The influence of cup anteversion on total hip arthroplasty dislocation mechanisms

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[INTRODUCTION] Dislocation continues to be a common complication of total hip arthroplasty (THA). Many in vitro studies have reported the range of motion (ROM) of the hip, impingement, and dislocation mechanism, but the influence of muscle and soft tissue remains little explored. Many factors affect the prevalence of dislocation after THA, including soft tissue laxity, surgical approach, component position, patient factors, and component design [1]. Bartz et al. investigated the dislocation mechanism using in vitro cadaver simulation with load cables to simulate muscle actions, and reported spontaneous dislocation that occurred without impingement [2]. An in vivo intraoperative study suggested soft tissue traction could be one major reason for subluxation or dislocation with hip flexion and internal rotation [3]. These studies suggest that soft tissue might play an important role for dislocation after THA. In this study, we used a three-dimensional numerical model to calculate all muscles forces crossing the hip and predict the soft-tissue tension and force directions. This numerical model has been validated with intraoperative in vivo measurements.

The objective of this study was to investigate the effects of the acetabular cup anteversion angles on ROM and dislocation mechanism using a numerical model that includes the effects of soft-tissue tension.

[MATERIALS AND METHODS] A three-dimensional computer aided design (CAD) model of pelvis and left femur with hybrid hip arthroplasty prosthesis (4-U; Nakashima Medical, Okayama, Japan [4]), and skeletal muscles crossing the hip joint was developed using SolidWorks (SolidWorks Co., Concord, Mass). Bone geometry was based upon a commercially available human bone replica (Sawbones, Vashon Island, WA). The femoral component was implanted in neutral position, preserving leg length and the anteversion was 15°. The polyethylene liner with 1 mm cup depth was implanted in the acetabulum with 45° inclination and four anteversion angles: 0°, 10°, 20°, and 30°. Muscle attachment data [5] were scaled to the bone model using an affine scaling transformation [6] and were positioned on the bone surfaces. All muscles were modeled as straight lines between these attachment points. Each two-joint muscle that crosses the knee was also modeled given fictitious attachment points [5]. Each muscle that wraps over bone has intermediate points to represent the muscle path more accurately. The number of these wrapping points is dependent upon thigh position. Force-length curves for all muscle tendon units were derived from the literature [7]. This study simulated the intraoperative conditions used in the previous in vivo study [3]. Only passive muscle forces were considered. To calculate the resultant hip force, quasi-static conditions were assumed with zero acceleration of the femur at each increment of movement. The calculated results were compared directly with in vivo measurements to validate the model.

The model was exercised with increasing hip flexion, adduction and internal rotation concurrently from the starting position until prosthetic or bony impingement, or spontaneous dislocation occurred. The starting position was defined at 0° of flexion, adduction, and internal rotation. Over 0° of hip flexion, adduction and internal rotation, all angles of their combination were analyzed with 1° increment. Spontaneous dislocation was defined to occur at the instant when the line of action of the resultant hip force vector moved from the bearing surface onto the lip chamfer before prosthetic or bony impingement occurred.

[RESULTS] Fig. 1 shows the resultant hip force from extension to 90° flexion with adduction and internal rotation was kept at 0° constant. Within this motion, prosthetic or bony impingement or spontaneous dislocation was not observed regardless of cup position. With increasing hip flexion, superior force components decreased, and posterior force components increased. With increasing cup anteversion angle, the angles of flexion, adduction, and internal rotation before impingement were increased. With 0° cup anteversion, prosthetic impingement occurred at 95° of flexion in 0° of adduction and internal rotation. With 10° cup anteversion, prosthetic impingement occurred at 109° of flexion. With 20° and 30° cup anteversion, bony impingement occurred at 114° flexion. Changing the hip angle from the starting position, three different mechanism of dislocation were observed: prosthetic impingement between the femoral stem neck and the liner rim, bony impingement between the osseous femur and the osseous pelvis and spontaneous dislocation. A transition from prosthetic to bony impingement occurred with increasing cup anteversion angle. Spontaneous dislocation occurred with cup anteversion angles more than 10° (Fig.2). With 30° cup anteversion, spontaneous dislocation occurred at the narrow zone around 80° flexion, 30° adduction and 32° of internal rotation.

[DISCUSSION] A three-dimensional computer model that was validated by in vivo measurements was used to predict the resultant hip force, and indicated spontaneous dislocation could occur due to muscle tractions without impingement. Recent studies [2, 3] suggest soft tissue may play an important role in hip dislocation after THA. During surgery, the shuck test is used to determine the overall soft tissue tension around the hip joint with hip extension. However, our model results based on passive muscle tension indicate the hip force is quite different from hip extension to hip flexion. With 90° flexion the resultant hip force vector is directed posteriorly and inferiorly near the outer rim of the polyethylene liner. This finding seems to correlate well with posterior dislocation of the hip that occurs clinically with hip flexion and internal rotation, especially when the cup is retroverted.

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Fig. 1 Hip force as a function of flexion. Positive values indicate anterior, superior, and medical forces. Internal/external rotation and adduction/abduction were constant at 0°.

Fig. 2 The effect of the cup anteversion angle on the mechanism of impingement/dislocation.