A new method for measurement of bone bending stiffness non-invasively by echo tracking

+1Tobita, K; +1Ohnishi, I; +1Matsuyama, J; +1Matsumoto, T; +1Ohashi, S; +1Bessho, M; +1Kaneko M; +1Nakamura, K
+1 Department of Orthopaedic Surgery, Faculty of Medicine, University of Tokyo, Tokyo, Japan; +1International University of Health and Welfare, Japan
tobitak.ort@gmail.com

INTRODUCTION:
We have attempted to noninvasively assess the bone deformation angle of a fracture healing site under a load using Echo tracking (ET). The ET method can be used to evaluate the bending stiffness, but previous studies [1] have not validated the accuracy of bending stiffness as measured by ET because this was in vivo study. In order to evaluate the accuracy of bending stiffness as determined using the ET method, it is absolutely imperative to perform the study in vitro. The purpose of the present study was therefore to evaluate the accuracy of bending stiffness measured in vitro using the ET method.

METHODS:
Creation of the rabbit model
Unilateral, transverse, mid-tibial osteotomies with a 2-mm gap were performed in 28 rabbits. The osteotomy site was stabilized using a double-bar external fixator. The animals were divided into four groups (n=7/group/time point; 4, 6, 8 and 12 weeks).

In vitro measurement of bending stiffness by ET
The tibiae were loaded in a four-point bending manner using a stainless steel wire loop (breaking strength: 2,450 N) in the posterior-anterior direction with the anterior side in tension. The inner and outer spans of the wire were 10 and 110 mm, respectively, with the long axis of the tibia oriented perpendicular to the wire during the test. A constant displacement rate of 0.6 mm/min was used to test the tibia up to 15.0 N using a material testing machine (Servopulser; Shimadzu, Tokyo, Japan) (Fig. 5A). The displacements of two points on the posterior surface of the tibia were measured simultaneously using two ultrasound probes (Aloka, Tokyo, Japan). We used an ultrasound transducer equipped with a matrix array format with an accuracy of 2.6 µm (element count: 3 × 3, element pitch: 3 × 3 mm, frequency: 7.5 MHz) (Fig. 2A-C) and a receiver to enable simultaneous measurement of two points by each of the matrix array transducers.

Two probes were set parallel to the proximal and distal posterior surfaces of the tibia at the center of the two external fixation pins to calculate the bending angle (θ) (Fig. 3a) formed by the proximal and distal fragments. Stiffness values measured by ET (ET stiffness) were determined from the slope of the early linear portion of the bending moment versus the deformity angle curve.

RESULTS:
Of the 28 rabbits, 23 were available for mechanical analysis. Five rabbits could not be tested because the gap sites contained soft callus and re-fractured just after removal of the external fixator.

ET stiffness versus laser stiffness
Analysis of the relationship between ET stiffness and laser stiffness revealed a strong correlation between these two stiffness values (r = 0.978, p < 0.001) (Fig. 4).

DISCUSSION:
The relationship between the stiffnesses measured by these two devices was completely linear, indicating that the ET method could precisely measure bone stiffness.

SIGNIFICANCE:
The ET method can be used to evaluate bending stiffness non-invasively in vivo. Moreover, the ET method can be used widely and is applicable in various fracture management situations.

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REFERENCES:
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