Despite the fact that the older studies mainly concerned displaced fractures of the femoral neck treated with hook-pin fixation or two cannulated screws, the pattern of migration were similar to that illustrated in Figures 5 and 6, with signs of stabilisation of the fracture after three to four months.

The technique of RSA has evolved in the last 20 years as digital radiography and software improvements have led to more accurate calculation of rotational stability and results which are easier to interpret. In most previous studies, calculation of rotation was performed in the three orthogonal axes, which are difficult to interpret for clinical purposes,[19, 20] whereas the results of this study are expressed as translations and rota-

tions in an orthogonal axial system aligned with the longitudinal axis of the fixation device. Thus, these results can be interpreted as migration of the fracture with respect to the fixation device and other fracture fragments.
No double examinations were acquired to determine the precision of the RSA set-up in this study. The precision of the translational/rotational tracking of a tibial prosthesis using marker-based RSA measurements with the model-based RSA software and the same patient set-up in the same hospital was reported to be 0.083 mm for translations and < 0.25° for rotations.[24] The use of RSA in fractures is less accurate than in vitro measurements or when used for arthroplasties. In the study of Ragnarsson et al[20] regarding hip fractures, translations of 0.5 (X), 0.4 (Y) and 1 mm (Z) and rotation of 1.2°(X), 1.4° (Y) and 0.5° (Z) were considered significant.
The limitations of this study concern technical and logistical issues. We encountered some technical problems regarding the use of RSA in hip fracture surgery compared with its use in arthroplasty surgery: the implantation of markers in the different fracture fragments proved to be challenging due to limited access. Although RSA is a proven technique with high accuracy[25], the markers are less stable in fracture surgery. This may be due to the fact that it is more difficult to place the markers satisfactorily combined with micromotion of the fracture fragments and the low bone mineral density in the older patients who sustain these fractures. These problems resulted in fewer RSA acquisitions than anticipated being available for analysis. We also lost patients to follow-up, mostly because of the burden of their age, a well-known problem in studies of elderly patients with fractures of the hip. As many of these operations are undertaken as an emergency, some patients were not included due to unfamiliarity with placement of RSA markers. This is an extra challenge for RSA studies in fracture surgery compared with elective surgery. As a result the sample size of both groups was too small to draw statistical conclusions regarding migration profiles. Moreover, no reliable statements can be made concerning the different types of implant based on these data.
Despite these limitations, the data presented in this study are valuable for understanding the biomechanics of hip fracture surgery and will be helpful in the design of future studies, especially considering that these migration profiles concerned only stable fractures. More pronounced differences in migration will probably be found when studies compare unstable fractures. The results may be used to develop a predictive rule for poor outcome after surgery. For joint arthroplasty surgery, RSA studies have been performed successfully and will help to define quality rules for hip arthroplasty surgery in the future.

In conclusion, the RSA migration profiles showed that there is substantial translational instability in both un-displaced fractures of the femoral neck and AO-31 A2 trochanteric fractures treated with the most commonly used implants in the first four months after operation. Left-sided trochanteric fractures treated by DHS or intramedullary fixation, seem to be more rotationally unstable than right-sided fractures. Since rotation is most probably due to rotation of the medial fragment around the hip screw(s), systems which prevent rotation, or cement augmentation of the hip screw, may be valuable in elderly patients who sustain a fracture of the hip. Future research using RSA in patients who sustain a fracture of the hip may help develop risk profiles for adverse outcome and quality control to identify optimal reduction of the fracture and positioning of the implants.

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