다중방사선 사진을 이용한 하지 3차원 모델 개발

Reconstruction of three-dimensional geometric femoral model using X-ray and three CT images

#*김윤혁[1], 박원만[1], 고경[2]

#*Y. H. Kim(yoonhkim@khu.ac.kr)[1] , W.M. Park[1], K. Koh[2]

[1]경희대학교 기계공학과, [2]경희대학교 산학협력단

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1. INTRODUCTION

A patient-specific reconstruction of human bone model has been widely used for computer-aided planning of orthopedic surgeries or personalized biomechanical finite element models [1,2]. This reconstruction method is an important images analysis tool for clinical and biomechanical studies since it provides a 3D geometric model for bio-mechanical analysis and diagnosis of bone problems such as fractures, aging, and osteoporosis. Several reconstruction methods of human bones have been developed from computed tomography (CT), and magnetic resonance imaging (MRI) [4,5,6]. CT and MRI-based reconstruction method has been commonly used due to providing accurate bone models. However, these methods require intensive labor, time and high costs in generating accurate reconstruction. Moreover, CT-based reconstruction leads to a high radiation dose delivered to patients during CT procedures, which may lead to high incidence of cancer. Even though there have been achievements to generate 3D bone model with reduced CT radiation dose [6], the radiation exposure during CT procedures is still considered to be a big concern comparing to X-ray radiation exposure delivered to patients.

In the result of these disadvantages, 3D reconstruction methods using X-ray images have been recently developed [7,8,9,10] since X-ray images provides low costs and radiation dose comparing to CT or MRI. Skalli et al. [7] developed 3D reconstruction method of various different types of bones from biplanar X-ray images obtained by EOS device (Biospace med, Paris, France). Shim et al. [8] developed auto-generating FE models using sparse CT datasets. Ryo et al. [9] developed 3D reconstruction method using two 2D fluoroscopic images. Shimada et al. [10] developed cost- and time-effective 3D reconstruction method from orthogonal X-ray images. However, reported X-ray-based reconstruction methods of femoral models have a limitation to generate the femoral model with severe rotational deformity.

Thus, in this paper, we propose new reconstruction method which is not only a low dose, time efficient and cost effective, but also, is to improve the limitation of generating severely rotational deformed femoral model. The proposed method here is the 3D reconstruction method of the femur using two X-ray images taken from any direction and three CT slices. To achieve this goal, low dose X-rays in standing position and three CT slices of distal femur were proposed to create a patient-specific 3D bone model and a predefined 3D template bone model from a healthy subject with normal height and weight was used as a priori knowledge to obtain patient-specific models. Then, B-spline free form deformation (FFD) [11,12] process is performed to deform the 3D template bone model until the images from a template 3D bone model projected onto a two-dimensional (2D) plane match the X-ray images, and the cross-sectional contours of a template 3D bone model match the CT slices corresponding to its cross-sectional contours. Then, the accuracy of the deformed femoral models from 5 different subjects was evaluated.

2. MATERIALS AND METHODS

2.1 Subjects

A healthy subject (25 years, height 177cm, weight 75kg) has participated to generate accurate 3D template bone model by using CT-scan of a 1mm slice. 6 patients have participated to provide antero-posterior (AP) and lateral (LAT) X-ray images. In addition, five CT slices of the patient's distal femurs are given to generate the deformed femoral bone models for the rotational deformity. The X-ray images were taken by CXDI-40G device [(Canon Inc., Tokyo, Japan) which has max 2,6882,688 pixels, 43cm43cm image size] with our scaling-tool, which is able to measure an approximate size of the bone and angles between two X-ray image.

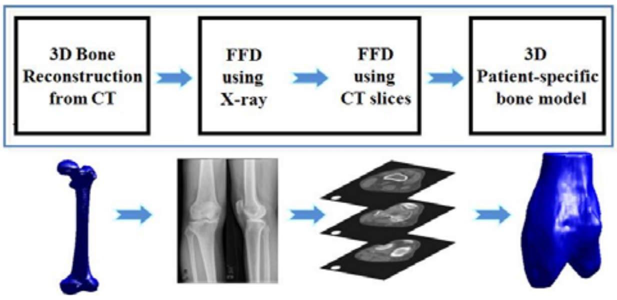

Fig. 1 Flowchart of 3D reconstruction

2.2 Three-dimensional reconstruction of the femoral model from two X-ray images and three CT slices

The process of our 3D reconstruction method can be summarized in three steps (shown in Fig. 1):

1. Generate a template 3D bone model using CT scan of a healthy subject with normal height and weight.

2. Obtain X-ray images taken from any direction, but usually front (AP) and side (LAT), and three CT slices of distal femurs.

3. Deform a template 3D bone model until the images from a template 3D bone model projected onto a two-dimensional (2D) plane match the X-ray images, and the cross-sectional contours of a template 3D bone model match the CT slices corresponding to its cross-sectional contours using the free-from deformation algorithm. This algorithm includes dissimilarity function which measure distance (difference) between 1. X-ray image and the projection images of a template 3D bone model 2. CT images and the cross-sectional contours corresponding to each CT slice. And then optimization is used to minimize dissimilarity function and align the X-ray with the projection images and CT slices with the cross-sectional contours.

3. RESULTS

3.1 Shape accuracy

In order to validate the deformed femoral models obtained by 5 participated subjects, we compared them to the models generated by 1 mm CT scan dataset. The experimental results of this study showed that this deformed femoral model was close to the femoral model obtained by millimetric CT-based reconstruction method.

3.3 Reconstruction time

The reconstruction time in generating 3D deformed femoral models from 5 subjects was from max 3 min 9 sec to min 2 min 55 sec and mean reconstruction time was 3 min 4 sec. This system is implemented by Matlab and runs on quad core 2.40GHz PC. These results indicate the remarkable improvement for time in generating geometric 3D bone model using the proposed method.

4. CONCLUSION

A low radiation dose, time efficient and cost effective patient-specific reconstruction method for the femur was developed using FFD techniques with two X-ray images and three CT images. A patient-specific femur model was reconstructed by deforming a 3D template model of the femur from a healthy subject using two X-ray images and three CT images. The results suggested that the obtained femur model is closer to a CT-based 3D femur model in comparison with the reconstruction method using only X-ray images. This method will have benefits for many clinical and biomechanical applications, such as computer-aided diagnosis or planning systems for orthopaedic surgery, as well as personalized biomechanical and biomedical analyses.

후기

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