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Potential pathogenic mechanism for stress fractures of the bowed femoral shaft in the elderly: Mechanical analysis by the CT-based finite element method

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ABSTRACT

Introduction: Stress fractures of the bowed femoral shaft (SBFs) may be one of the causes of atypical femoral fractures (AFFs). The CT-based finite element method (CT/FEM) can be used to structurally evaluate bone morphology and bone density based on patient DICOM data, thereby quantitatively and macroscopically assessing bone strength. Here, we clarify the pathogenic mechanism of SBFs and demonstrate this new understanding of AFFs through mechanical analysis by CT/FEM.

Patients and methods: A prospective clinical study was performed from April 2012 to February 2014. We assembled two study groups, the bowed AFF group ($n = 4$ patients; mean age, 78.0 years) including those with a prior history of AFF associated with bowing deformity and the thigh pain group ($n = 14$ patients; mean age, 78.6 years) comprising outpatients with complaints of thigh pain and tenderness. Stress concentration in the femoral shaft was analysed by CT/FEM, and the visual findings and extracted data were assessed to determine the maximum principal stress (MPS) and tensile stress–strength ratio (TSSR). In addition, we assessed femoral bowing, bone density, and bone metabolic markers. Wilcoxon's rank sum test was used for statistical analysis.

Results: All patients in the bowed AFF group showed a marked concentration of diffuse stress on the anterolateral surface. Thirteen patients in the thigh pain group had no significant findings. However, the remaining 1 patient had a finding similar to that observed in the bowed AFF group, with radiographic evidence of bowing deformity and a focally thickened lateral cortex. Patients were reclassified as having SBF ($n = 5$) or non-SBF ($n = 13$). Statistical analysis revealed significant differences in MPS ($p = 0.0031$), TSSR ($p = 0.0022$), and femoral bowing (lateral, $p = 0.0015$; anterior, $p = 0.0022$) between the SBF and non-SBF groups, with no significant differences in bone density or bone metabolic markers.

Conclusions: Significant tensile stress due to bowing deformity can induce AFFs. SBFs should be considered a novel subtype of AFF, and patients with complaints of thigh pain and femoral shaft bowing deformity must be considered at high risk for AFFs.

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Introduction

Severely suppressed bone turnover after prolonged bisphosphonates (BPs) therapy has been considered a cause of low-energy diaphyseal femoral fractures, commonly called atypical femoral fractures (AFFs) [1–4]. We previously studied stress fractures of the bowed femoral shaft (SBFs) among elderly Japanese for over a decade. Stress fractures of the femoral shaft are well recognised as fatigue fractures among young athletes and military marchers, whereas SBFs are insufficiency fractures caused by the daily stress load [5,6]. SBFs have been confused with AFFs caused by severely suppressed bone turnover, especially in Asians. Oh et al. [7] previously reported a case series of SBFs not associated with BPs use and advocated that SBFs should be recognised as one of the causes of AFFs. In most cases, SBFs occur bilaterally and in active elderly women. Some reports on stress fractures of the femoral shaft after total knee arthroplasty have also described involvement of femoral shaft bowing deformity and bilaterality [8,9].

On the other hand, the case definition of AFFs was revised by the American Society for Bone and Mineral Research (ASBMR) Task

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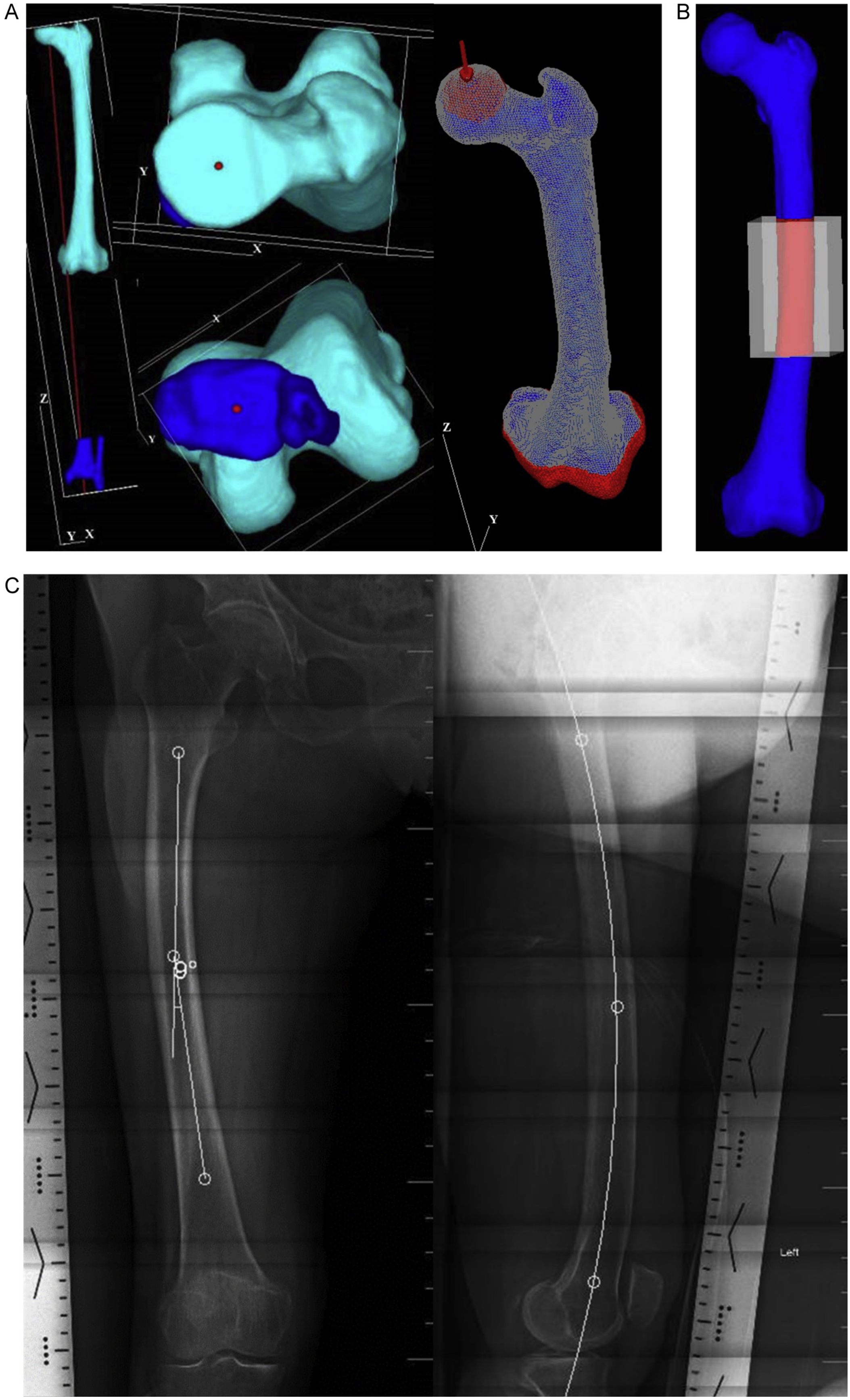

Fig. 1. Assessment of the femur. (A) The load axis is appropriately set up by creating a model of the lower extremity. The distal condyle of the femur is constrained and the load of an individual weight is applied to the femur. (B) Maximum values of maximum principal stress and the tensile stress–strength ratio are extracted from a 100-mm section of the middle of the femoral shaft. (C) To quantify the lateral bowing angle, the centre of the medullary cavity is aligned on an accurate anteroposterior view. To quantify the anterior radius of curvature, the centre of the medullary cavity is aligned on an accurate lateral view.