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Original

Radiographic Analysis of Preoperative and Postoperative 3DCT Images of Trochanteric Femoral Fractures

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Abstract: The present study compared a 3-dimensional computed tomography (3DCT) classification (Nakano classification) with conventional x-ray classifications (Jensen classification and AO classification) in 44 patients with trochanteric femoral fractures, and evaluated the patterns of fracture lines using 3DCT images. The concordance rate between the Jensen and 3DCT classification, and between the AO and 3DCT classification was 65.9% and 75.0%, respectively. 3DCT scans enabled the creation of detailed images of fracture lines. The anterior fracture line was found to run along the intertrochanteric crest in 90.9% of patients, while the location of the posterior fracture line was in the same approximate position in all patients, including those with comminuted fractures (34.1%). Posterior destruction along lateral fracture lines was present in 63.6% of patients. Furthermore, the preoperative and postoperative CT images of 33 patients with fractures treated via insertion of short femoral nails demonstrated that there was difficulty reducing greater trochanteric fractures. This included reducing fracture sites separated by nail insertion (42.4%) and greater trochanteric fracture sites displaced after surgery (54.5%), suggesting that the use of short femoral nails is limited.

Key words: trochanteric femoral fracture, posterolateral fragment, 3DCT classification

Introduction

A wide variety of x-ray classification methods for trochanteric femoral fractures are available, including the Evans classification, Jensen classification (Fig. 1)[1], and AO classification (Fig. 2)[2]; however, gaining a clear understanding of the types of fractures is difficult with any of these methods. Recently, 3-dimensional computed tomography (3DCT) images have made it possible to gain a more detailed understanding of the types of fractures. The use of 3DCT images for trochanteric femoral fractures consisting of three major fracture lines (anterior, posterior, and lateral) was first reported by Konishi[3], who proposed an anatomical classification of 5 types, representing the range of contact between the proximal and distal fragments. Recently, Nakano[4] broadly divided trochanteric femoral fractures into two types: Type I, where the primary fracture line extends diagonally from the greater trochanter to the lesser trochanter; and Type II, where the primary fracture line extends from the lesser trochanter to the lateral diaphysis. Type I fractures

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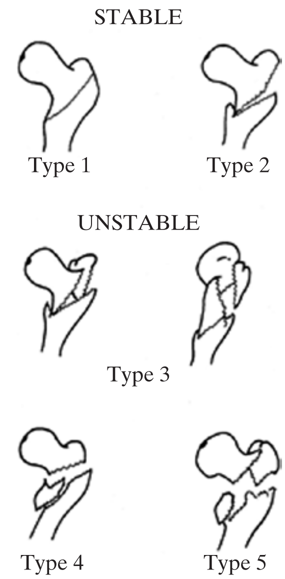

Type 1 : undisplaced 2-fragmentary fracture
Type 2 : displaced 2-fragmentary fracture
Type 3 : 3-fragmentary fracture without posterolateral support
Type 4 : 3-fragmentary fracture without medial support
Type 5 : 4-fragmentary fracture

Fig. 1. Jensen classification (X-ray).

31-A : Femur proximal, trochanteric area

A1 : Pertrochanteric simple
A1.1 : Along intertrochanteric line
A1.2 : Through the greater trochanter
A1.3 : Below lesser trochanter

A2 : Pertrochanteric multifragmentary
A2.1 : With 1 intermediated fragment
A2.2 : With several intermediated fragments
A2.3 : Extending more than 1 cm below lesser trochanter

A3 : Intertrochanteric
A3.1 : Simple oblique
A3.2 : Silmple transrerse
A3.3 : Multifragmentary

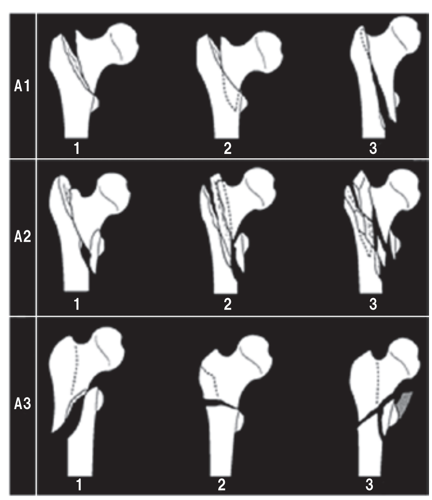

Fig. 2. AO classification (X-ray).

have been further subdivided into 10 types based on a 4-part theory, and this classification method has been widely used (Fig. 3). The present study compared this 3DCT classification (Nakano classification) with conventional x-ray classifications (Jensen classification and AO classification) in patients with trochanteric femoral fractures and evaluated the patterns of fracture lines using 3DCT images. Furthermore, the limitations of using short femoral nails (SFNs) are also discussed using preoperative and postoperative CT images of fractures treated via insertion of SFNs.

Patients and methods

Comparison of conventional x-ray classification and 3DCT classification

This study included 44 patients with trochanteric femoral fractures (12 males and 32 females) ;

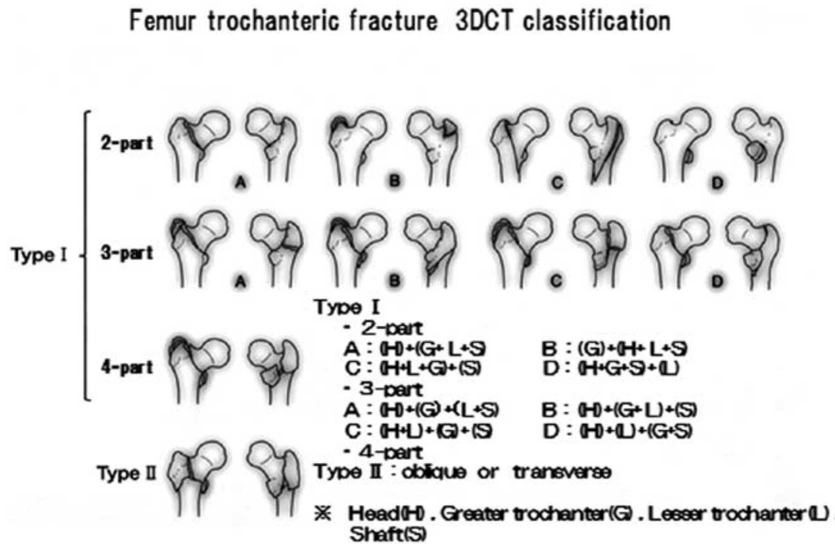

Fig. 3. 3-dimensional computed tomography (3DCT) classification.

the mean age at the time of injury was 82.8 years (range, 68 to 99 years). Falls were reported as the cause of injury in 42 patients, while the other 2 patients were involved in motor vehicle accidents. Using the Jensen classification, fractures were classified as Type 1 in 7 patients (15.9%), Type 2 in 9 patients (20.5%), Type 3 in 13 patients (29.5%), Type 4 in 8 patients (18.2%), and Type 5 in 7 patients (15.9%). Using the AO classification, 10 patients (22.7%) were classified with 31-A1.1 fractures, 3 patients (6.8%) with A1.2 fractures, 22 patients (50%) with A2.1 fractures, 3 patients (6.8%) with A2.2 fractures, and 6 patients (13.6%) with A2.3 fractures.

The 3DCT classification method revealed Type I, 2-part A fractures in 8 patients (18.2%), 2-part B in 1 patient (2.3%), 3-part A in 11 patients (25%), 3-part B in 6 patients (13.6%), 3-part C in 1 patient (2.3%), 3-part D in 1 patient (2.3%), 4-part in 15 patients (34.1%), and Type II in 1 patient (2.3%).

Preoperative and postoperative CT images before and after insertion of SFNs

Of these 44 patients, 33 patients underwent insertion of SFNs and were included in the second part of this study. This group consisted of 8 male and 25 female patients, with a mean age of 83.0 years (range, 68 to 99 years), and with Type I, 3-part (n = 18), Type I, 4-part (n = 14), and Type II (n = 1) fractures. The types of SFNs used were INTERTAN (22 patients), Multi fix (7 patients), and PFNA (4 patients). These patients underwent 3DCT three times (prior to surgery and on days 3 and 14 after surgery) to determine the anteroposterior diameter of the greater trochanter before and after surgery, the location of the lag screw tip in axial images, and the differences between the anteversion of the affected femur and the nail.

The Wilcoxon signed rank test was used to evaluate the increase in anteroposterior diameter of the greater trochanter prior to surgery (between the affected and unaffected side), and on

Table 1. Comparison of the Jensen classification with the 3-dimensional computed tomography (CT) classification

Jensen classification (n) \ CT classification	Type I 2-part	3-part	4-part	Type II	concordance rate
Type 1 (7)	5	2			71.4% (5 / 7)
Type 2 (9)	4	4		1	44.4% (4 / 9)
Type 3 (13)		10	3		76.9% (10 / 13)
Type 4 (8)		3	5		37.5% (3 / 8)
Type 5 (7)			7		100% (7 / 7)
					65.9% (29 / 44)

Values are number of patients, unless indicated otherwise

days 3 and 14 after surgery (on the affected side). To compare the increase in the diameter among the three groups (prior to surgery, day 3, and day 14), the Bonferroni correction was applied to the Wilcoxon test.

Results

Comparison of conventional x-ray classifications and 3DCT classification

A comparison of the Jensen classification versus the 3DCT classification showed a concordance rate of 71.4% (5 of 7) for Jensen Type 1 fractures, 44.4% (4 of 9) for Type 2 fractures, 76.9% (10 of 13) for Type 3 fractures, 37.5% (3 of 8) for Type 4 fractures, and 100% (7 of 7) for Type 5 fractures, with an overall mean concordance rate of 65.9% (29 of 44) (Table 1).

A comparison of the AO classification versus the 3DCT classification revealed a concordance rate of 80% (8 of 10) for AO 31-A1.1 fractures, 33.3% (1 of 3) for A1.2 fractures, 68.2% (15 of 22) for A2.1 fractures, 100% (3 of 3) for A2.2 fractures, and 100% (6 of 6) for A2.3 fractures, with an overall mean concordance rate of 75.0% (33 of 44) (Table 2).

Analyses of fracture lines using 3DCT images and the classification method proposed by Konishi showed that the anterior line ran along the intertrochanteric line at a concordance rate of 34.1% (15 of 44) for A1 fractures, 50.0% (22 of 44) for A2 fractures, 6.8% (3 of 44) for A3 fractures, 6.8% (3 of 44) for A4 fractures, and 2.3% (1 of 44) for A5 fractures. This indicates that the combined concordance rate of 90.9% for A1, A2, and A3 fractures, which have simple fracture lines, was higher than the rate for A4 and A5 fractures, which have multiple fracture lines. The location of the posterior fracture line was in the same approximate position in almost all patients, with 65.9% of patients (29 of 44) having a P1 fracture (without comminution) and 34.1% (15 of 44) having a P2 fracture (with comminution). The lateral

Table 2. Comparison of the AO classification with the 3-dimensional computed tomography (CT) classification

AO classification (n) \ CT classification	Type Ⅰ 2-part	3-part	4-part	Type Ⅱ	concordance rate
A1.1 (10)	8	2			80% (8 / 10)
A1.2 (3)	1	2			33.3% (1 / 3)
A2.1 (22)		15	6	1	68.2% (15 / 22)
A2.2 (3)			3		100% (3 / 3)
A2.3 (6)			6		100% (6 / 6)
					75.0% (33 / 44)

Values are number of patients, unless indicated otherwise

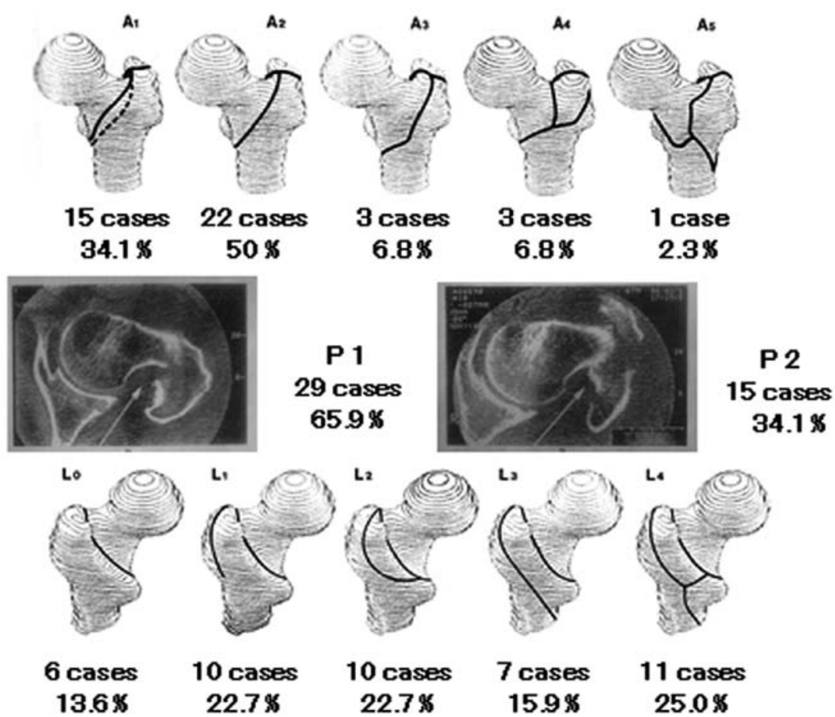

Fig. 4. Details of anterior, posterior, and lateral fracture lines.

fracture line was located at L0 in 13.6% of patients (6 of 44), at L1 in 22.7% (10 of 44), at L2 in 22.7% (10 of 44), at L3 in 15.9% (7 of 44), and at L4 in 25.0% of patients (11 of 44). Posterior fragment formation along the lateral fracture line was observed in 63.6% of patients (Fig. 4).

Fig. 5. Case 1 : 68-year-old female. X-ray classification : Jensen Type 3 ; AO 31 A2.1. 3-dimensional computed tomography classification : Type I, 4-part. Fracture lines : anterior fracture line at A2 ; posterior fracture line at P1 ; lateral fracture line at L4.

Cases

Case 1 : A 68-year-old female sustained a right trochanteric femoral fracture. Radiographs revealed a Jensen Type 3 and AO 31-A2.1 fracture. 3DCT classification showed a Type I, 4-part fracture with the anterior fracture line at A2, posterior fracture line at P1, and lateral fracture line at L4 (Fig. 5).

Case 2 : An 86-year-old female sustained a left trochanteric femoral fracture. Radiographs revealed a Jensen Type 4 and AO 31-A2.3 fracture. 3DCT classification showed a Type I, 4-part fracture with the anterior fracture line at A3, posterior fracture line at P2, and lateral fracture line at L4 (Fig. 6).

Preoperative and postoperative CT images before and after insertion of SFNs

The mean anteroposterior diameter of the greater trochanter prior to surgery was 52.1 mm on the affected side and 41.7 mm on the unaffected side of patients with 3-part fractures ($P<0.01$), 52.4 mm on the affected side and 41.5 mm on the unaffected side of patients with 4-part fractures ($P<0.01$), and 46.9 mm on the affected side and 36.6 mm on the unaffected side of

Fig. 6. Case 2: 86-year-old female. X-ray classification: Jensen Type 4; AO 31 A2.3. 3-dimensional computed tomography classification: Type I, 4-part. Fracture lines: anterior fracture line at A3; posterior fracture line at P2; lateral fracture line at L4.

Table 3. Anteroposterior diameter of the greater trochanter before and after surgery (affected side and unaffected side)

	affected side			unaffected side		
	Pre-op	Post-op ①	Post-op ②	Pre-op	Post-op ①	Post-op ②
overall rate	52.1	51.3	51.9	41.7	41.8	41.7
3-part	52.1	52.0	52.3	41.7	41.9	41.6
4-part	52.4	51.0	51.8	42.0	42.0	42.1
Type II	46.9	43.0	44.0	36.6	36.6	36.6

Values are mm.
Post-op ①: 3 days after surgery; Post-op ②: 14 days after surgery.

patients with Type II fractures ($P<0.01$). These results indicate a significant increase in the diameter of the affected side compared to the diameter of the unaffected side, irrespective of fracture type, with an overall mean diameter of 52.1 mm for the affected side and 41.7 mm for the unaffected side. The anteroposterior diameter of the greater trochanter remained almost the same on CTs performed on days 3 and 14 after surgery compared with prior to surgery ($P>0.05$), and the diameter of the affected side was greater than that of the unaffected side (Table 3). Additionally, the differences in the diameters of the affected side in each case were analyzed. On day 3 after the surgery, the anteroposterior diameter of the greater trochanter

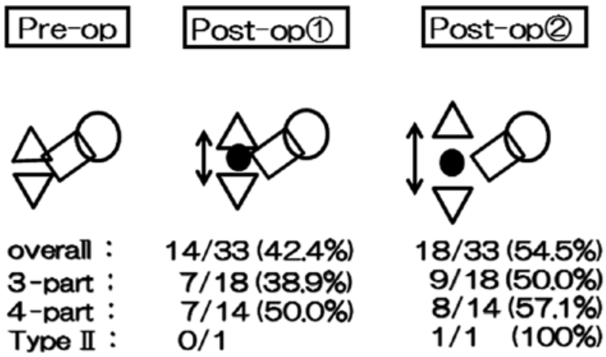

Fig. 7. Increase in the anteroposterior diameter of the greater trochanter after surgery (affected side). Pre-op, before surgery; Post-op ①, 3 days after surgery; Post-op ②, 14 days after surgery.

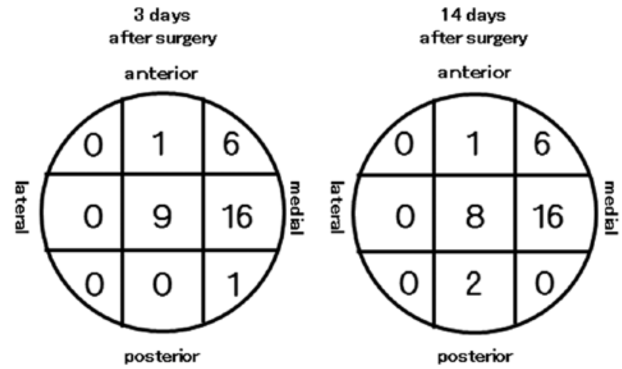

Fig. 8. Position of lag screw tip (axial view).

was found to have increased on CT images in 38.9% (7 of 18) of patients with 3-part fractures and in 50.0% (7 of 14) of those with 4-part fractures. Overall, the diameter increased after surgery in 42.4% (14 of 33) of patients. On day 14 after the surgery, the diameter was found to have further increased on CT images in 50.0% (9 of 18) of patients with 3-part fractures, 57.1% (8 of 14) with 4-part fractures, and in 100% (1 of 1) with Type II fractures. Overall, the diameter further increased in 54.5% (18 of 33) of patients (3-part, $P>0.05$; 4-part, $P<0.05$), demonstrating increases in the anteroposterior diameter of the greater trochanter corresponding to the degree of instability (Fig. 7).

On axial images, the lag screw tip was most often found to be located in the medial center (48.5%, 16 of 33) or the anterior center (27.3%, 9 of 33), with almost no changes observed on CT images taken on day 14 after surgery (Fig. 8).

On CT images taken on day 3 after surgery, the difference between the anteversion of the affected femur and the nail was 12.1° in patients with 3-part fractures, 5.7° in patients with 4-part fractures, and 8° in patients with Type II fractures. This changed to 10.9° in patients with 3-part fractures, 3.1° in patients with 4-part fractures, and 4° in patients with Type II fractures by day 14 after surgery. The overall mean differences were 9.3° and 7.4° on CT images taken on days 3 and 14, respectively, demonstrating that the nail was inserted from the posterior side.

Cases

Case 3: A 92-year-old female sustained a right trochanteric femoral fracture. Radiographs revealed a Jensen Type 5 and AO 31-A2.2 fracture. 3DCT classification showed a Type I, 4-part fracture with the anterior fracture line at A4, posterior fracture line at P2, and lateral fracture line at L4 (Fig. 9). She underwent open reduction and internal fixation using an SFN (Fig. 10). The anteroposterior diameter of the greater trochanter was 58.5 mm on the affected side and 42.4 mm on the unaffected side on postoperative day 3 CT scans, with similar values observed on postoperative day 14 CT scans (58.6 mm on affected side, 42.4 mm on unaffected side; Fig. 11).

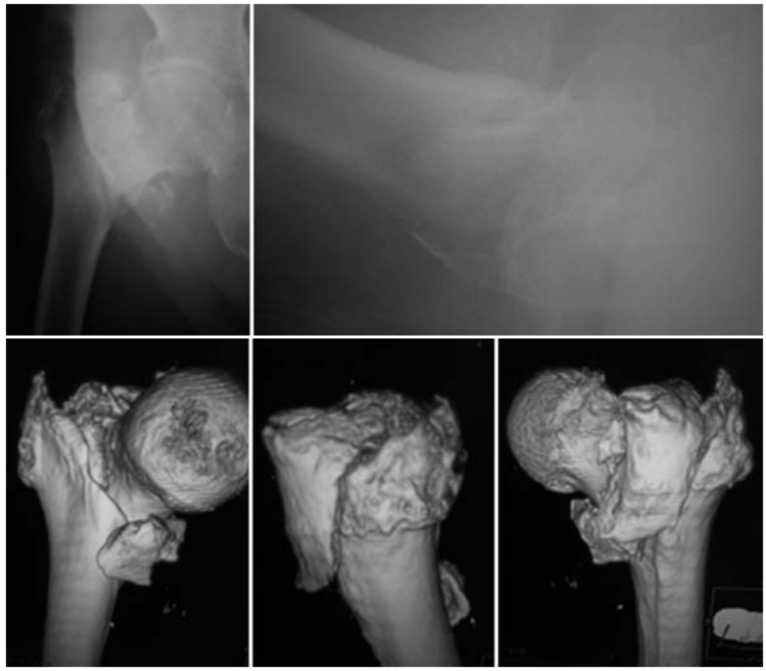

Fig. 9. Case 3 : 92-year-old female. X-ray classification : Jensen Type 5 ; AO 31 A2.2. 3-dimensional computed tomography classification : Type I, 4-part. Fracture lines : anterior fracture line at A4 ; posterior fracture line at P2 ; lateral fracture line at L4.

Discussion

Radiographic analysis of fracture types using 3DCT

Several authors have reported that using 3DCT for patients with trochanteric femoral fractures allows surgeons to create more accurate fracture images, thereby contributing to a better understanding of the fracture type, unlike conventional x-ray classifications that exhibit limitations. Ochi *et al*[5] compared the Jensen classification with the 3DCT classification, in terms of fracture type, in 93 patients and reported that the concordance rate was 53.6% in patients with Jensen Type 1 and Type 2 fractures, 79.3% in patients with Type 3 fractures, 11.8% in patients with Type 4 fractures, and 68.4% in patients with Type 5 fractures, with an overall concordance rate of 57.0%. Uehara *et al*[6] evaluated 110 patients with trochanteric femoral fractures and reported that there were substantial differences between conventional x-ray and CT images ; in particular, patients classified as having 2-part fractures using conventional x-rays often had 3-part fractures with displaced fragments of varying sizes on the posterior side. In the present study, the concordance rate between the Jensen and 3DCT classification was 65.9%, while the concordance rate between the AO and 3DCT classification was 75.0%. Since it is often difficult to identify posterior fragments on conventional x-rays, there are limitations in accurately gaining an understanding of fracture types using conventional x-rays.

According to the detailed report on the fracture lines of trochanteric femoral fractures by

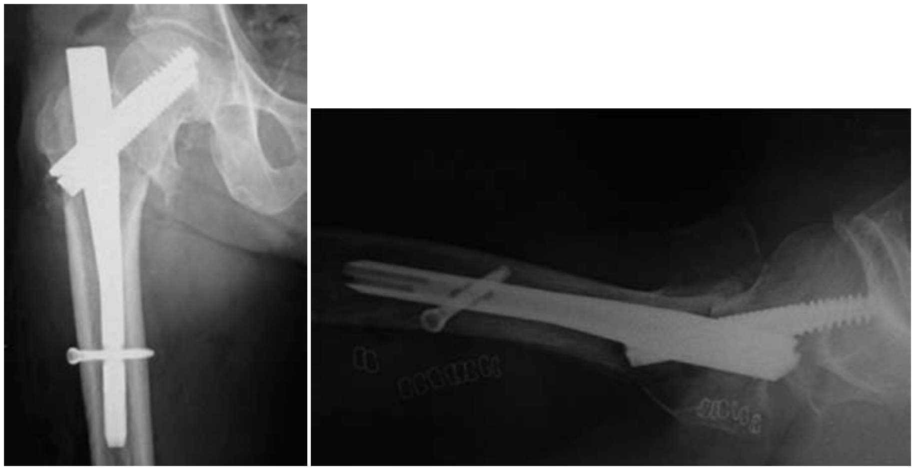

Fig. 10. Case 3 : postoperative radiographs showing the result of open reduction and internal fixation using a short femoral nail.

Konishi[3], a trochanteric femoral fracture consists of three major fracture lines (anterior, posterior, and lateral). The posterior fracture line extends along the shape of the concavity extending from the trochanteric fossa to the lower posterior area, with posterior destruction along the lateral fracture line occurring at a high frequency. In our study, A1, A2, and A3 fractures, where the anterior fracture line runs along the intertrochanteric line, accounted for 90.9% of all the fractures. Our study also showed that the incidence of comminuted fractures was 34.1% in patients with posterior fracture lines, and the incidence of L2, L3, and L4 fractures, where posterior fragments were formed along lateral fracture lines, was 63.6%. Thus, the patterns of fracture lines found in our study were similar to those reported by Konishi, demonstrating a certain tendency for trochanteric femoral fractures to occur along these fracture lines.

Limitations of SFNs for trochanteric femoral fractures

Unstable trochanteric femoral fractures have been variously defined as fractures that have lost posterolateral or medial support[1], fractures with comminuted posterior walls in the greater trochanter[7], fractures with large lesser trochanter fragments[7], or fractures with medial fragments and large posterior fragments[8]. Yamazaki *et al*[9] assessed trochanteric femoral fractures in 37 patients using CT imaging and reported that rotational deformity is more likely to occur after surgery if the greater and lesser trochanters are displaced from the proximal and distal fragments and there is a posterior wall fragment. Tokunaga *et al*[10] compared 47 patients with stable fractures with 44 patients with fractures with posterolateral defects and reported that the degree of sliding was significantly greater in patients with posterolateral defects, which led to an increased risk of delayed healing or cut out. Thus, it has been suggested that not only the medial cortex, which includes the lesser trochanter, but also the posterolateral fragment, which includes the greater trochanter, may contribute to postoperative instability.

The use of SFNs is currently recommended for the treatment of unstable trochanteric femoral

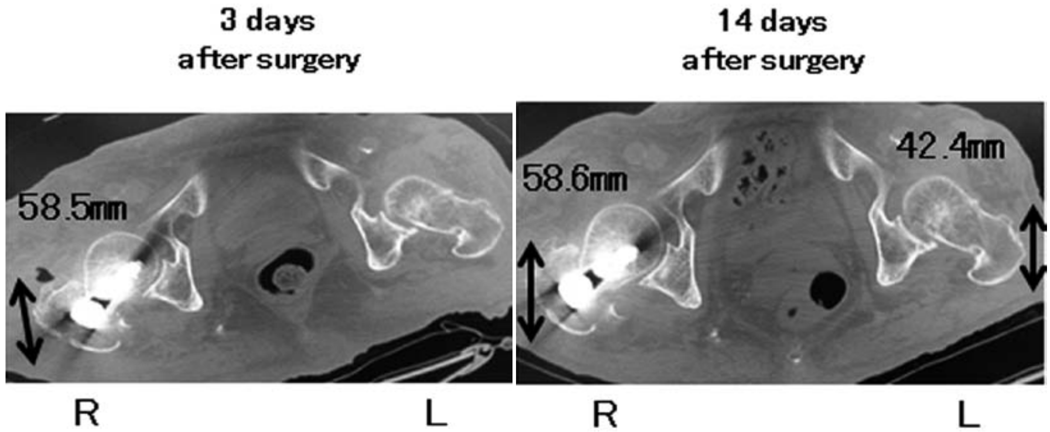

Fig. 11. Case 3: postoperative day 3 computed tomography (CT) image (left panel) showing an anteroposterior diameter of the greater trochanter of 58.5 mm (affected side) and 42.4 mm (unaffected side). Postoperative day 14 CT image (right panel) showing an anteroposterior diameter of the greater trochanter of 58.6 mm (affected side) and 42.4 mm (unaffected side).

fractures. For this treatment, the anteromedial cortex is overlapped, creating an extramedullary type of fixation, to establish bony contact of primary fragments. In this instance, however, the third fragment in the posterior side, which may contribute to postoperative instability, is not fixed. Shoda[11] reported that nails are inserted through the fracture site if the fragment is severely displaced to the posterior side in cases where the greater and lesser trochanters are combined together along with large fragments. The report also states that, for 3-part fractures, the greater trochanter extends anteroposteriorly after the nail is inserted, since it cannot be fixed and there is no posterior support. In the present study, larger increases in the anteroposterior diameter of the greater trochanter on the affected side were observed compared to the unaffected side, both before and after surgery, indicating that reduction of greater trochanteric fractures was not achieved. The anteroposterior diameter of the greater trochanter on the affected side increased after surgery in 42.4% of patients (14 of 33), indicating dehiscence at the fracture site due to nail insertion. On the second CT performed, the anteroposterior diameter of the greater trochanter on the affected side increased in 54.5% of patients (18 of 33), indicating displacement at the site of the greater trochanteric fracture after surgery. The study also showed that the lag screw tip was most frequently located in the medial and anterior center, indicating that the nail was inserted from the posterior side of the greater trochanter, since greater nail anteversion was observed, compared to the affected femur. Thus, the use of SFNs for the treatment of unstable trochanteric femoral fractures is limited, necessitating a review of current treatments rather than selecting SFN insertion for all patients with unstable fractures. The authors currently treat patients with unstable trochanteric femoral fractures by establishing bony contact for the medial cortex of the main fragments and aggressively fixing the third fragment on the posterior side, as both these factors are considered to contribute to postoperative instability. Surgery using a combination of sliding hip screws and trochanteric plates or surgery with SFNs combined with cannulated screws are selected on a case-by-case basis, according to the condition of each patient.

In conclusion, when fracture lines of trochanteric femoral fractures were evaluated using 3DCT images, and CT images of fractures before and after insertion of SFNs were compared, the concordance rate between the Jensen classification and the 3DCT classification, and between the AO classification and the 3DCT classification was 65.9% and 75.0%, respectively. 3DCT scans facilitated the creation of detailed images of fracture lines. The anterior fracture line ran along the intertrochanteric line in 90.9% of patients, and the location of the posterior fracture line was in approximately the same position in almost all patients. Comminuted fractures were observed in 34.1% of patients, and posterior destruction along lateral fracture lines was present in 63.6% of patients. As a result, a comparison of CT images before and after insertion of SFNs revealed that reduction of greater trochanteric fractures, including fracture sites separated by nail insertion (42.4%) and greater trochanteric fracture sites displaced after surgery (54.5%), is difficult, suggesting that the use of SFNs is limited.

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