Evaluation of artificial hip joints with a hip joint motion simulator

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Introduction: Total hip arthroplasty (THA) is performed to replace all or part of the biological hip joint with an artificial joint for patients who have rheumatoid arthritis or osteoarthritis. For the preoperative planning and the designing of the artificial hip joint, it is important to analyze the dynamic relation between the daily hip joint motion and the possible complication such as dislocation and wear of the artificial hip joint. In this paper, we propose a hip joint motion simulator that can generate the desired hip joint angle and the contact force for any given daily life motion in order to evaluate the performance of the artificial hip joint. The effectiveness of the proposed simulator has been evaluated through experiments.

Materials and Methods: We have developed the hip joint motion simulator that can realize the range of motion (135° Flexion, 20° Extension, 20° Adduction, 45° Abduction, 45° Internal Rotation and 45° External Rotation) and joint contact force, which reaches 3.5 times of body weight, of the hip joint in daily activities. The schematic of the proposed simulator is shown in Fig.1. The simulator consists of a DC servo motor to generate the hip flexion-extension motion, six linear actuators (parallel mechanism) to generate the other hip joint motion and the joint contact force, a six-axis force sensor to measure the three directional joint contact force, an artificial hip joint (stem, cup), and physiological salt solution. The initial angular position (i.e., 0° of hip flexion-extension) shown in Fig.2 is defined at the place which is deviated 30° from the horizontal plane to avoid the mechanical interference between the parallel mechanism and the femur part of the simulator. Experiment has been carried out using the hybrid position/force control theory of robot manipulators to evaluate the effectiveness of the proposed hip joint motion simulator. The target angle and contact force of the hip joint are defined based on the results of human motion analysis using a motion capture system and implanted sensors [1]. In addition, experiment of the hip joint dislocation has been performed to evaluate the risk of dislocation induced by impingement of the stem-cup. In this experiment, the flexion-extension motion was performed with 0° of adduction-abduction, 0° of internal-external rotation, 45° of cup lateral opening angle, 0°, 20°, 40° of cup anterior opening angle, and 0°, 20°, 40° of stem anteverision angle. The six-axis force sensor was used to realize the impingement between the stem neck and the cup of the artificial joint and also to measure its three directional force.

Results: The experimental results of the hybrid position/force control have shown that the angle and the force of a hip joint in daily life activities, such as during walking, can be realized simultaneously by using the developed simulator. In addition, postures with high risk of impingement of the artificial hip joint were clarified in the experiment on dislocation (see Fig.2), i.e., more than 110° of flexion at 0° of cup anterior opening angle and 0° of stem anteverision angle (posterior dislocation), or more than 40° of extension at 40° of cup anterior opening angle and 40° of stem anteverision angle (anterior dislocation). These results show that experimental data obtained with the simulator are almost the same as clinical findings. They also show that the developed simulator can be effectively applied as a new evaluation device for the artificial hip joint.

Discussion: A hip joint motion simulator for the analysis of dislocation and wear of the artificial hip joint has been developed. The experimental results showed that the proposed simulator can realize the joint angle and the contact force for daily life motion and able to define the posture which induces the dislocation of the hip joint, such as anterior dislocation and posterior dislocation. Thus, the developed simulator can be used as an effective tool for the preoperative planning and designing of artificial hip joint. Furthermore, the developed simulator is useful not only for the evaluation of the artificial hip joint but also the evaluation of other artificial joints since it generates 6 degree of freedom motion. In future research, additional experiments are planned expected to be carried out in order to establish the criteria for optimal design of the artificial joint.