Variability of center of rotation in knee joint during daily activities using novel motion analysis technology

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Introduction: The goal of total knee arthroplasty (TKA) is to restore knee motion during normal activities such as walking and sitting. The center of rotation (COR) of the knee is a fundamental information to analyze the knee kinematics. Conventional implants for the TKA have been designed under the assumption that COR of the knee is located at the anatomical center of the knee joint. However, there has been a controversy regarding COR of the knee. It was shown based on fluoroscopy that the COR was located at the medial part of the knee joint during unloaded flexion and extension, while it was moved to the lateral part during weight-bearing activities such as walking. Because the aforementioned imaging studies used radiographic images, they were difficult to analyze various weight-bearing activities. Marker-based motion analysis method could be an alternative. However it has been known that the marker-based method implied errors due to movement of markers attached to the skin by skin deformation during motions. Recently, novel technologies were developed to improve accuracy of the marker-based kinematic analysis by compensating movement of markers such as the optimal common shape technique (OCST) [1] and the symmetrical axis of rotation approach (SARA) [2]. In this study, movements of COR of the knee joint were investigated during several activities (gait, squat, stair climbing up and stair climbing down) based on the novel motion analysis technology.

Materials & Methods: Seven healthy subjects (6 males and 1 female, 25±1 years old, and 66±10 kg), who have no history of knee or lower limbs injury in the past one year, were participated in the experiment with their agreement. Reflective markers were attached on the skin and each subject warmed up for 10 minutes. The motion capture was then performed during four activities (gait, squat, stair climbing up and stair climbing down) using a motion analysis system with six cameras (Hawk Digital®, Motion Analysis Inc, USA). For gait, subjects walked in a normal speed about 1.1 m/s and repeated the cycle. For squat, subjects were asked to repeat the motion in 2 seconds per one cycle. For stair climbing, subjects were required to climb up and down on a 2-steps stair (20 cm high for each layer) in a normal speed. The combined technique of the OCST and the SARA was developed and it was validated by virtual tests. Three dimensional location of instant COR of each subject was estimated and recorded during an activity. Then the distance between the estimated COR and the anatomical center of the knee joint center in the lateral-medial direction were investigated.

Results: The CORs of the knee joint were moved about 20 mm to 110 mm to the lateral direction during the gait (Figure). The translation was much dependent on the subject, while all CORs were located in the lateral side. During the squat, the CORs were moved to 10 mm lateral side in one subject and to up to 60 mm medial side in the other six subjects. All CORs during climbing up the stair were located in 10 mm to 70 mm lateral side, while one COR was moved to the medial side and the others were moved to the lateral side.

Discussion: The COR was much dependent on not only the subject but also the activities, although the CORs were mainly in the lateral side during the gait, stair climbing up and down, while they were in the medial side during the squat. The patterns of COR movement during activities could be investigated after analyzing many numbers of subjects by grading healthy people and patients using the novel marker-based motion analysis technology with the OCST and the SARA techniques. The developed technology can analyze various daily activities because it is based on the motion capture data instead of radiographic images. Therefore, it can provide fundamental information regarding kinematics of the knee joint, which is helpful to improve the surgical method for TKA or to design new implants.

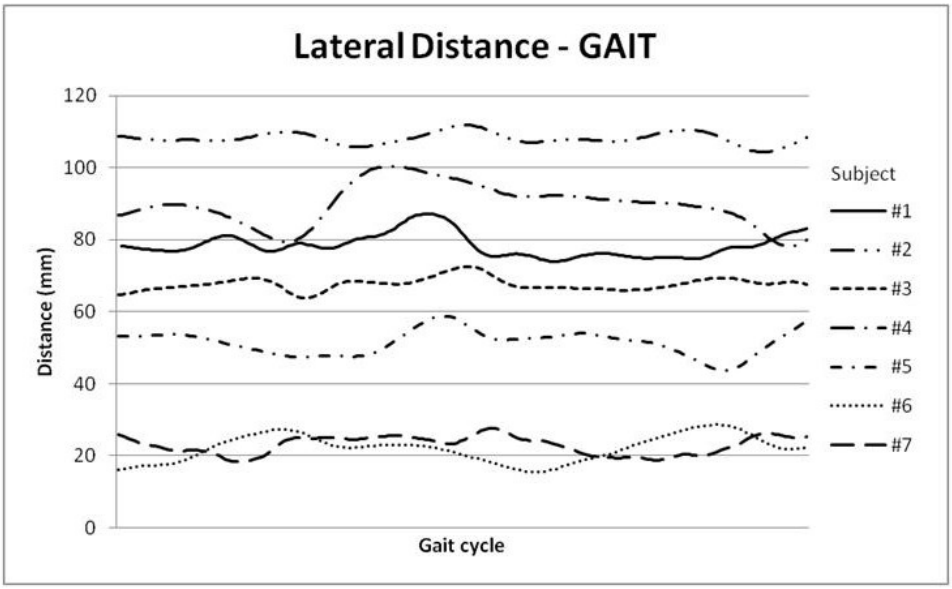

Figure: Center of rotation estimation of seven subjects' left knee at each instance during walking, which were all occurred on the lateral side of knee.

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References

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