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Risk of edge-loading and prosthesis impingement due to posterior pelvic tilting after total hip arthroplasty

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ABSTRACT

Background: Proper implant orientation is essential for avoiding edge-loading and prosthesis impingement in total hip arthroplasty. Although cup orientation is affected by a change in pelvic tilt after surgery, it has been unclear whether surgeons can prevent impingement and edge-loading by proper positioning by taking into account any change in pelvic alignment associated with alteration of hip range of motion.
Methods: We simulated implant orientation without edge-loading and prosthesis impingement, even with a change in pelvic tilt and associated change in hip range of motion after surgery, by collision detection using implant models created with computer-aided design.
Findings: If posterior pelvic tilting with a corresponding hyperextension change in hip range of motion after surgery remains within 10°, as occurs in 90% of cases, surgeons can avoid edge-loading and impingement by correctly orienting the implant, even when using a conventional prosthesis. However, if a 20° change occurs after surgery, it may be difficult to avoid those risks.
Interpretation: Although edge-loading and impingement can be prevented by performing appropriate surgery in most cases, even when taking into account postoperative changes in pelvic tilt, it may also be important to pay attention to spinal conditions to ensure that pelvic tilting is not extreme because of increasing kyphosis.

1. Introduction

In total hip arthroplasty (THA), acetabular cup orientation is essential for avoiding edge-loading and prosthesis impingement, which may lead to serious complications such as dislocation, mechanical loosening, wear or breakage of the polyethylene liner, metallosis or metal ion release in metal-on-metal bearings, and squeaking or breakage in ceramic-on-ceramic bearings (Bader et al., 2004; Barrack, 2003; Chen et al., 2005; De Haan et al., 2008; Gambera et al., 2002; Grammatopoulos et al., 2010; Iida et al., 1999; Shon et al., 2005). Many clinical and basic-science studies (Callanan et al., 2011; De Haan et al., 2008; Little et al., 2009) have shown that to avoid edge-loading, which means that the femoral head makes contact with the acetabular component near the rim in loading conditions, it is recommended to position the acetabular cup radiographically at an inclination of <50°. Moreover, since the 1990s several authors (D'Lima et al., 2000; Jerosch J et al., 2002; Seki et al., 1998; Widmer and Zurfluh, 2004; Yoshimine, 2005) have investigated what prosthesis orientation and design features are best for maximizing range of motion (RoM) and thus preventing prosthesis impingement. Prosthesis RoM is affected by stem anteversion, cup inclination, cup anteversion, neck-shaft angle, and oscillation angle (Fig. 1). Oscillation angle, which is the maximum movable arc of the neck on a cross-sectional plane through the top of the dome of the cup, is dependent on head size, head–neck ratio, and cup opening plane level (Yoshimine, 2005) (Fig. 1). It was reported that cup inclination less than 35° significantly reduced prosthesis RoM (Kummer et al., 1999), and it has been recommended that cup anteversion be decided by positioning the stem in anteversion to prevent prosthesis impingement within a required hip RoM, which is the so-called combined anteversion theory (Widmer and Zurfluh, 2004). A neck-shaft angle between 125° and 131° has been reported to produce maximum prosthesis RoM (Widmer and Majewski, 2005), and an oscillation angle of >135° has been recommended to provide sufficient prosthesis RoM to avoid prosthesis impingement in conventional THA (Yoshimine, 2005). Although many available prostheses have an appropriate neck-shaft angle, there are few hip implant systems with such a large oscillation angle. A larger prosthesis RoM can be obtained by selecting a larger head size from system options (Chandler et al., 1982), although there are limits to how large a head can be used,

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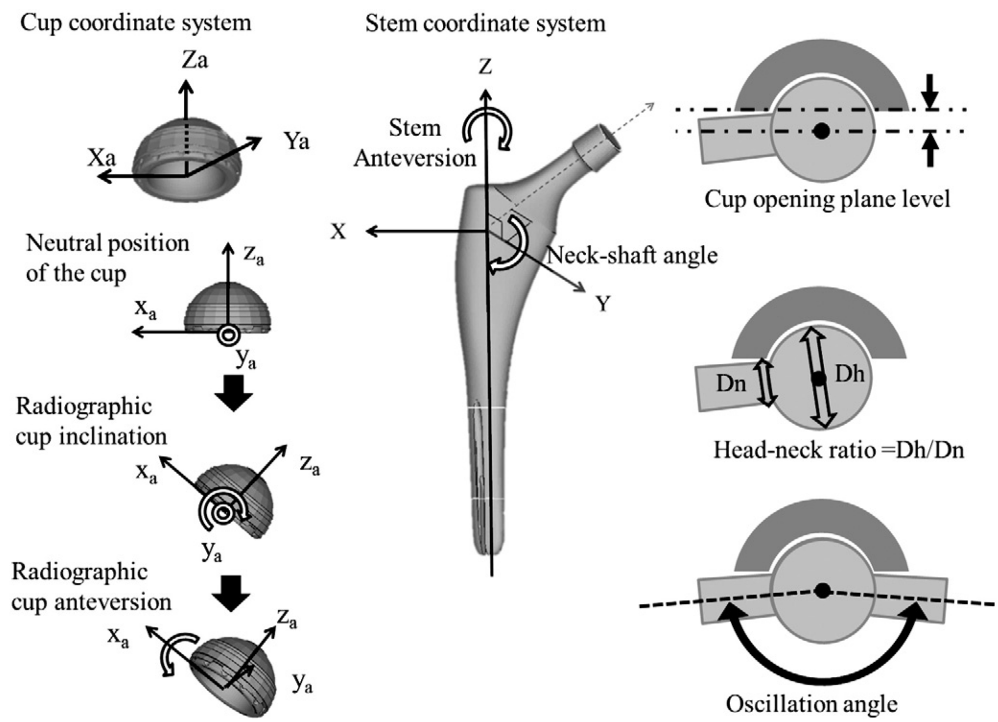

Fig. 1. The coordinate system of the femoral stem and the acetabular cup, radiographic cup inclination and anteversion, stem anteversion, neck-shaft angle, cup opening plane level, head–neck ratio, and oscillation angle. The *z-axis* of the stem passes through the center of the distal cylindrical portion. The *y-axis* is perpendicular to the *z-axis* and the line perpendicular to the circular plane of the top of the neck. The *x-axis* is perpendicular to the *y-axis* and *z-axis*. The x_a-*axis* and y_a-*axis* of the cup are included in the opening plane of the cup, and the z_a-*axis* passes through the top of the cup's dome. Radiographic cup inclination and anteversion were defined as the angles around the y_a-*axis* and x_a-*axis* of the cup, respectively, from the position in which the cup and the pelvic coordinate systems were parallel. Stem anteversion was defined as the rotation angle around the *z-axis* of the stem from the position in which the stem and the femoral coordinate systems were parallel. Neck-shaft angle is the angle between the *z-axis* of the stem and the line perpendicular to the circular plane of the top of the neck. Cup opening plane level is the distance between the head center and the cup opening plane. Head–neck ratio is a value calculated from the following formula; the diameter of the head (Dh) / the diameter of the neck at the level of impingement point to the liner (Dn). Oscillation angle is the maximum movable arc of the neck on a cross-sectional plane through the top of the dome of the cup.

because head size is dependent on cup size and liner thickness, and too large a head size can introduce the risk of corrosion at the head–neck junction (Dyrkacz et al., 2013). Therefore, in modern THA surgeons commonly aim for a cup inclination of 40° to 45°, choose cup anteversion on the basis of combined anteversion theory, and select a larger head size if possible. In addition, cup orientation can be affected by pelvic position, because the acetabular cup is fixed on the pelvis.

Preoperative cup planning has been generally performed using supine anteroposterior (AP) radiographs of the pelvis. However, it is known that the preoperative change in pelvic tilt from the supine to the standing position (positional change) tends to be in the posterior direction and that it is maintained in the early stages just after THA (Nishihara et al., 2003; Parratte et al., 2009; Taki et al., 2012) (Fig. 2). Moreover, when the pelvis is in the standing position, it tends to tilt posteriorly (temporal change) after surgery (Babisch et al., 2008; Nishihara et al., 2003; Parratte et al., 2009; Taki et al., 2012) (Fig. 2). A large posterior pelvic tilt of >10° has been seen in almost 10% of cases in both preoperative positional change and temporal change in the standing position (Nishihara et al., 2003; Taki et al., 2012). These changes are seen especially in older patients and are considered to be associated with degenerative changes in the lumbar spine (Kyo et al., 2013; Miki et al., 2012). Therefore, as the size of the elderly population increases, it is important take into consideration that a discrepancy in pelvic tilt in comparison with the supine pelvic position at preoperative planning might generate edge-loading and prosthesis impingement a long time after the THA.

Until recently, surgeons have focused appropriate cup orientation for patients with a large preoperative posterior positional change in pelvic tilt. In these patients, the standing hip position was further extended than in the supine neutral position. Therefore, some authors theorized that in these patients, the hip neutral position and hip RoM might shift in the direction of extension (a change to hyperextension) because of the extent of posterior pelvic tilt, and thus they recommended decreasing cup inclination and anteversion in initial operations to help avoid new edge-loading or prosthesis impingement (Nishihara et al., 2003; Sato et al., 2013; Taki et al., 2012). However, it was reported that such a change to hyperextension did not occur in the early stages just after THA and that it was not necessary to change cup target orientation even in patients with a large preoperative positional posterior pelvic tilt (Miki et al., 2012). Indeed, no cases of anterior dislocation have been reported one year after THA with appropriate orientation using a navigation system, even for patients with a large preoperative positional posterior change in pelvic tilt (Kyo et al., 2013). However, studies have not focused on the temporal posterior change in pelvic tilt, although it has been reported that a posterior change in pelvic tilt in the standing position long after surgery might cause new prosthesis impingement between the femoral neck and the posterior edge of the acetabular cup (Di Schino et al., 2009; Onda et al., 2008). Di Schino et al. and Onda et al. also showed that it is possible that a change in hip RoM to hyperextension is associated with a posterior temporal change in pelvic tilt (Fig. 2).

Regarding edge-loading, it was reported that a maximum change in pelvic tilt from the preoperative supine position to the standing position 1 year after THA was 23° in the same patient and that cup inclination was within 50° when the original cup inclination was set at 40°, even if the maximum posterior pelvic tilt occurred soon after THA (Kyo et al., 2013). However, the effect of further posterior tilting because of a temporal change had not been elucidated. Therefore the objective of this study was to investigate what was the appropriate cup orientation when some temporal posterior change in pelvic tilt is present in the