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Open wedge high tibial osteotomy using three-dimensional printed models: Experimental analysis using porcine bone

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ABSTRACT

Background: The purpose of this study was to evaluate the usefulness of three-dimensional (3D) printed models for open wedge high tibial osteotomy (HTO) in porcine bone.
Methods: Computed tomography (CT) images were obtained from 10 porcine knees and 3D imaging was planned using the 3D-Slicer program. The osteotomy line was drawn from the three centimeters below the medial tibial plateau to the proximal end of the fibular head. Then the osteotomy gap was opened until the mechanical axis line was 62.5% from the medial border along the width of the tibial plateau, maintaining the posterior tibial slope angle. The wedge-shaped 3D-printed model was designed with the measured angle and osteotomy section and was produced by the 3D printer. The open wedge HTO surgery was reproduced in porcine bone using the 3D-printed model and the osteotomy site was fixed with a plate. Accuracy of osteotomy and posterior tibial slope was evaluated after the osteotomy.
Results: The mean mechanical axis line on the tibial plateau was 61.8 ± 1.5% from the medial tibia. There was no statistically significant difference ($P = 0.160$). The planned and post-osteotomy correction wedge angles were 11.5 ± 3.2° and 11.4 ± 3.3°, and the posterior tibial slope angle was 11.2 ± 2.2° pre-osteotomy and 11.4 ± 2.5° post-osteotomy. There were no significant differences ($P = 0.854$ and $P = 0.429$, respectively).
Conclusion: This study showed that good results could be obtained in high tibial osteotomy by using 3D printed models of porcine legs.

1. Introduction

In patients with medial knee osteoarthritis and varus deformity, high tibial osteotomy (HTO) is the good option of several treatment methods, and good results have been reported by several authors [1–5]. Determining the correction angle and gap through preoperative planning has a significant effect on the post-operative results of HTO; therefore, it could be considered one of the most important parts of the process [6–8]. One method of planning is checking the intraoperative mechanical axis of the lower limb using a radiopaque line such as an electrocautery cord, and the other is determining the correction gap and angle using preoperative weight-bearing radiographs of the lower extremity, especially with a picture-archiving communication system (PACS) or with software such as PreOPlan or mediCAD [9–12]. The method using the intraoperative radiopaque line enables real-time monitoring of the correction gap, but the non-weight-bearing status can lead to unfavorable post-operative results, and the surgeon and patient are exposed to more intraoperative radiation. In contrast, the method using preoperative

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radiographs has the advantages of calculating the correction gap and angle in weight-bearing status and reducing intraoperative radiation exposure, but has the disadvantages of not involving real-time monitoring, the possibility of changes from preoperative planning by rotation of the lower limb, and difficulty in controlling the posterior tibial slope.

Three-dimensional printing (3D) techniques have become more common and widely used in various fields of medicine recently. This technique has been used widely in cranio-maxillofacial surgery since the 1990s [13,14], and orthopedic surgeons have recently begun to use this technique to plan preoperatively, especially for pelvic bone fractures [15,16]. Preoperative planning is possible using 3D-printing techniques, which can simulate the real-sized model and can enable surgery to be performed more accurately. In this study, we used computed tomography (CT) to evaluate bone deformities, and 3D-printing techniques using images obtained from CT evaluation.

In this study, we hypothesized that accurate correction could be made possible in HTO by using 3D-printing techniques. A 3D wedge model created with 3D-printing techniques could be obtained from preoperative CT images, and could be used in HTO operations. Accurate correction angles and posterior tibial slope angles could be ensured, and this technique could involve less radiation due to the decreased use of C-arm fluoroscopy.

The purpose of this study is to evaluate the usefulness of 3D-printed models for open wedge high tibial osteotomy in porcine legs, to determine whether accurate correction angle and maintaining the posterior tibial slope is possible.

2. Materials and methods

A total of 10 porcine legs were used, and the specimens were disarticulated at the hip and ankle joints. All pigs weighed over 90 kg, were at least eight months old, and were without disease. The mean lengths of the whole leg and tibia were 36.6 ± 0.8 cm and 16.4 ± 0.4 cm, respectively.

Preoperative planning was performed using 3D images of porcine leg, which were obtained by CT imaging using 3-D Slicer (Brigham Women's Hospital, Boston, MA) software (Figure 1). For the reconstruction of HTO surgery, the osteotomy was performed using the 3D images. The medial osteotomy site was determined at three centimeters under the medial tibial plateau, and the lateral hinge point was determined at the upper margin of the fibular head on the proximal tibiofibular joint. The target point was determined at the Fujisawa point, that is, the point 62.5% from the medial border along the longest medial-to-lateral width of the tibial plateau [17]. The osteotomy site was extended until the mechanical axis line was placed at the targeted point on the knee joint maintaining the posterior tibial slope angle (Figure 2). Using the osteotomy plane and angle extension,

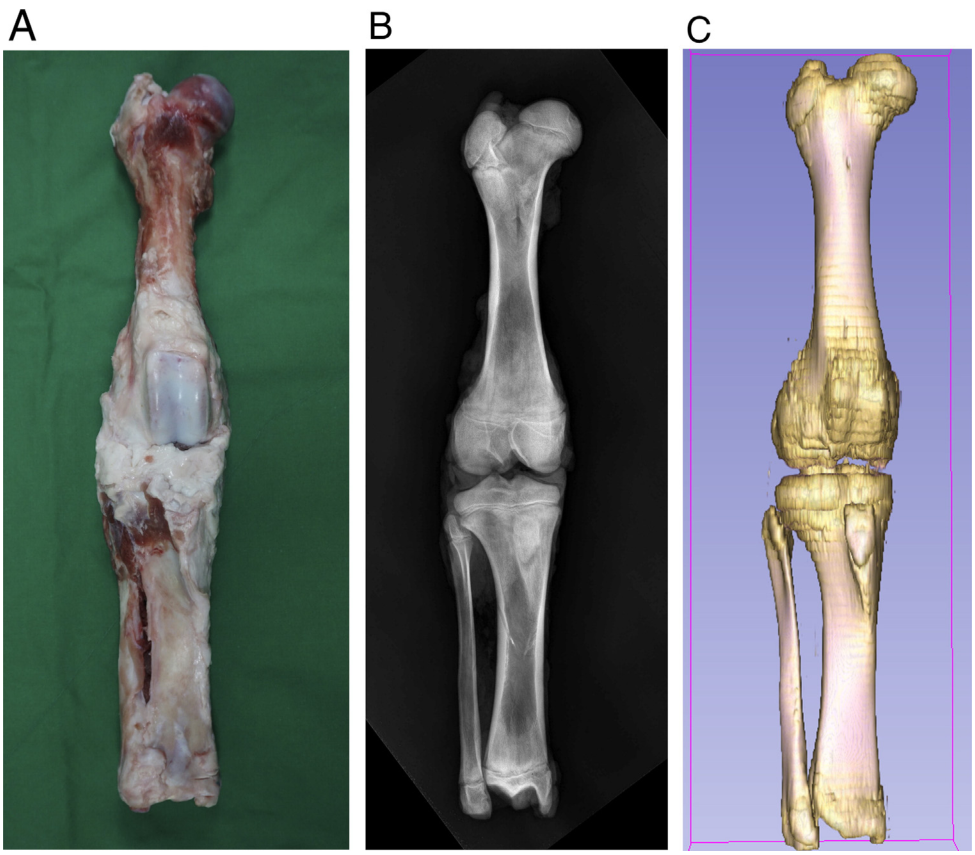

Figure 1. (A) Gross porcine leg. (B) Radiographic image of porcine leg. (C) 3D image of porcine leg reconstructed by the software program.

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