Generation of artificial hip joint dislocation by the hip joint simulator considering joint muscle force and joint fluid

+Kazuo Kiguchi; 1Yoshiaki Hayashi; 2Masaru Ueno; 3Tsuneyuki Kobayashi; 1Masaaki Mawatari; 1Takao Hotokebuchi;
+1Department of Advanced Technology Fusion, Saga University, Saga, Japan, 2Japan Medical Materials Corporation, Osaka, Japan,
3Saga Medical School Faculty of Medicine, Saga University, Saga, Japan
kiguchi@mc.saga-u.ac.jp

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. The hip joint simulator which can generate the desired hip joint angle and the joint contact force has been developed in order to evaluate the performance of the artificial hip joint [1]. In this simulator, to become similar to the real artificial hip joint behavior, the muscle force vector which is the resultant force around the hip joint was calculated based on the muscle model and applied to the joint contact force [2]. In this paper, the phenomenon of the artificial hip joint dislocation is analyzed under physiological condition in which the artificial hip joint is soaked in physiological saline instead of the joint fluid in the simulator. The experimental results show that the artificial hip joint dislocation is generated by the effect of the combination of the muscle force and the impingement.

Methods:
Fig. 1 shows the hip joint simulator. The simulator consists of a DC motor, six linear actuators (a parallel link mechanism), a 6-axis force sensor, an artificial-hip-joint, universal joints, and 3-DOF passive joint units. Fig. 2 shows the artificial hip joint part. The artificial hip joint consists of a stem, a ball, and a cup. The simulator has 7 degrees of freedom, and can generate the desired hip joint angle and the desired joint contact force. To realize more realistic behavior of the artificial hip joint, the desired hip joint angles obtained by measuring the daily life motion with the motion capture system are used as the desired hip joint angles. And the muscle force vector is used as the desired joint contact force. The muscle force vector is calculated by using the muscle model [3,4]. In the muscle model, 28 muscles around a hip joint are modeled. In addition, the artificial hip joint is soaked in physiological saline instead of the joint fluid as shown in Fig. 3. The experiment has been carried out using the impedance control to generate a daily hip joint motion and realize realistic hip joint dislocation with the hip joint motion simulator. The daily hip joint motions which might cause an anterior dislocation or a posterior dislocation were selected as the target angles. One motion is the squatting motion with deep knee flexion, i.e., the motion which might include the posterior dislocation. The other is the twisting motion of the upper body in the direction opposite to the artificial-hip-joint, i.e., the motion which might include the anterior dislocation. In the experiments, the desired hip joint angles are the daily hip joint motions which might induce an anterior dislocation or a posterior dislocation. To realize more realistic behavior of the artificial hip joint, the desired angle obtained by measuring the daily life motion with the motion capture system are used as the desired hip joint angles. On the other hand, the artificial hip joint is installed at 45° of cup lateral opening angle, 0° of stem anteverision angle, and 0° of stem anteversion angle when the squattin motion. The on the other hand, the artificial hip joint is installed at 45° of cup lateral opening angle, 40° of cup anterior opening angle, and 40° of stem anteverision angle when the twisting motion. In the experiments, the diameter of the ball is 26mm.

Results:
The daily hip joint motions were recreated and the realistic hip joint dislocation phenomenon was realized by the simulator. In the squatting motion, the posterior dislocation occurs when the hip flexion/extension angle is about 73°-80°, the hip adduction/abduction angle is about (-23°) (-22°), and the hip internal/external rotation angle is about 12°-15°. When the posterior dislocation occurs, the amount of the joint contact force which acts on the hip joint is about 2080N. In the twisting motion, the anterior dislocation occurs when the hip flexion/extension angle is about 3°-4°, the hip adduction/abduction angle is about (-6°) (-7°), and the hip internal/external rotation angle is about (-20°) (-16°). When the anterior dislocation occurs, the amount of the joint contact force which acts on the hip joint is about 2290N. An example of the experimental results is shown in Fig. 3. In the experiments, the joint contact force generated by muscles acts in the direction that the ball presses the cup backward. However, since the contact position between the cup and the ball is changed because of the impingement between the cup and the stem, as a result, the dislocation occurs by the joint contact force. The experimental results show that experimental data obtained with the simulator are almost the same as clinical findings.

Discussion:
The phenomenon of the artificial hip joint dislocation has been generated under physiological condition using the hip joint simulator in this study. In the experiments, the desired hip joint angles are the daily hip joint motions which might induce an anterior dislocation or a posterior dislocation. In addition, the joint contact force vector is calculated by the muscle model and applied to the joint contact force. The experimental results show that the muscle force vector acts in the direction that ball presses the cup, and then the dislocation occurs since the contact position between the cup and the ball is changed because of the impingement between the cup and the stem. The dislocation would not occur if the impingement is not occurred. Furthermore, the muscle force vector itself does not make the dislocation. The dislocation is generated by the effect of the combination of the muscle force and the impingement.

Reference: