Prediction Of Pathological Fracture In The Proximal Femora With Bone Lesions Using A CT Scan-based Finite Element Method

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Disclosures:

Introduction:
Patients with bone lesions, such as tumors and abscess, in the proximal femur are at risk of pathological fracture. The lesions with a high fracture risk are surgically treated using prophylactic osteosynthesis or prosthetic replacement, whereas low risk lesions are treated conservatively. However, it is difficult to discriminate between low and high risk lesions based on available radiographic imaging material, even for experienced physicians. Keyak et al. have showed that finite element (FE) models constructed from quantitative CT scans is a powerful tool for assessing the strength and failure load of bones (Keyak 2001). Recently, predictive value of FE models to predict fracture loading and location in cadaver models with artificial bone defects have been reported(1). The purpose of this study was to determine whether patient-specific quantitative CT scan based FE models can be used to predict fracture load and location in the cases with proximal femoral lesions.

Methods: FE models were constructed from quantitative CT scans of 7 cases (3 men and 4 women) of human femora. The mean age of the patients was 44 years (range: 13-65). CT images of the femur of all patients were taken with a slice thickness of 1.5 mm. FE models of the femur were obtained from CT data by Mechanical Finder (Research Center of Computational Mechanics Inc., Tokyo, Japan), software that creates FE models showing individual bone shape and density distribution. Three-dimensional FE models with 1.5 to 4 mm tetrahedral elements for the trabecular and inner cortical bone and three nodal-point shell elements with a thickness of 0.4 mm for the outer surface of the cortical bone were constructed for each patient. The FE models of the femur consisted of approximately 800000 elements. The mechanical properties of the bone were determined from CT density values, using the equations proposed by Keyak et al (Figure 1). All femora were experimentally loaded until fracture. FE models simulations of the experimental set-up were performed and stiffness were determined. Loading direction was defined as the angle γ with reference to the long axis of the femur in the frontal plane and δ with reference to the femoral neck axis in the horizontal plane. (Figure 2) Angles γ=160° and δ=0° were assigned as stance configuration(2).
Cortical shell
0.4 mm

Trabecular bone
1 mm - 4 mm

The mean number of element 80000

Mechanical Finder Ver.6.2 (RCCM)
Results:
All simulations were successfully performed. Clinical information, the type of treatment, and fracture loads in affected and unaffected femora were shown in Figure 3. A representative data of FE models was shown in Figure 4,5. The simulated fracture line in the unaffected femur started at the subcapital region, however that started thinnest part of medial cortex and then extended to the subcapital region in the affected femur. The mean fracture loads in unaffected femora was 5250±732N, and that in affected femora was 2433±1102N (p=0.033). There was no significant difference between in affected and unaffected femora, however, 3 out of 7 affected femora showed apparently lower fracture loads which were less than two third of opposite side (high risk group). On the other hand, the rest of 4 demonstrated similar fracture loads which were within 10% difference between affected and unaffected (low risk group). The mean percentage of fracture loads in affected side compared to that in unaffected side was 50±16.09% in the high risk group and 98±5.85% in the low risk group (p=0.033). Interestingly, there was no difference in volume of lesions between high risk and low risk groups (mean 23.15±15.19cm$^3$, 24.68±13.65cm$^3$, respectively, p=1.000), which indicates that the size of lesion does not directly increase the risk of pathological fractures. Since fracture lines in the simulations started thinnest part of medial aspect in the high risk group, we hypothesized that the
destruction of medial cortex of femoral neck to subtrochanteric region decrease the fracture loads. The thicknesses of medial cortex were measured using CT scan and compared with unaffected side. As a result, the mean thickness of medial cortex in the affected femora decreased 36±5.03% compared to that in unaffected femora in the high risk group, on the other hand, the thicknesses of affected femora did not differ from that of unaffected (mean thickness rate was 90±11.57%) in the low risk group. We now treat patients using prophylactic osteosynthesis or prosthetic replacement only in the high risk group.

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<th>Lesion</th>
<th>Pain</th>
<th>Curettage</th>
<th>Bone transplant</th>
<th>Fixation</th>
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(Figure 3)
Discussion:
In the clinical practice, there is an urgent need to improve the prediction of pathological fracture risk for patients with tumors in femur. Until now, prediction is mainly based on the individual judgment of clinicians using X-rays. However, it is hard to interpret the mechanical consequences of a lesion based on X-ray alone. In this study, we have calculated fracture loads in the proximal femora with or without bone lesions, using FE models. As Deriks et al reported in the metastatic lesions, fracture loads calculated using FE models were well demonstrated as cadaveric experiments(3). It is reasonable that operative indication could be done by fracture loads using FE models. However, the problem is that performing FE models are complicated and time consuming. We here are suggesting that the thickness of medial cortex could be substitute of FE models, because high risk group in FE models analysis showed apparently thinner medial cortex compared low risk group. We need additional sample number and further investigations to establish the criteria of operation and stabilization using osteosynthesis or prosthetic replacement.

Significance: It is reasonable that operative indication could be done by fracture loads using FE models.

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