J Orthop Sci (2014) 19:1012–1018
DOI 10.1007/s00776-014-0616-1

ORIGINAL ARTICLE

Accuracy of specimen-specific nonlinear finite element analysis for evaluation of distal radius strength in cadaver material

Yusuke Matsuura · Kazuki Kuniyoshi · Takane Suzuki · Yasufumi Ogawa · Koji Sukegawa · Tomoyuki Rokkaku · Kazuhisa Takahashi

Received: 3 October 2013 / Accepted: 6 July 2014 / Published online: 7 August 2014
© The Japanese Orthopaedic Association 2014

Abstract

Background Distal radius fracture, which often occurs in the setting of osteoporosis, can lead to permanent deformity and disability. Great effort has been directed toward developing noninvasive methods for evaluating the distal radius strength, with the goal of assessing fracture risk. The aim of this study was to evaluate distal radius strength using a finite element model and to gauge the accuracy of finite element model measurement using cadaver material.

Methods Ten wrists were obtained from cadavers with a mean age of 89.5 years at death. CT images of each wrist in an extended position were obtained. CT-based finite element models were prepared with Mechanical Finder software. Fracture on the models was simulated by applying a mechanical load to the palm in a direction parallel to the forearm axis, after which the fracture load and the site at which the fracture began were identified. For comparison, the wrists were fractured using a universal testing machine and the fracture load and the site of fracture were identified.

Results The fracture load was 970.9 N in the finite element model group and 990.0 N in the actual measurement group. The site of the initial fracture was extra-articular to the distal radius in both groups. The finite element model was predictive for distal radius fracture when compared to the actual measurement.

Conclusion In this study, a finite element model for evaluation of distal radius strength was validated and can be used to predict fracture risk. We conclude that a finite element model is useful for the evaluation of distal radius strength. Knowing distal radius strength might avoid distal radius fracture because appropriate antiosteoporotic treatment can be initiated.

Introduction

Distal radius fractures are the most common upper extremity fractures in elderly people [1]. Because many of the falls causing distal radius fractures occur from a lower height, distal radius fractures are considered to be low energy fractures and are often related not so much to the fall, but to bone of lower quality. Distal radius fracture can lead to permanent deformity, disability, and pain.

To evaluate the risk of distal radius fracture and its prevention by appropriate antiosteoporotic treatment, it is necessary to predict the strength of the distal radius bone. Clinically, measurement of bone mineral density by methods including quantitative ultrasound (QUS), quantitative computed tomography (QCT), and dual energy radiograph absorptiometry (DXA) have been used to predict the risk of fracture for evaluation of osteoporosis; however, these methods are often not sufficient. Around 50 % of the osteoporotic fractures occur in patients with bone mineral density above the defined thresholds, such as

---

Y. Matsuura (✉) · K. Kuniyoshi · Y. Ogawa · K. Sukegawa · K. Takahashi
Department of Orthopedic Surgery, Graduate School of Medicine, Chiba University, 1-8-1 Inohana, Chuo-ku, Chiba 260-8670, Japan
e-mail: y-m-1211@khaki.plala.or.jp

T. Suzuki
Department of Bioenvironmental Medicine, Graduate School of Medicine, Chiba University, 1-8-1 Inohana, Chuo-ku, Chiba 260-8670, Japan

T. Rokkaku
Department of Orthopedic Surgery, Chiba Aoba Municipal Hospital, 1273-2 Aoba-cho, Chuo-ku, Chiba 260-0852, Japan

more than 2.5 SD below the young adult average value [2, 3]. Mineral density is just one of the elements of bone strength. Bone strength is defined by bone mineral density and bone quality [4]. The components of bone quality are trabecular bone structure, geometry, microarchitecture, mineralization, crystallinity, collagen characteristics, microfracture, and bone turnover [4, 5]. The risk of fracture can be defined as the ratio between the load under a particular loading condition and the ultimate load supported by the bone, that is, the bone strength [6, 7]. Subject-specific finite element models (FEMs) are effective tools for fracture strength assessment [8].

Because the FEMs evaluate geometry, architecture, and heterogeneous mechanical properties of bone, a FEM based on QTC data may predict the strength of the distal radius more accurately. CT-based FEMs are known to provide accurate predictions of fracture loads for femurs [9–12] and vertebra [13–16]. Keyak [12] reported that the patient-specific nonlinear FEMs as reported here provide an unprecedented level of precision for predicting proximal femoral fracture load.

Edwards and Troy reported that a CT-based linear FEM, which generates an algorithm, offers realistic estimates of distal radius strength under a physiological loading scenario simulating a fall and that this FEM is a suitable candidate for in vivo or clinical examinations of preventive strategies to minimize the occurrence of distal radius fractures [8]. Varga [17] reported nonlinear FEMs for distal radius fracture using embalmed human radii. However, to our knowledge, there is no previous report specifying that patient-specific CT-based nonlinear FEMs provide measures of fresh frozen distal radius fracture strength. Therefore, the aim of this study was to evaluate distal radius strength using patient-specific CT-based nonlinear FEMs and to gauge the accuracy of this FEM measurement compared with that using a universal testing machine in fresh frozen cadaver specimens.

Materials and methods

Specimens

Ten wrists with intact hands from 6 women and 4 men with a mean age of 89.5 years at death (range 79–96 years) were obtained from their fresh frozen cadavers. They were thawed at room temperature just before examination by computed tomography (CT) and were not refrozen. With the wrist in the extended position and the forearm in the neutral position, the area distal from the midpoint of the forearm was imaged using CT (Aquilion ONE; Toshiba Medical Systems, Tokyo, Japan, 320-row detector 120 kV, 200 mA, slice thickness 0.5 mm, pixel width 0.3 mm). After that, all soft tissue proximal to the wrist joint capsule was removed, and the radius and ulnar were cut at the midpoint of the forearm. To keep the specimens moist, they were sprayed with a saline solution.

Nonlinear FEM

CT data were transmitted to an HP Z400 workstation (Hewlett-Packard, Palo Alto, CA, USA). Three-dimensional FEMs were constructed from the CT data using Mechanical Finder software (Research Center for Computational Mechanics, Tokyo, Japan). The radius, ulnar, and carpale were simulated making use of 1.2 mm linear tetrahedral elements, and were overlaid with 1.2 mm triangular shell elements (Fig 1). The imaginary thickness of shell element was set as 0.3 mm.

On average, there were 436807.2 tetrahedral elements and 45565.6 triangular-plates simulating bone. Areas of cartilage were set among bones. We made carpal bone, periarticular radius, and ulnar bones ROI 2 mm expanded, and exchanged the ROI as cartilage. Cartilage was simulated making use of 1.2 mm linear tetrahedral elements without triangular shell elements. On average, there were 102547.4 tetrahedral elements simulating cartilage.

In order to allow for bone heterogeneity, the bone material properties of each element were calculated using the Hounsfield unit (HU) value at their location as indicated in Eq. (1). The ash density of each element was set as the average ash density of the voxels contained in one element.

$$\begin{aligned}\text{Ash density}\left(\text{g/cm}^3\right) &= (\text{HU} + 1.4246)\\ &\quad \times 0.001/1.0580\ (\text{HU value} > -1)\end{aligned} \tag{1}$$

$$\text{Ash density}\left(\text{g/cm}^3\right) = 0.0\,(\text{HU value} \leq -1)$$

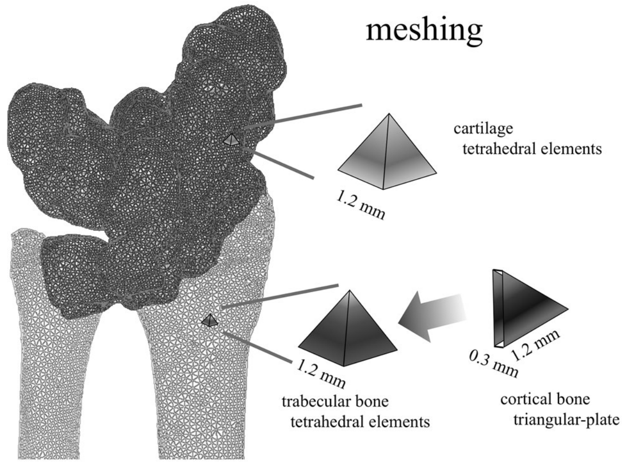

Fig. 1 Meshing. Bone was simulated using 1.2 mm linear tetrahedral elements, and the outer surface of the cortical bone was modeled using 1.2 mm triangular shell elements

Download English Version:

https://daneshyari.com/en/article/10175018

Download Persian Version:

https://daneshyari.com/article/10175018

Daneshyari.com