Dynamic Hip Kinematics During Golf Swing In Patients After Total Hip Arthroplasty

Daisuke Hara, M.D.1, Yasuharu Nakashima, M.D., Ph.D.1, Satoshi Hamai, M.D., Ph.D.1, Hidehiko Higaki, Ph.D.2, Satoru Ikebe3, Takeshi Shimoto, Ph.D.1, Masanobu Hirata, M.D.1, Masayuki Kanazawa, M.D.1, Yusuke Kohno, M.D.1, Yukihide Iwamoto, M.D., Ph.D.1.

1Department of Orthopaedic Surgery, Graduate School of Medical Sciences, Kyushu University, Fukuoka, Japan, 2Department of Medical Engineering, Faculty of Engineering, Kyushu Sangyo University, Fukuoka, Japan, 3Department of Mechanical Engineering, Faculty of Engineering, Fukuoka Institute of Technology, Fukuoka, Japan.


Introduction: Total hip arthroplasty (THA) provides excellent pain relief, correction of deformity, and improved function. The improvement in pain and function allows some patients to participate in sports activities. The expectation of returning to sports activities after THA has become more important to patients than ever. Golf is a popular recreational sport played more frequently among seniors in whom THAs are usually performed. Despite the fact that golf is considered low-impact sport, concerns exist about whether a golf swing can be performed in a safe manner after THA. To our knowledge, no study has been published the hip motion during golf swing after THA. The purpose of this study was to clarify the dynamic hip kinematics during the golf swing after THA using the 3D-to-2D model-to-image registration technique.

Methods: This study group consisted of eight patients with 10 primary THAs with a minimum follow-up of 6 months and no other joint arthroplasties. These ten hips included four women and six men, averaging 66 ± 12 years (range, 55-84). The preoperative diagnoses were osteoarthritis in eight hips and osteonecrosis of the femoral head in two hips. Each operation was performed using a posterolateral approach. A cementless hemispherical press fit cup, a straight metaphyseal fit stem, and highly cross-linked polyethylene liner (AMS & PerFix HA, Aeonian; Kyocera, Osaka, Japan) were used in all hips. Nine of ten polyethylene liners used had the elevated portion of 15°. Postoperative follow-up periods and Harris Hip Score were 58 ± 62 months (6-164), 97 ± 4 (91-100), respectively. All subjects were right-handed recreational golfers. Five trail hips (the right hip in the right-handed golfer) and five lead hips (the left hip in the right-handed golfer) were analyzed. Continuous anteroposterior radiographic images of golf swing were recorded using a flat panel X-ray detector (Ultimax-I, Toshiba, Tochigi, Japan) with an image area of 420 mm (H) × 420 mm (V), and 0.274 mm × 0.274 mm/pixel resolution. The frame rate was set 3.5 frames/sec to acquire high-resolution images. Five X-ray images from the set-up position to the end of the follow-through (set-up, early backswing, late backswing, top of the backswing, and end of the follow-through) were analyzed using 3D-to-2D model-to-image registration technique (Fig. 1) [1, 2]. Each subject was scanned by CT (Aquilion, Toshiba, Tochigi, Japan) with a 512 × 512 image matrix, a 0.35 × 0.35 pixel dim, and a 1-mm thickness spanning from superior edge of the pelvis to below the knee joint line. The 3D digital image was constructed in a virtual 3D space by the CT data, and computer simulation of the radiographic process was carried out to generate virtual digitally reconstructed radiograph (DRR). The density-based DRRs and projection images of the computer aided design (CAD)
models of the implants were then compared with the serial X-ray images acquired using the flat panel X-ray detector. Correlations of the pixel values between the DRRs and real X-ray images were used to fine-tune the 3D models and the 6 degrees of freedom of the pelvis, the femur, the acetabular cup, and the stem were determined. The relative orientations of the femur to the anterior pelvic plane and the stem to the acetabular cup were defined as hip and implant movements (flexion/extension, adduction/abduction, internal/external rotation: IR/ER). The relative distance between the center of cup and femoral head (cup-head distance) and the minimum distance between the stem and liner were also measured using a CAD software program. In postoperative CT data, the cup inclination, cup anteversion, and stem anteversion were measured as an abduction angle using the inter-teardrop line as the baseline, the operative anteversion, and the angle of the prosthetic femoral neck relative to the epicondylar line, respectively. The sum of the cup and stem anteversion was calculated as combined anteversion (CA). Hip kinematics, the orientation of implants, and cup-head distance were compared between patients with and without liner-to-stem contact by Mann-Whitney U test.

**Results:** At the top of backswing, the lead hips showed 26 ± 11° ER with 4 ± 9° of flexion and 6 ± 12° of abduction, and the trail hips showed 24 ± 19° IR with 11 ± 14° of flexion and 2 ± 7° of abduction (Fig. 2). At the end of follow-through, the lead hips showed 24 ± 19° IR with 7 ± 16° of flexion and 1 ± 9° of abduction, and the trail hips showed 24 ± 12° ER with 6 ± 13° of flexion and 8 ± 9° of adduction. The mean cup inclination and anteversion, stem anteversion, and CA were 40 ± 5°, 18 ± 11°, 33 ± 14°, and 50 ± 8°, respectively. The minimum distance between stem and liner showed the smallest value of 3 ± 4 mm at the maximum ER in all hips. The liner-to-stem contact was observed in four hips with elevated liners (two trail hips and two lead hips, all men). Patients with elevated liner-to-stem contact demonstrated significantly (p = 0.04, 0.04, and 0.01, respectively) larger maximum ER and cup anteversion (33 ± 5° and 27 ± 6°, respectively) than patients without contact (19 ± 10° and 12 ± 9°, respectively). The cup-head distances demonstrated 0.9 ± 0.5 mm of translation on average. No significant difference was found in the flexion/extension and adduction/abduction at the maximum ER, cup inclination, CA, and cup-head distance between patients with and without contact (-5 ± 16°, -12 ± 10°, 42 ± 3°, 45 ± 9°, and 0.9 ± 0.2 mm vs. 2 ± 7°, -4 ± 9°, 38 ± 6°, 53 ± 6°, and 0.9 ± 0.5 mm, p = 0.75, 0.34, 0.39, 0.24, and 0.83, respectively). Bone-to-bone and bone-to-implant contacts were not observed in all hips at all phases.

**Discussion:** Golf swing produced approximately 50° of axial rotations on average in both the lead and trail hips after THA, which is equivalent for the amount of axial rotations during golf swing in normal hips. The mean cup-head distances showed less than 1.0 mm of translation, and there was no significant difference between patients with and without stem-liner contact. Therefore, we consider that dynamic stability without excessive hip rotations or subluxation was demonstrated during golf swing in all patients after THA using 3D-to-2D model-to-image registration technique. Although there was no evidence of implant malpositioning on CT analysis of the hips, elevated liner-to-stem contact during golf swing was observed in 40% of hips with significantly larger ER and cup anteversion. The contact between stem and elevated liner may be a concern with regard to the long-term prognosis following THA. In order to avoid liner-to-stem contact during golf swing, further attention must be given to the anteversion of the implants and the use of elevated liner at the time of surgery.
**Significance:** Dynamic stability without excessive rotations or subluxation was demonstrated during golf swing in all hips after THA. However, elevated liner-to-stem contact was observed in 40% of hips with significantly larger ER and cup anteversion.

Fig. 1: Subjects performed a golf swing (upper stand) while their hip motion was observed using a flat panel X-ray detector. The X-ray images (lower stand) showed the lead (left) hip being studied.
Fig. 2: Hip rotation angles during golf swing in the lead hip (blue line) and trail hip (red line).

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