Determination of bone coordinates and kinematic assessment of knee motion using skeletal markers in a cadaver study

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Introduction: Surgical navigation has been brought to clinical use since decades, and even up to now, it is still being used mostly for total knee replacements. However, there are numerous other applications for navigated surgeries in the field of orthopedics, such as fracture fixation or corrective osteotomies, and in order to develop an appropriate system, accurate determination of bone coordinates and thorough understanding of the knee kinematics are important. In this study, we tried to verify our algorithm for determination of bone coordinates in a cadaver study using skeletal markers, and at the same time, attempted to obtain a better understanding of the knee kinematics.

Materials and Methods: The research was performed at the Medical Simulation Center of Tzu Chi University. Optical measurement system (Polaris® Vicra®, Northern Digital Inc.) was used, and reflective skeletal markers were placed over the right iliac crest, right femur shaft, and right tibia shaft. For determination of the hip center, circumduction of the femur was performed, and the center was calculated by the point at the equidistance from the femur markers, assuming that the femur pivoted at the center of hip joint. To verify this data, the head of femur was partially exposed through anterior arthrotomy, and the surface of head was then painted with a probe, in order to find out its center. The femur coordinates were obtained by direct probing the bony landmarks of distal femur through arthrotomy of knee joint, including the medial and lateral epicondyle and Whiteside line. The tibia axis was determined by the center of tibia plateau which was decided via direct probing, and the center of ankle joint obtained by the midpoint between bilateral malleoli. After acquiring the coordinates in both femur and tibia, repeated flexion and extension of knee joint was performed, and positions of the reflective marker spheres were collected. The rotation axis of the tibia was compared to the epicondylar axis. The mechanical axis was also calculated during knee motion, which was determined by the angle formed between the femur and tibia axis.

Results: A very small amount of motion was detected from the iliac crest, and all the data were adjusted at first. There was a discrepancy of about 16.7mm between the two methods for finding the hip center, and the position found by the first method was located more proximally. When comparing the epicondylar axis to the rotation axis of the tibia around knee joint, there was a difference of 2.46 degrees. The total range of motion for the knee joint measured in this study was 0~144 degrees, and the mechanical axis detected was found gradually changing from 0 degrees to undetermined at 90 degrees of flexion, and then returned. Taking the value of 5 degrees as an acceptable range of error, the calculated mechanical axis exceeded this value when knee flexion angle was between 60~120 degrees.

Discussion: The discrepancy between the hip centers calculated from the two methods suggested that the pivoting point of the femur head during hip motion might not be at the center of femur head, and the former location seemed closer to the surface of head at the weight bearing site. Under such circumstances, the mechanical axis obtained through circumduction of the thigh might be 1~2 degrees apart from that obtained from the actual center of femur head. During knee flexion, the mechanical axis also changed...
gradually, which could be due to laxity of knee joint or intrinsic valgus/varus alignment. However, this value became unreliable at the knee position between the flexion angle of 60–120 degrees, and this should be a concern during navigation surgery.

**Conclusions:** In this study, we have developed our own algorithm to build the bone coordinates for both femur and tibia, and we have attempted to evaluate the kinematics of lower limb with our model.