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ORIGINAL ARTICLE

Rotational malalignment after closed intramedullary nailing of femoral shaft fractures and its influence on daily life

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Abstract
Background Any intraoperative rotational malalignment during intramedullary nailing (IMN) of femoral shaft fractures will become permanent. We hypothesized that rotational malalignment of the femur and its compensatory biomechanics may induce problems in the hip, knee, patellofemoral and ankle joints. We purposed to clarify the influence of a femoral rotational malalignment of ≥10° on daily activities.
Methods Twenty-four femoral shaft fracture patients treated with closed antegrade IMN were included. At last follow-up, to reveal any rotational malalignment, computerized tomography (CT) scans of both femurs (injured and uninjured sides) were examined. The patient groups with or without CT-detected true rotational malalignment ≥10° were compared with respect to the activity scores.
Results Ten of the 24 patients (41.7 %) had a CT-detected true rotational malalignment of ≥10° compared with the unaffected side. The AOFAS scores were 100.00 for all of the patients. LKS, WOMAC knee, and WOMAC hip scores were significantly decreased in the patients with rotational malalignment compared to those without. Patients without rotational malalignment tolerated climbing stairs significantly better than those with rotational malalignment. Patients who could not tolerate climbing stairs were consistently complaining of anterior knee pain.
Conclusions A femoral rotational malalignment of ≥10° is symptomatic for the patients, and the hip, knee, and patellofemoral joints were affected. Because of the possibly altered joint loadings and biomechanics, these could render patients prone to degenerative joint disease. In addition, due to the high rates of rotational malalignment after femoral shaft fracture and consequent malpractice claims, it is important for surgeons to be more aware of rotational alignment during surgery.

Keywords Femoral shaft fracture · Closed intramedullary nailing · Femoral rotational malalignment · Patellofemoral joint

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Background

Intramedullary nailing (IMN) is the gold standard for the treatment of femoral shaft fractures in adults [1]. Closed IMN is favored because the fracture is not exposed and is stabilized by a load-sharing device; and the patient can be mobilized rapidly with a high union rate [2, 3]. However, because of the closed approach of IMN, intraoperative rotational control of the femur is a technically demanding procedure [1, 4]. Any intraoperative rotational malalignment will become permanent [1, 2, 4].

Rotational deformity after locked IMN is the most common form of malunion [1, 2, 5–9]. But, there appears to be little consensus on what represents a symptomatic rotational malalignment of the femoral shaft. Generally, torsional differences <10° are considered normal variations and >15° are considered as true torsional deformity [5, 7, 8]. Rotational malalignment between 10° and 14° is the controversial zone, as a symptom-free possible deformity or a symptomatic true deformity [7, 8]. In a very recent study, it was emphasized that >10° of external rotation deformity is related with patellofemoral joint symptoms [10]. The symptoms may occur during demanding activities, such as climbing stairs, running, and participating in sports. Patients tend to compensate for rotational malalignment by rotating their ipsilateral lower extremity to lessen their physical complaints [6].

We hypothesized that rotational malalignment of the femur and its compensatory biomechanics may induce problems in the hip, knee, patellofemoral and ankle joints, affecting daily life. Therefore, the aim of this study was to clarify the influence of a femoral rotational malalignment of ≥10° on daily activities.

Methods

This study was approved by Istanbul University, Cerrahpasa Faculty of Medicine ethics committee. Between 2001 and 2007, 66 femoral shaft fracture patients were treated using IMN at our institute. Patients with bilateral femoral shaft fractures (4), ipsilateral femur and tibia fractures (4), multiple sclerosis (2), polio sequelae (2), and patients who were operated with open reduction and IMN (10) or retrograde IMN (4) were excluded. Four patients with previous knee arthroscopy were also excluded, which may have affected the functional scores. The inclusion criteria were as follows: solid union of the fracture, being previously ambulatory with no systemic disease, and with no previous lower extremity surgery. In total, 36 patients were suitable for the study. However, we were unable to make contact with eight patients and four were unwilling to take part. Finally, 24 femoral shaft fracture patients treated with closed antegrade IMN were included in this retrospective comparative study. Informed consent was obtained from these patients.

The patients' preoperative femoral X-rays were divided into three equilength sections. The location of the major part of the fracture was the determining factor as to whether a fracture was proximal shaft, midshaft, or distal shaft. The effect of fracture location on the rotational malalignment was assessed.

During surgery, the patients lay supine on the fracture table. The anterior superior iliac spine and the midpoints of the knee and ankle joints were in the same axis and parallel to the floor. All patients were operated on using a locking AO antegrade femoral nail by one of the authors. The shape of the ipsilateral lesser trochanter was used to align the fracture. The postoperative rehabilitation protocol was same for all of the patients. The hip, knee, and ankle range of motion exercises were started at postoperative day one.

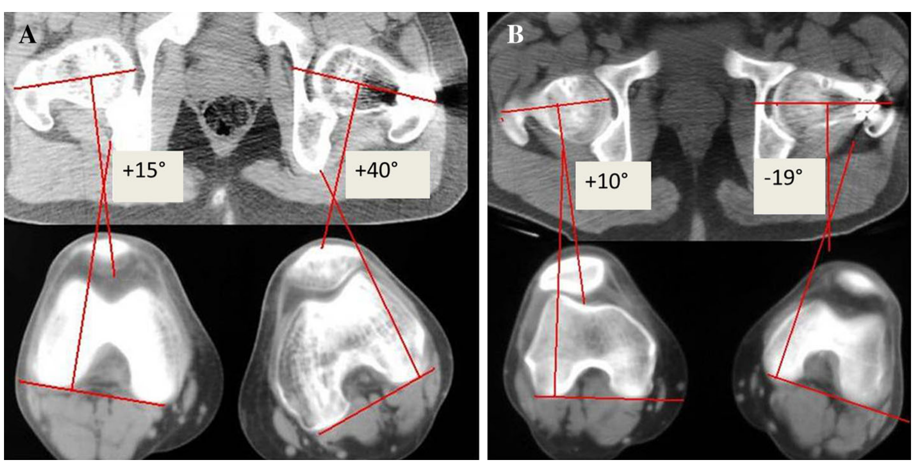

Fig. 1 Femoral rotational malalignment is determined by the method described by Jeanmart et al. [11]. Femoral torsion is determined by the angle between a *line* drawn along the posterior border of the femoral condyles and a *line* drawn through the femoral neck. Rotational malalignment is calculated by the angular difference between the fractured and unaffected side. A decrease in angle of the fractured side means increased external rotation of the distal fragment. An increase in this angle means an increased internal rotation of the distal femoral fragment. **a**. On the injured left side, there is a difference in rotation angle of 25° (internal rotational malalignment of $40° - 15° = 25°$). **b**. On the injured left side, there is a difference in rotation angle of 29° (external rotational malalignment of $-19° - 10° = -29°$)

Partial weight bearing with crutches was allowed at postoperative week six. Full weight bearing was allowed after the radiographic fracture union was observed.

At the final follow-up, to determine length discrepancy, the anterior superior iliac spine-medial malleolus and the umbilicus-medial malleolus length were measured and lower extremity anteroposterior orthoroentgenograms were obtained. To reveal any rotational malalignment of the femur, a computerized tomography (CT) scan was performed. The patient lay in the supine position during CT scanning, and the lower extremities were stabilized using a radiolucent strap around the ankles while the hallux pointed toward the ceiling. The rotational alignment was determined according to Jeanmart et al. [11] (Fig. 1). All CT images were measured by both a radiologist and an orthopedic surgeon to exclude any inaccuracy. Rotational malalignment was determined from the difference in the torsion angle between the injured and uninjured sides. Patients with a difference in the torsion angle $\geq 10°$ were considered to have a true rotational malalignment.

The patient groups with or without CT-detected true rotational malalignment were compared with respect to the Lysholm knee scale (LKS) score, the Western Ontario and McMaster University Osteoarthritis Index (WOMAC) knee score, the WOMAC hip score, and the American Orthopedic Foot and Ankle Society (AOFAS) score. The questionnaires showed that the primary complaint of patients was knee pain during climbing stairs. Therefore, the patients were asked a closed-end question (e.g., "yes" or "no") as to whether they experienced knee pain during climbing stairs.

Statistical analysis

The data were analyzed using the Statistical Package for the Social Sciences for Windows version 15.0 software. The unpaired Student's t test was used to assess differences between the groups (Table 2), the Fisher's exact test was used to analyze the significance of association between the variables (Table 3), and Pearson's method was used for correlation analysis (Table 1). $p \leq 0.05$ was defined as significant for all tests.

Results

There were 18 male (75 %) and six female (25 %) patients with an average age at surgery of 36 years (range 18–50 years). The mean follow-up was 50.5 months (range 14–90 months). A solid union was achieved in all of the fractures.

Four patients had a mean length discrepancy of the lower extremities of 1.37 cm (range 1–2 cm). In total, 10 of the 24 patients (41.7 %) had a CT-detected true rotational malalignment of $\geq 10°$ (range 10–25) compared to the unaffected side, seven patients had an external rotation deformity, and three patients had an internal rotation deformity.

The patients exhibited five proximal shaft, twelve midshaft, and seven distal shaft fractures. The incidence of torsional deformity was independent of fracture location ($p = 0.6232$) (Table 1).

The AOFAS scores were 100.00 for all of the patients. LKS ($p < 0.0001$), WOMAC knee ($p < 0.0001$), and WOMAC hip ($p = 0.0044$) scores were significantly decreased in the patients with rotational malalignment compared to those without (Table 2). There were no significant differences in regard to mean age ($p = 0.9219$) and mean follow-up ($p = 0.8411$) of patients between these groups. Patients without rotational malalignment tolerated climbing stairs significantly better than those with rotational malalignment ($p = 0.0005$) (Table 3). Patients who could not tolerate climbing stairs were consistently complaining of anterior knee pain.

Discussion

The determination of rotation during closed femoral IMN can be difficult, and intraoperative rotational malalignment can be symptomatic throughout life [1, 2, 7, 8]. This study

Table 1 Rotational deformity versus location of the fracture

Localization	Rotation <10°	Rotation ≥10°	Total
Proximal shaft	2	3	5
Midshaft	8	4	12
Distal shaft	4	3	7

$p = 0.6232$

Table 2 Rotational malalignment versus function

	Age	Follow-up	Lysholm	WOMAC knee	WOMAC hip
Rotational malalignment <10°	35.78 ± 13.70	51.31 ± 19.00	99.35 ± 1.64	93.85 ± 0.26	99.83 ± 0.45
Rotational malalignment ≥10°	36.40 ± 16.60	49.48 ± 25.36	95.20 ± 2.25	92.70 ± 0.70	98.59 ± 1.37
p value	0.9219	0.8411	<0.0001	<0.0001	0.0044

Table 3 Climbing stairs tolerance (anterior knee pain)

	Can tolerate (%)	Cannot tolerate (%)	
Rotational malalignment <10°	13 (92.9)	1 (7.1)	$p = 0.0005$
Rotational malalignment ≥10°	2 (20.0)	8 (80.0)	

supports that a rotational malalignment of the femur of ≥10° was symptomatic for the patient and the hip, knee, and patellofemoral joints were affected. Anterior knee pain with stair climbing was the predominant complaint of patients with rotational malalignment.

We found that 41.7 % of the patients displayed a femoral rotational malalignment of ≥10°. Similar high rates of rotational malalignment were found in studies using ultrasound or CT [7, 8]. Bråten et al. [7] reported a femoral rotational malalignment of ≥10° in 42.7 % of their 110 patients, and Jaarsma et al. [8] reported this malalignment in 55 % of their series. LKS, WOMAC knee, and WOMAC hip scores were decreased significantly in patients with rotational malalignment compared to those without. Similarly, many authors have reported that rotational deformities occur frequently and are problematic [1, 2, 7, 8, 10]. Jaarsma et al. [8] reported that patients complained mostly about demanding activities, including climbing stairs, running, and taking part in sports. In a very recent study, Yildirim et al. [10] concluded that patellofemoral malalignment following closed IMN could cause pain and decreased patellofemoral scores, even in ranges accepted as tolerable. Similarly, our patients were consistently complaining of anterior knee pain while climbing stairs. Repetitive patellofemoral joint activity is likely to be painful for these patients during such demanding activities. A possible mechanism for these complaints may be the imbalance of the patellofemoral mediolateral force caused by a torsional deformity of the femur [12]. Consequently, the patellofemoral contact pressure will be increased, reflected in abnormally high stresses on the articular surface of the patellofemoral joint. This scenario may lead to chondromalacia and arthrosis.

Lee et al. [12] reported the influence of fixed rotational deformities of the femur on the patellofemoral contact pressures. They showed in an in vitro study with seven human cadaver knees that an external rotation deformity of the femur for all knee flexion angles had significantly higher peak patellofemoral contact pressure increases on the medial facet of the patella compared to the lateral patellofemoral contact pressure increase resulting from an internal rotational deformity of the femur. Supporting this, in a recent study, the external rotational malalignment of >10° led to a significant medial tilt at the patellofemoral joint when compared with the contralateral normal knee [10]. Because of the small number of patients (seven external malrotation and three internal malrotation patients), we could not perform a comparison to determine whether there was a relationship between the malrotation direction (internal or external) and patient complaints. The relationship between the malrotation direction (internal or external) and patient complaints may be of interest with a larger cohort.

In this study, the patients with rotational malalignment were also suffering of hip pain with worse WOMAC hip scores. Rotational deformities restrict activities, especially those requiring demanding activities like climbing stairs, running, and sports [8, 10]. Rotational malalignment is also a well-known risk factor for osteoarthritis [13–15]. Eckhoff [15] reported that rotational malalignment altered the pressure distribution in an otherwise normal joint and caused degenerative joint disease. We think that the altered joint loading may be the cause of patient complaints during demanding activities.

Rotational malalignment occurs during IMN due to inadequate fracture reduction. Generally, the lesser trochanter is used as an anatomical landmark to avoid rotational malalignment [4]. To minimize rotational malalignment, Kim et al. [16] suggested considering the shape of the contralateral lesser trochanter as a reference for the lesser trochanter of the fractured femur using a C-arm image intensifier. Jaarsma et al. [17] reported in a more recent in vitro cadaver study that looking at the profile of the lesser trochanter alone on the injured side was an inaccurate method that results in a rotational malalignment of up to 19°. Similar to Kim et al. [16], they suggested using the profile of the contralateral lesser trochanter as a reference and found differences of only up to 4°. Although we have not used this method, it may facilitate avoidance of rotational malalignment. Moreover, computer navigation systems had offered a hopeful method to assess rotation intraoperatively [18]. In the future, computer navigation systems may regularly be used to decrease the high incidence of femoral rotational malalignment following closed IMN of femoral shaft fractures.

We found that femoral rotational malalignment had no effect on foot and ankle functions; the AOFAS scores of all patients were perfect. We could not find any data on AOFAS scoring for patients with femoral rotational malalignment in the literature. We suggest that foot and ankle biomechanics in patients with femoral rotational malalignment may be of interest for future investigations.

Thoresen et al. [19] reported a higher frequency of rotational malalignment in distal femoral shaft fractures. In contrast, we found that torsional deformities were independent of the fracture location, similar to Jaarsma et al. [8]. Jaarsma et al. assumed that the muscle actions on both the proximal femoral fracture (e.g., the abductors and external rotators) and distal femoral fracture (e.g., the plantaris and gastrocnemius) could affect the amount or direction of the malalignment. However, this theory was not supported by their results [8].

It has been reported that limb length discrepancies of up to 2 cm can be easily tolerated or even go unnoticed by the patients [20]. Because none of our patients exhibited a limb length discrepancy of >2 cm, the symptoms of the patients were likely related to the rotational deformity rather than the limb length discrepancy.

The major limitation of this study was the small number of patients. However, when all of the exclusion criteria are considered, it is difficult to include a large group in such a single-center study. Moreover, we could not find any validated functional score specifically for femoral shaft fractures, and then, we used the functional scores that evaluated the adjacent joints. These scores are validated for other problems than rotational malalignment after femoral fractures, which may be a limitation of this study also.

In conclusion, a femoral rotational malalignment of $\geq 10^{\circ}$ is symptomatic for the patients, and the hip, knee, and patellofemoral joints were affected. Because of the possibly altered joint loadings and biomechanics, these could render patients prone to degenerative joint disease. In addition, due to the high rates of rotational malalignment after femoral shaft fracture and consequent malpractice claims, it is important for surgeons to be more aware of rotational alignment during surgery.

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