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Case report

Iatrogenic distal femur fracture following medial femoral supracondylar bone graft harvest: a case report and finite element analysis

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Abstract

Objective: This report presents a case of supracondylar femur fracture with finite element analysis and discusses its causes and prevention.
Patient and Methods: A 53-year-old man presented with right talar osteonecrosis after osteosynthesis for a talus fracture. A medial femoral condyle-free vascularized bone graft (size, 20 × 12 × 17 mm) from the contralateral femur was performed, including the posteromedial cortical corner. The patient suffered a donor-site supracondylar femoral fracture while standing up from a cross-legged sitting position on the bed on postoperative day 6. The fracture was treated with intramedullary nailing. We analyzed the effects of the location of the bone graft harvest in an intact model using the three-dimensional finite element method (FEM).
Results: The talar necrosis and the femur fracture healed. The FEM result revealed that the longitudinal axial pressure had minimal effect on the femur; however, the stress around the bone defect increased with rotation, especially in the posteromedial bone defect model.
Conclusion: Harvesting the bone graft should not include the posteromedial corner of the supracondylar femur. The patient should strictly limit the motion of torsional stress, such as standing from a cross-legged sitting position or pivoting turn.

Key words: medial femoral supracondylar flap, femur fracture, complication, iatrogenic, finite element method

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Introduction

The medial supracondylar region of the femur has become a reliable source of vascularized bone, with many advantages for reconstructive microsurgery[1]. The most common complications at the donor site after the flap harvest are nerve-related, including paresthesia and numbness in the saphenous nerve distribution[2].

Sporadic complication cases of distal femur fracture following flap harvest have been recently reported in literature[3–5]. The causes of these fractures remain unknown. This study reports a case of supracondylar femur fracture complication, analyzes its mechanism of injury using the finite element method (FEM), and discusses the probable causes and prevention strategies.

Case Presentation

A 53-year-old man sustained a right talus fracture due to a vehicular collision. The patient had previously undergone osteosynthesis with screws; however, the right talus developed osteonecrosis. Consequently, the patient was referred to our institution for further treatment 8 months after the injury.

The patient, who had no significant history of illness with a body mass index (BMI) of 24.1 kg/m^2, underwent a free vascularized bone graft to treat the talar osteonecrosis. After debridement of bone necrosis tissues through the anterior approach, the corticocancellous bone graft was harvest-

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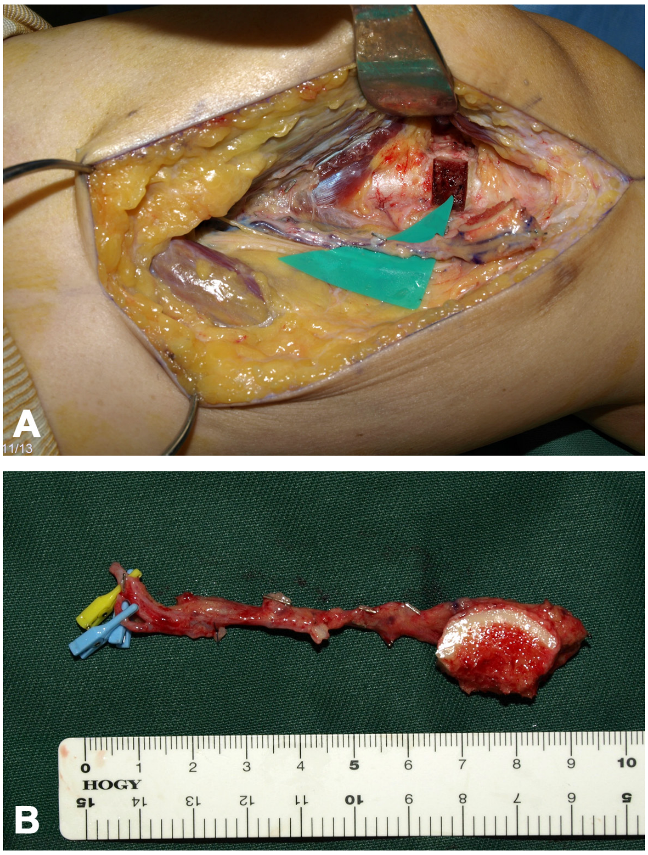

Figure 1 Intraoperative findings. (A) Intraoperative picture reveals that the harvested bone includes the posteromedial corner. The black arrow details the harvested site. (B) The bone graft size is 20 × 12 × 17 mm.

ed from the medial supracondylar region of the contralateral femur, where was selected as the donor because of the patient's request and ischemic time matter. The bone graft was harvested along with a transverse brunch of a descending genicular artery as a vascular pedicle. The harvesting was performed first by using an oscillating saw and then by using osteotomes in a gentle manner. We did not cut over beyond each corner. The size of the bone graft was 20 × 12 × 17 mm, which included a posteromedial cortical corner (Figure 1), and additional cancellous bone (approximately 10 × 10 × 10 mm) was harvested after elevating the bone graft.

The bone graft was inserted into the talus, followed by anastomosis with the anterior tibial artery and concomitant vein. The anastomosis and wound closure were uneventful. The recipient leg was immobilized with a plaster splint, whereas the donor leg was not immobilized and was allowed full weight bearing (Figure 2).

However, the patient sustained an injury to the left knee on postoperative day 6 while standing up from a cross-legged sitting position on the bed. The patient presented no symptoms prior to the fracture. Preliminary radiographs revealed a supracondylar femur fracture, with the fracture line traversing the harvested bone site (Figure 3). The fracture was an extraarticular simple spiral fracture, AO-33A2, according to the AO classification system. The patient underwent surgical fixation with a retrograde intramedullary

Figure 2 Radiography reveals the fracture across the harvested bone defect.

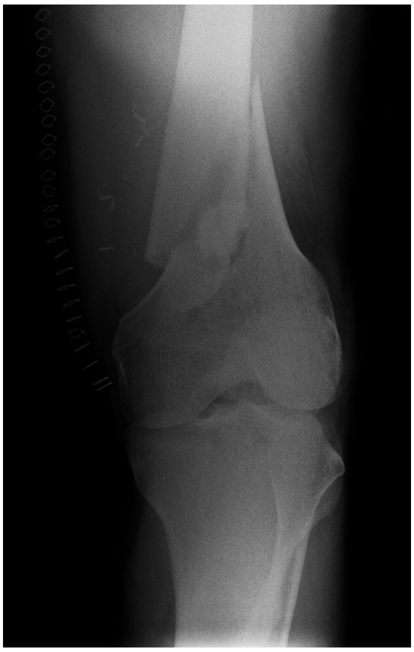

Figure 3 Postoperative radiography shows avascular necrosis of the talus after bone grafting.

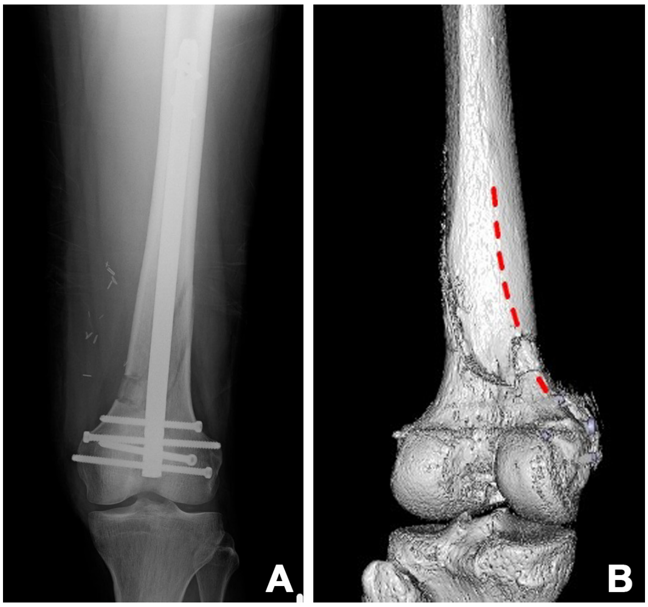

Figure 4 Post-osteosynthesis radiologic findings. (A) Radiography of the femur. (B) CT reveals the harvested bone defect on the medial supracondylar line. The dotted line reveals the medial supracondylar line.

nail four days later (Figure 4).

The patient's right talus healed from osteonecrosis, and the left knee regained its full range of motion with no disability, with 1-year postoperative radiographs revealing complete union. Consequently, the distal screws were removed due to the uncomfortable palpable screws over the skin. The patient was informed that data concerning the case would be submitted for publication, and consent was provided.

FEM Analysis

Medical images

Computed tomography (CT) femoral images (slice thickness of 1.0 mm) of a 36-year-old healthy female volunteer were obtained using the Brilliance 64 CT scanner (Philips Healthcare, Amsterdam, Netherlands), with written informed consent. Unfortunately, CT of the uninvolved femur in this fractured case was not performed; therefore, the CT data from another patient were used.

Model construction

The model was constructed using the FEM software (Simpleware ScanIP, version M-2017.06; Synopsys Inc., Mountain View, CA, USA). A three-dimensional femoral model (intact model) was constructed by mapping cortical and cancellous bone. The total elements and nodes were 152,467 and 33,625, respectively (Figure 5A). Young's modulus was a reference, as previously described[6]. Young's

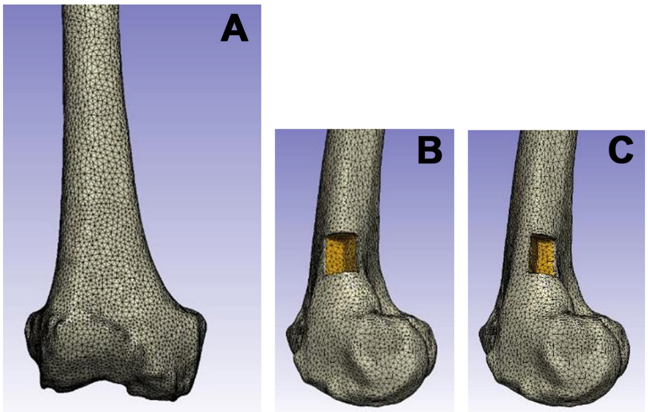

Figure 5 Three-dimensional femoral models are constructed by mapping the cortical bone and cancellous bone. (A) The intact model. (B) The medial bone graft harvest model is created as a 10 × 10 × 15 mm rectangle, excluding the medial supracondylar line. (C) The posteromedial bone graft harvest model is created using the same rectangle size, including the medial supracondylar line.

modulus was 12,000 and 500 MPa in the cortical and cancellous bones, respectively. Poisson's ratio was 0.3 and 0.1 in the cortical and cancellous bones, respectively.

Two bone graft harvest models were created in this study. We created a 10 × 10 × 15 mm rectangle as the medial bone graft harvest model (MBG model), excluding the medial supracondylar line. We created a 10 × 10 × 15 mm rectangle as the posteromedial bone graft harvest model (PBG model), including the medial supracondylar line (Figure 5B and 5C).

Load application

As an axial load, the distal femur was constrained in the x-, y-, and z-directions. The load was applied to the long axis from the femoral head center to slightly medial to the intercondylar region. We decided that the load was 500 N, based of model patient's height and BMI of 150 cm and 24.1 kg/m^2, respectively. Using these values, her weight was calculated at 54 kg, which would correspond to approximately 500 N (54 kg × 9.8 m/s^2 = 529 N).

As a rotational load, the femoral head was constrained in the x-, y-, and z-directions, and a lateral rotational load was applied to the distal femur. Analyses were performed using the LS-DYNA version R9.1.0 software (JSOL Corporation). Four combinations were evaluated, and the highest von Mises stress values for the femur were recorded for each combination.

The Ethics Committee of Ogori Daiichi General Hospital (Institutional Review Board 21-02) and the Center for Clinical Research of Yamaguchi University Graduate School of Medicine (Institutional Review Board H28-054) approved this study.

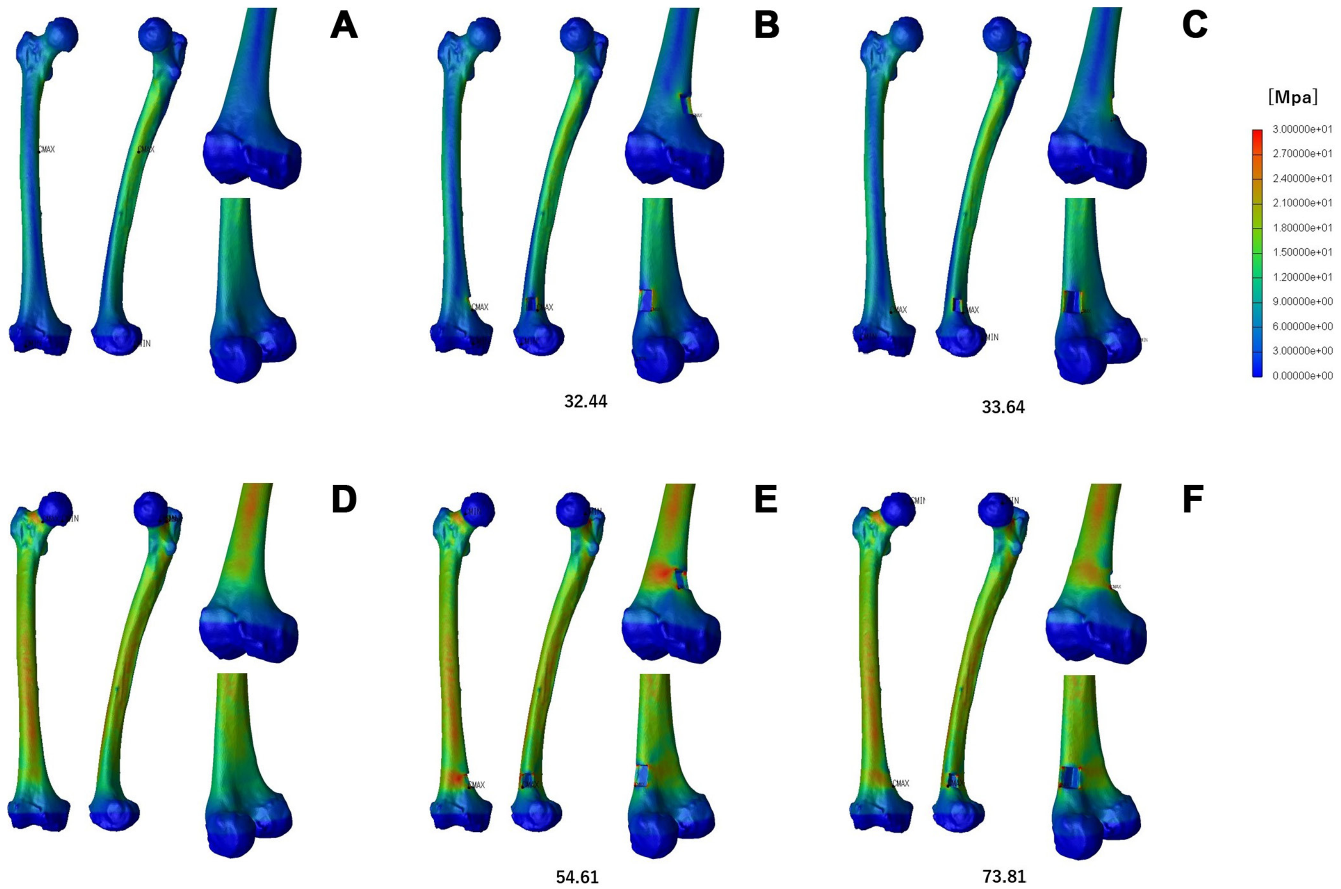

Figure 6 The results of stress under the axial and rotational load. (A) The intact model under the axial load. The right bar is color-coded according to stress (MPa). (B) The medial bone graft harvest model under the axial load. The maximum stress is 32.44 MPa. (C) The posteromedial bone graft harvest model under the axial load. The maximum stress is 33.64 MPa. (D) The intact model under the rotational load. (E) The medial bone graft harvest model under the rotational load. The maximum stress is 54.61 MPa. (F) The posteromedial bone graft harvest model under the rotational load. The maximum stress is 73.81 MPa.

Result

Axial load

The stress of the intact model increased from the diaphysis to the intercondylar fossa, and the highest stress (18.20 MPa) occurred at the medial diaphysis center. The stress around the bone defect increased in the PBG model compared to that in the MBG model; however, the difference was approximately 1 MPa (Figure 6A–6C).

Rotational load

The stress of the intact model increased from the diaphysis to the intercondylar fossa compared with the long axial load, and the highest stress (34.12 MPa) occurred anterior to the femoral neck. In the MBG model, the maximum stress was lower than that in the PBG model; however, the range of the stress increase was spread. In the PBG model, the stress around the bone defect was 135% higher than that in the MBG model (Figure 6D–6F).

Discussion

The current study reports a rare case of supracondylar fracture, a complication of the donor site following bone graft harvest, and the mechanical analysis of this case using FEM. To date, only three cases of iatrogenic femur fracture have been reported[3–5], two of which have been described in detail (Table 1). Haines *et al.*[4] considered osteoporosis the cause of the fracture in a 61-year-old woman. Son *et al.*[5] demonstrated that the excess harvest of cancellous bone past the intercondylar fossa from the femur after flap elevation caused the fracture in their case. In contrast, the current case involved a healthy, middle-aged man without osteoporosis. Additional cancellous bone was harvested after elevating the bone graft; however, the amount of harvested cancellous bone was reasonable and not excessive. Therefore, other possible causes of the fracture complication can be presumed.

Several studies have analyzed the biomechanics of fem-

Table 1 Summary of the reported cases

	Hamada *et al.*[3]	Haines *et al.*[4]	Son *et al.*[5]	Current case
Age and sex	A 53-year-old man	A 61-year-old woman	A 61-year-old man	A 53-year-old man
Purpose of the flap	Nonunion of the clavicle	Nonunion of the clavicle	Osteomyelitis of the distal radius	Osteonecrosis of the talus
Date of onset after surgery	No data	3 weeks	2 weeks	6 days
Causes pointed out by authors	Harvest from posteromedial corner	Osteoporosis	Excess harvest of cancellous bone	Harvest from posteromedial corner and Torsional loading
Harvested bone:				
Type	Corticoperiosteal bone	Corticocancellous bone	Corticoperiosteal bone	Corticocancellous bone
Size	No data	length 60 × wide 10 × depth 10 mm	55 × 32 (× 42) mm	20 × 12 × 17 mm
Site	Supracondylar (Posteromedial corner)	Supracondylar – Medial condylar	Supracondylar – Medial condylar	Supracondylar (Posteromedial corner)
Additional cancellous bone	No data	No data	Much	Little
Movement at onset	No data	Mobilising with partial weight up a step	Changing direction while walking	Standing up from a cross-legged sitting position

oral bone tolerance. Edgarton *et al.*[7] reported that screwed or drilled holes >20% of the bone diameter decreased the bone torsional strength by approximately 60%. A similar effect was predicted in patients at the harvested bone site. In this case, the defect size measured using CT imaging was 15% of the bone diameter (20-mm defect size/135-mm outer bone diameter), not exceeding 20%. The defect size, in this case, cannot be completely ruled out as the cause of the fracture; however, we believe this was not the primary reason.

Endara *et al.*[8] reported a study using a cadaveric torsional loading model, revealing that harvesting >7 cm from the distal femur was associated with a greater risk of iatrogenic fractures under torsional loading. Nonetheless, the sizes of the bone grafts were <7 cm in our study and two previously reported cases. These findings suggest that other factors, excluding defect size, should be considered.

A biomechanical study by Katz *et al.*[9] revealed that the femur could tolerate supraphysiologic axial loads after harvesting the corticocancellous flap up to 24 cm. Moreover, as mentioned earlier, harvesting >7 cm was associated with a greater risk of iatrogenic fracture with torsional loading. These results suggest that femur tolerance to torsional loading is significantly lower than that to axial loading. In our study, the patient sustained an injury while standing up from a sitting cross-legged position, considered torsional loading. A case reported by Son *et al.*[5] was of a fracture that occurred while changing walking direction, which can also be considered torsional loading. Another case reported by Haines *et al.*[4] was of a fracture during mobilization with partial weight up a step, and it can also be presumed as torsional loading. Given these cases, torsional loading is a critical factor causing fractures.

Clark *et al.*[10] observed that increasing the defect width significantly reduced bone strength, whereas increasing the length did not. This study revealed that strength reduction depends not only on the defect size but also on the location. CT findings of the current case revealed that the harvested region was on the posteromedial cortical corner, where the medial supracondylar line was located. We suspected that the bone defect location is a critical factor for fractures, particularly in the posteromedial cortical corner. Hamada *et al.*[3] first reported iatrogenic fractures and pointed out that harvesting the posteromedial cortical corner was a cause.

We performed a mechanical analysis of this case using FEM to determine the posteromedial cortical corner defect risk. There has been no FEM report on events after harvesting the medial femoral supracondylar bone graft. In this analysis, the bone graft effect on the load on the long axis was insignificant. In rotation, the range of stress of the MBG model increased significantly, and there is a fracture risk. However, the stress in the PBG model increased more than in the MBG model, and the fracture risk was higher.

Limitations to this case study include using CT models of different cases, one type of mechanical property, and one type of bone graft size. However, this analysis suggests that the posteromedial cortical corner is where stress is easily concentrated; therefore, bone harvesting should not include this corner. Future biomechanical analysis using finite element analysis is required to verify the findings of this study.

Rao *et al.*[11] demonstrated that a minimal amount of regenerated bone was displayed on volumetric analysis of the medial femoral condyle donor site a year after graft harvest. Patients would remain at a high fracture risk if bone regeneration cannot be expected. Therefore, filling the donor site with artificial bone is recommended to resolve this problem.

A discussion on which side is better for harvesting in leg reconstruction is needed. This study suggests that harvesting the bone graft from the contralateral leg is one of the major reasons for the fracture. The reconstructed leg had to be regularly immobilized with a plaster splint for rest; therefore, the patient concentrated the stress on the other leg. Therefore, harvesting the ipsilateral femur should be considered.

In summary, the following are suggested to prevent supracondylar fractures, in addition to those mentioned in previous reports: first, the full thickness of the cortical bone, including the posteromedial corner of the femur, should not be harvested; second, filling the donor site with an artificial bone graft instead of the harvested bone would be better; third, the bone graft should be harvested from the ipsilateral femur; and finally, the patient should limit mobilization such as standing from a sitting cross-legged position or pivoting turn, to avoid torsional stress to the harvested leg until the grafted artificial bone achieves union.

Conflict of interest: The authors declare that there are no conflicts of interest.

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