Automated determination of pelvic coordinate system and application to clinical study using MDCT images

Introduction
For evaluating hip joint kinematics in total hip arthroplasty (THA), the pelvic coordinate system is commonly used. These anatomical coordinate systems are based on shape of each region. And anatomical landmarks in each region are needed to detect. Today, anatomical landmarks have been manually detected by orthopaedic doctors in multidetector-row computed tomography (MDCT) images. However, manual detection causes inter- and intra-operator variability, which affects diagnosis of osteoarthritis, functional evaluation of hip joint and operation. In case of diagnosis over the long term, MDCT image is acquired more than once, subjects pose is different every acquisition. Therefore automated determination of anatomical coordinate system without subjects pose is required.

There are few studies for automated determination of anatomical coordinate system. In pelvic region, methods based on anterior pelvic plane (APP) that is a tangent plane of pelvis are proposed because anatomical landmarks are on APP. In order to find APP, they extract the anatomical landmarks by registering the predefined atlas data with MDCT images of evaluating subject. The other method finds APP by using the mirror plane associated with the right and left anterior superior iliac spine (ASIS). Although, the conventional methods did not consider about robustness for subjects pose. Diagnosis using anatomical coordinate system uses angle and/or position as a guide, useful data for detection of arthritis is not revealed.

This paper proposes automated determination of lower limb coordinate system using MDCT images and application to clinical study. Pelvic coordinate system is determined by calibration using projected images and finding APP.

As application to clinical study, evaluating symmetry of pelvis and pelvic tilt is proposed to diagnose osteoarthritis.

Materials and methods
MDCT images were acquired by MDCT scanner (Somatom Plus, Siemens, Germany) with a matrix size of 512 by 512 pixels, a spatial resolution of about 0.75 mm square, a slice thickness of 1.0 mm, a number of slices of about 300 for pelvic images, of about 150 for knee images. Subjects were scanned with a feet-first supine (FFS) pose in MDCT scanner. In this study, 4 normal subjects and 6 THA subjects were recruited. THA subject data included metal artifacts because metal components were implanted in body. To extract bone, thresholding is performed to all subject data. In addition, metal artifacts reduction is performed for THA subjects. Pelvic coordinate system is a left-handed coordinate system (X, Y, Z) based on anterior pelvic plane (APP) is a tangent plane to pelvic region. Fig. 1 shows pelvic coordinate system and pelvic landmarks. Pelvic coordinate system is defined by the following definition.

Firstly, the proposed method calibrates pelvic pose to suppress variability by pose change in acquisition using projected images. Next, APP and 4 pelvic landmarks (the right and left ASIS and the right and left pubic tubercles) are determined by searching a plane which contacts with anterior pelvic region. Finally, pelvic synphysis is determined by using a graph and pelvic coordinate system is determined by definition.

Step 1 Calibrate pelvic pose
Pelvic pose is calibrated by using silhouette images. Calibration is achieved by finding a pose which faces the larger area of the anterior pelvis to the front (Z-X plane) and the smaller area of the lateral pelvis to the side (Y-Z plane). Firstly, pelvic pose is rotated around Y and Z axes so that area of projected image to Y-Z plane is the largest. Next, pelvic pose is rotated around X axis so that area of projected image to Z-X plane is the smallest. These rotations are performed by using steepest descent method.

Step 2 Determine APP and pelvic landmarks
APP is constructed by candidate voxels around 4 pelvic landmarks (the right and the left ASIS and the right and the left pubic tubercles). Location of pelvic landmarks can be limited by anatomical knowledge. In each pelvic landmarks area, bone voxels in sphere whose center is voxel with the largest Y-coordinate value for each pixel in Z-X plane, radius is r are determined as candidate voxels. And APP is determined by minimizing number of bone voxels before a plane is constructed by candidate voxels. Four pelvic landmarks are determined by calculating gravity center of candidate voxels on APP in each area. Step 3 Determine pubic symphysis
Pubic synphysis has low CT value because it is cartilage. And it locates between the right and the left pubic tubercles. Thus, the graph of density of bone voxel on the line segment connects the right pubic tubercle and the left pubic tubercle is made. And mean point of points have density is lower than 5 percent is calculated and this point is decided as pubic synphysis.

This paper proposes application to clinical study using anatomical coordinate systems.

To evaluate pelvic symmetry, this method compares right and left pelvis by using projected image to X, Y, Z planes. Z plane is assumed symmetrical axis in projected image to X, Y planes, Z plane is assumed symmetrical axis in projected image to Z, X plane. The coordinate values of each pixel farthest from symmetrical axis are obtained as graph in right and left area. Fig. 2 shows projected image to Z, X plane and obtained corresponding graph. And degree of symmetry is calculated by correlation coefficient of these graphs.

Discussion
This paper proposed automated anatomical coordinate system determination method and application to clinical study. By automating determination of, anatomical coordinate system, inter- and intra-observer variabilities were reduced. As a result of comparing with manual determination by orthopaedic doctors about pelvic coordinate system, the mean ± standard division (SD) of origin displacement was 2.6 ± 1.6 mm, and of pose difference was 0.78 ± 0.34 deg. The proposed method determined pelvic coordinate system was similar to those given manually by the orthopaedic doctors. Pelvic symmetry was quantified by correlation coefficient. As a result of calculating correlation coefficient, mean

Results
The proposed method succeeded to apply to any subjects and anatomical coordinate system is determined. Fig. 3 shows APP and 4 pelvic landmarks determined by proposed method. And the proposed method determined pubic synphysis using a graph of density of bone voxels on the line segment connects the right pubic tubercle and the left pubic tubercle. As a result of comparing with manual determination by orthopaedic doctors about pelvic coordinate system, the mean ± standard division (SD) of origin displacement was 2.6 ± 1.6 mm, and of pose difference was 0.78 ± 0.34 deg. The proposed method determined pelvic coordinate system was similar to those given manually by the orthopaedic doctors. Pelvic symmetry was quantified by correlation coefficient. As a result of calculating correlation coefficient, mean