• EVALUATION OF FOUR-DIMENSIONAL KINEMATICS OF THE KNEE USING HIGH-SPEED CONE BEAM COMPUTED TOMOGRAPHY

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Introduction
Since Hounsfield and Ambrose installed a prototype of the EMI-scanner in 1971, computed tomography (CT) technology has improved rapidly. Moreover, the development of the 16-slice scanner has made dynamic 3D imaging i.e. four dimensional (4D) imaging possible. However, a 32 mm maximum axial field of view imposes a limit on the application of 4D imaging. In order to take 4D images of a wider field of view, a prototype 256-slice CT-scanner has been developed.

In the orthopaedic field, the accurate determination of in-vivo knee kinematics remains a technical challenge. Techniques using the combination of single plane fluoroscopic images and 3D-CT data have been applied to determine in-vivo kinematics, but the accuracy has not been sufficient. The aim of this study is to evaluate detailed kinetic images of the knee, including bone, menisci, both cruciate ligaments, and popliteal arteries in 4D kinematic analysis.

Materials and methods
A prototype 256-slice cone-beam CT (Toshiba Medical Systems, Tokyo, Japan) allows an entire knee to be scanned within a single gantry rotation, and continuous 10 second scanning allows 4D analysis. Scan conditions for the 256-slice scanner were 120 kV, 150 mA, 1.0 s exposure, 1.0 s gantry rotation time, 256 x 0.5 mm slice collimation and 512 x 512 x 256 matrix size. A motion controller was developed to move the knee at a constant speed to avoid irregular movement. The volunteer’s foot was set on the foot plate, and the knee was moved with one to-and-fro movement between 0 and 70 degrees of flexion for 10 seconds.

This study protocol was approved by the ethics committee of the National Institute of Radiological Sciences and Chiba University. Consents forms were signed by all the subjects prior to the study. 15 volunteers (age 25 – 43 years) were enrolled for continuous 10 second scanning in 4D films. Five were scanned without contrast material for kinematics of femoral condyles, tibia and patella. Five were scanned angiographically 40 seconds after intravenous injection of 100ml contrast material (320mgI/ml) for the spatial relationship of the popliteal arteries to the bones in the knee. Five were scanned arthrographically after injection of 5ml contrast material (240mgI/ml) into the knee for kinetics of the menisci and both cruciate ligaments.

Results
Using the region growing method, the femur and tibia bones were extracted from 4D CT data. The flexion angles of the knee were calculated using volume matching and principal component analysis. This determined the minimum distance point-pairs of the medial and lateral compartment at each angle of flexion. The estimated contact points on the medial and lateral condyles of the femur were connected between extension and flexion of 70 degrees (Figure 1). In all of the knees scanned, the internal tibial rotation increased with flexion. The lateral condyle of femur moved posteriorly at knee flexion with a medial pivot. The medial condyle of femur also moved posteriorly but the distance of translation was smaller than the lateral.

The volume-rendered image without contrast material did not show the anterior cruciate ligament. However, when the opacity and window level of volume rendered images were changed, the posterior cruciate ligament emerged. The anterior cruciate ligament could be only confirmed angiographically. The spatial relationships of popliteal vessels, sural vessels, and bones could be also observed in 4D images of angiography (Figure 2).

Discussion
256-slice cone-beam CT can clearly show kinetics of the knee, allowing motion disorders to be easily identified. Combined with angiography or arthrography, the spatial relationships of the arteries or meniscal movement can be evaluated. 256-slice con-beam CT is a powerful and helpful tool in the orthopaedic field, that can result in a more accurate diagnosis and thus providing better options for treatment.