European Journal of Orthopaedic Surgery & Traumatology (2019) 29:807–812
https://doi.org/10.1007/s00590-019-02383-w

ORIGINAL ARTICLE • HIP - ARTHROPLASTY

Total hip arthroplasty using stem-first technique with navigation: the potential of achievement of the optimal combined anteversion being a risk factor for anterior cup protrusion

Taishi Okada[1] · Shigeo Fukunishi[1] · Yu Takeda[1] · Tomokazu Fukui[1] · Yuki Fujihara[1] · Shoji Nishio[1] · Shohei Okahisa[1] · Yoshinobu Masumoto[1] · Shinichi Yoshiya[1]

Received: 16 October 2018 / Accepted: 10 January 2019 / Published online: 17 January 2019

Abstract

Purpose In the combined anteversion (CA) technique for total hip arthroplasty (THA) with a cementless stem, cup anteversion is strongly influenced by the native femoral anteversion. It is hypothesized that in cases with large native femoral anteversion, cup anteversion can be decreased, and anterior cup protrusion from the anterior edge of the acetabulum could occur due to the achievement of optimal CA. In this study, the accuracy of CA in THA with the CA technique using imageless navigation and the relationship between the protrusion of the anterior edge of cup and optimum CA was retrospectively evaluated.

Methods Ninety-seven patients (104 hips) who underwent primary THA by the CA technique using image-free navigation were enrolled in the study. The femoral stem was placed following the individual femoral anteversion so that the target cup anteversion could be determined following a mathematical formula (37 = femoral stem anteversion × 0.7 + cup anteversion).

Results The resulting CA values effectively achieved accurate CA with 39.49 ± 5.03° postoperatively. On the other hand, anterior cup protrusion was measured by computed tomography image. A cup protrusion length of more than 3 mm was indicated for 60 cases (57.7%). All included patients were divided into two groups: Group 1 as protrusion positive and Group 2 as protrusion negative. In Group 1, preoperative femoral anteversion and postoperative stem anteversion were significantly higher, while postoperative cup anteversion was significantly lower. However, the postoperative CA value indicated no significant difference between the groups.

Conclusions The CA (stem-first) technique with image-free navigated THA could effectively achieve accurate CA. On the other hand, a large number of cases revealed anterior cup protrusion due to the low cup anteversion.

Keywords Combined anteversion · Stem-first THA · Imageless navigation · Cup protrusion

Introduction

In THA, positioning of the cup and stem is one of the important factors influencing the postoperative surgical outcome [1–5]. Recently, the concept of combined anteversion (CA), the sum of acetabular anteversion and femoral anteversion, has been proposed as a parameter to assess appropriateness of the overall prosthetic alignment in THA procedure [5–9]. Based on the results of a computerized 3-D model analysis, Widmer et al. proposed a formula (cup anteversion + 0.7 × stem anteversion) to figure out the CA value and defined the ideal value to be 37.3° [1]. Yoshimine et al. described similar computer simulation studies and proposed the following formula: cup anteversion + 0.8 × stem anteversion + cup inclination = 90.8° [7]. To achieve an appropriate CA for each case, the method of adjusting cup anteversion according to stem anteversion, the so-called CA technique, has been recommended in cementless THA by Dorr et al. [8, 9]. Following their paper, the CA technique (stem-first procedure) has been generally accepted to achieve the optimal CA value in THA. On the other hand, the groin pain due to iliopsoas impingement after THA has been identified as a poor outcome of surgery [10–12]. As a result of the

✉ Taishi Okada
okadataishi20@yahoo.co.jp

[1] Department of Orthopedic Surgery, Hyogo College of Medicine, 1-1, Mukogawa-cho, Nishinomiya, Hyogo 663-8501, Japan

anterior cup protrusion from the margin of the acetabulum, the impingement occurs between the iliopsoas tendon and the anterior edge of the cup overhanging from the acetabular rim [10–12]. In the CA technique for THA, cup anteversion strongly influenced the native femoral anteversion using a cementless stem. It is hypothesized that in cases with large native femoral anteversion, cup anteversion can be decreased, and anterior cup protrusion from the anterior edge of the acetabulum could occur due to the achievement of optimal CA. There have been no reports describing the relationship between the protrusion of the anterior edge of the cup and optimal CA in THA with the CA technique. In this study, the accuracy of CA in THA with the CA technique using imageless navigation and the relationship between the protrusion of the anterior edge of cup and optimum CA was retrospectively evaluated.

Materials and methods

This study was approved by the Institutional Review Board of Hyogo College of Medicine (No. 2265), and informed consent was obtained from the patients.

Study population

A consecutive series of patients who underwent primary THA by CA technique using an imageless navigation system (OrthoPilot THA Pro™, B/Braun-Aesculap, Germany) were initially enrolled in the study. Patients with a native femoral AT of more than 53° or less than 0° were not targeted at the native angle due to the difficulty of the achievement of optimal CA, and thus, these subjects were excluded from the study.

Ninety-seven patients (104 hips) underwent primary THA using an image-free navigation system with the CA technique during the period from January 2012 to February 2017. There were 21 male (22 hips) and 76 female patients (82 hips) with a mean age of 68.2 years (range 23–86 years). Hip pathologies in this study population included osteoarthritis due to hip dysplasia in 86 cases (91 hips) and osteonecrosis in 11 cases (13 hips).

Preoperative evaluation

All included patients underwent preoperative CT (Somatom, Siemens, Munich, Germany) examination from the level of the pelvis to the posterior femoral condyles to measure the native femoral anteversion. The CT data were transferred as DICOM files to a desktop computer. The DICOM data were recognized by the CT-based preoperative planning software (ZedHip, LEXI Co., Ltd., Tokyo, Japan). For the measurement of native femoral anteversion, the 3D model of the femur in the software was re-positioned with the tabletop plane coincident with the posterior condyles and the most prominent posterior point of greater trochanter as described by Kingsley and Olmsted [13]. The femoral neck axis was defined in the transverse slice on the most proximal portion of the inferior neck that has no head portion as proposed by Sugano et al. [14]. The native femoral anteversion was measured by determining the angle between the femoral neck axis and the tabletop plane.

Surgical procedure

Surgery was performed by two senior surgeons (SF and YT) who are experienced with using the image-free navigation system. In order to use navigation, the screw with the tracker device was placed into the ipsilateral ilium with the patient in the supine position before surgery. In addition, another tracker device (femoral clamp) was attached to the greater trochanter of the femur during surgery. The surgical approach was either the modified Hardinge approach with the patient positioned in the lateral position or the anterolateral approach in the supine position. The modified Hardinge approach was employed for 66 cases (71 hips), and the anterolateral approach was employed for 31 cases (33 hips). An image-free THA navigation system was utilized to determine cup and stem alignment. The implanted prosthetic system was composed of a cementless cup (Plasma cup BTM, B/Braun-Aesculap, Germany), a cementless stem (BicontactTM, B/Braun-Aesculap, Germany), a ceramic 32-mm head, and a ceramic liner from the same manufacturer. The stem-first procedure was performed, and the femoral stem was placed following the value of the individual native femoral anteversion angle as measured on preoperative CT images. During surgery, the surgeon confirmed the final stem anteversion value in the monitor of the navigation so that target cup anteversion could be determined following a mathematical formula ($37.3 = \text{femoral stem anteversion} \times 0.7 + \text{cup anteversion}$). The cup was inserted at the target anteversion angle corresponding to the mathematical formula with navigation. The target cup inclination angle was fixed at 40 degrees.

Postoperative evaluation

For assessment of the postoperative implant orientation, all included patients underwent postoperative CT examinations a week after surgery. A helical CT scan providing an image with a 3-mm slice interval from the pelvis to the knee was performed for all cases. Postoperative cup and stem position were assessed using a 3D-Template system (ZedHip) after CT examination. In this measurement, cup anteversion and inclination were evaluated in reference to the anterior pelvic plane (APP), and stem anteversion was evaluated using the condylar axis on the tabletop plane as a reference line. During the calculation of the angles for prosthetic alignment, anatomical angles obtained from the CT measurements were automatically converted to an angle for radiological definition in the software as used in the navigation assessment to enable fair comparison.

Parameters adopted for the analysis were as follows: preoperative native acetabular anteversion, preoperative native femoral anteversion, radiographic cup inclination, radiographic cup anteversion, radiographic stem anteversion, accuracy of the navigation system, and CA. Furthermore, Widmer's mathematical formula (cup anteversion + 0.7 × stem anteversion) was applied to these parameters, and the resultant values were compared with the target value of their formula (37.3°) [1]. In the assessment of the appropriateness of the overall alignment, the calculated Widmer's CA values from 25° to 50° were regarded as to be the satisfactory range [8, 9]. In order to test the accuracy of the navigation system, the intra-operative navigation results and the corresponding values obtained from the postoperative CT measurements were compared.

Cup protrusion length

CT measurements were obtained using imaging ZedHip. Each protrusion length was measured on both axial and sagittal view of the CT image on the slice passing through the center of the head [15–17]. Anterior cup protrusion more than 3 mm on either the axial or sagittal view of the CT image was defined as protrusion positive. After the measurement of the cup protrusion, all included patients in this study were divided into two groups with Group 1 as protrusion positive (Fig. 1) and Group 2 as protrusion negative (Fig. 2). Preoperative and postoperative parameters with CT evaluation were compared between Group 1 and Group 2.

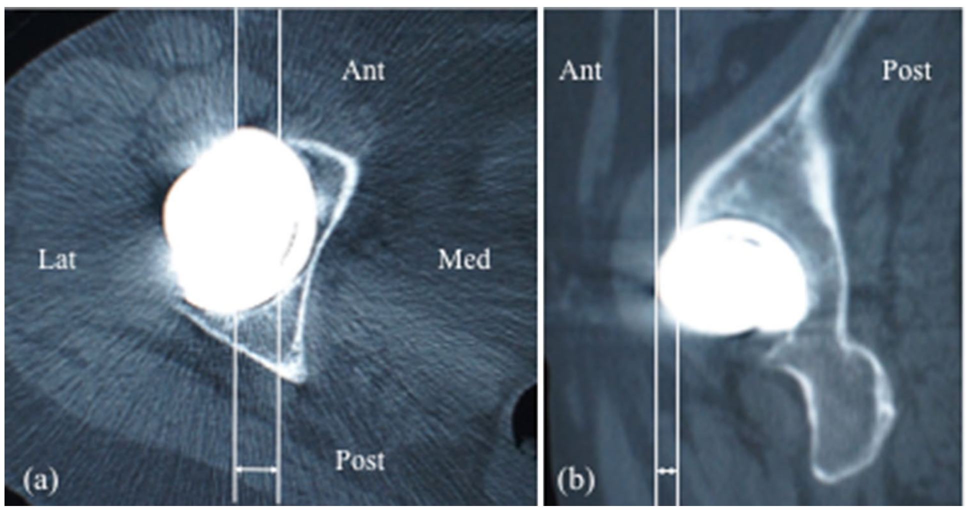

Fig. 1 CT images of Group 1. Protrusion lengths from the cup edge to the acetabular bony boundary were measured on the axial and sagittal views of the postoperative CT images. **a** The white arrow represents the protrusion length on the axial view. **b** The white arrow represents the protrusion length on the sagittal view. Ant (anterior) Post (posterior) Med (Medial) Lat (lateral)

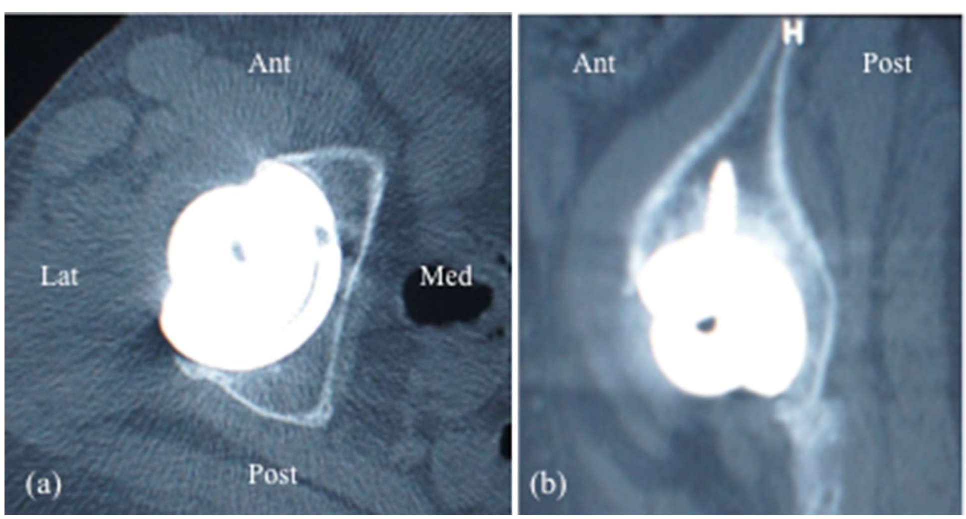

Fig. 2 CT images of Group 2. The cup protrusion is not shown in either the axial view (**a**) or sagittal view (**b**) of the CT image. Ant (anterior) Post (posterior) Med (Medial) Lat (lateral)

Statistical analysis

All statistical analyses were conducted using SPSS (version 19; IBM SPSS Statistics, Inc, Chicago, IL) for Windows. Group comparisons for quantitative dates were analyzed with nonparametric independent Student's t test, and $P < 0.005$ was considered significant.

Results

Comparison of intra-operative navigation and postoperative CT measurements

In the assessment of the accuracy of the navigation systems in 104 consecutive THAs, comparison of intra-operative navigation value and postoperative CT evaluation indicated that the cup RI, AV, and stem AT were 38.40 ± 2.50° (range 34.0–43.0°), 18.21 ± 5.59° (range 8.0–32.1°), 21.53 ± 11.28° (range 2.0–39.9°) intra-operatively, and 38.56 ± 4.87° (range 26.9–45.5°), 21.96 ± 6.44° (range 10.7–34.8°), 26.15 ± 10.87° (range 4.10–48.2°) postoperatively. Absolute discrepancy between intra-operative and postoperative assessment was 4.01 ± 3.19° (range 0.51–15.66°), 5.52 ± 4.68° (range 0.58–13.48°) and 5.81 ± 4.42° (range 0.01–17.4°), respectively (Table 1).

Achievement of CA

In the assessment of overall alignment, the calculated Widmer's CA values were 39.49 ± 5.03° (range 31.0–53.0°). There were 102 hips (98.1%) within 25–50° of CA.

Cup protrusion length

Cup protrusion length averaged 7.48 mm ± 4.23 mm (3.25–20.12 mm) in axial view and 2.83 mm ± 2.72 mm (0.46–6.37 mm) in sagittal view. Cup protrusion length more than 3 mm in either axial or sagittal views was indicated in 60 cases (57.7%) in all included cases.

Additionally, cup protrusion length more than 5 mm and 10 mm was indicated in 36 hips and 13 hips.

These cup protrusion cases were defined as Group 1 ($N = 60$), and the remaining cases without protrusion as Group 2 ($N = 44$) (Table 2).

Comparative assessment between Group 1 and Group 2

Preoperative acetabular anteversion, preoperative femoral anteversion, postoperative cup anteversion, postoperative stem anteversion, and CA values measured on CT images in Group 1 and Group 2 are shown in Table 3. In Group 1, preoperative femoral anteversion and postoperative stem anteversion were significantly higher, while postoperative cup anteversion was significantly lower. However, the postoperative CA value indicated no significant difference between the groups.

There were 59 hips (98.3%) and 43 hips (97.8%) within 25–50° of CA in Group 1 and Group 2.

Discussion

The concept of CA has been recognized for the optimization of the prosthetic alignment in THA procedure. There have been several proposed "safe zones" for the optimal CA reported in clinical papers. Ranawat et al. [18] proposed that the CA value should be within the range from 25° to 45° in cemented THA. Jolles et al. [3] examined multiple predisposing factors for dislocation after THA and showed that the dislocation rate increased by 6.9 times when the CA value was outside the range of 40° and 60°. In order to achieve the optimal CA value during THA, Amuwa and Dorr first proposed the CA technique for component positioning in

Table 2 Results of intra-operative navigation values and postoperative CT measurement values

	Group 1 ($n = 60$)	Group 2 ($n = 44$)
Gender (male/female)	9/51	12/32
Age (years)	69.3 (28–82)	64.4 (23–86)
Diagnosis: OA/ON (number of hips)	56/4	35/9
Surgical position: lateral/supine (number of hips)	20/40	13/31

Table 1 Demographic data of Group 1 and Group 2

	Intra-operative navigation values	Postoperative CT measurement value	Absolute discrepancy
Cup inclination	38.40 ± 2.50°	38.56 ± 4.87°	4.01 ± 3.19° (range 0.51–15.66°)
Cup anteversion	18.21 ± 5.59°	21.98 ± 6.44°	5.52 ± 4.6S° (range 0.58–13.48°)
Stem anteversion	21.53 ± 11.28°	26.15 ± 10.87°	5.81 ± 4.42° (range 0.01–17.4°)
CA		39.49 ± 5.03°	

Table 3 Comparison of the parameters in Group 1 and Group 2

	Group 1 ($n=60$)	Group 2 ($n=44$)	p value
Preoperative acetabular anteversion	19.37 ± 4.58°	20.25 ± 5.49°	0.38 (N.S.)
Postoperative cup anteversion	20.25 ± 6.03°	25.19 ± 6.32°	0.00015 ($p<0.05$)
Preoperative femoral anteversion	25.30 ± 9.01°	15.41 ± 10.62°	0.0000011 ($p<0.05$)
Postoperative stem anteversion	29.89 ± 8.95°	21.25 ± 11.33°	0.0000014 ($p<0.05$)
CA values	39.69 ± 4.55°	39.23 ± 4.22°	0.61 (N.S.)

THA, which prepared the stem first so that the femoral stem anteversion is known before cup implantation [8]. Additionally, Dorr et al. published a subsequent paper in which the CA technique was concomitant with imageless navigation. The resultant postoperative CA value was satisfactory with 37.6° ± 7° (range 19°–50°), and the safe zone of 25° to 50° was attained for 45 of 47 hips (96%) [9]. Nakashima et al. compared the clinical and radiographic assessments between the CA (stem-first) technique group and the conventional cup-first group [5]. The results showed that the conventional cup-first group was 5.8 times more likely to have dislocation compared to the stem-first technique group. In our previous study, postoperative CA was compared between the cup-first procedure and stem-first procedure in cementless THA with use of imageless navigation [19]. The results were summarized that the satisfactory range (37° ± 5°) of the Widmer's CA values was achieved in 38.7% of the cases in the cup-first group and 93.5% in the stem-first group. Based on these results, the CA technique has been generally accepted to achieve optimal CA and better clinical outcome. On the other hand, in patients with DDH, native femoral anteversion could be more variable than normal subjects and end-stage osteoarthritis resulted in other diagnosis [20]. Sugano et al. reported on the native femoral anteversion for 35 hips with DDH and 15 hips with age-matched control patients [21]. They stated that femoral anteversion in DDH had averaged more than 10° to 14° of the age-matched control, and the incidence of anteversion over 40° was only 7% in the control compared with 23% in DDH. In these DDH patients with large native femoral anteversion, the cup anteversion is strongly influenced by large stem anteversion during cementless THA with the CA technique. It is possible that the acetabular component might be placed at a lower anteversion value compared with the native acetabular anteversion value. In this situation, the acetabular component cannot be placed in the anatomical position in the acetabulum, and the anterior protrusion of the cup in the acetabulum might appear. Recently, several studies have been focused on groin pain after THA due to malpositioning of the acetabular component [10–12, 15–17, 22]. In addition, iliopsoas impingent (IPI) is a potential cause of groin pain and functional limitations after THA. The impingement occurs between the iliopsoas tendon and the anterior edge of the cup overhanging from the acetabular rim [15, 22]. The mean length of cup protrusion in patients with symptomatic IPI measured on CT images varied from 5.8 mm to 19.2 mm in previous studies [10, 15]. Ueno et al. reported that a protrusion length of 12 mm on CT axial image and a protrusion length of 4 mm on CT sagittal image were determined as independent predictors of symptomatic IPI [17]. Park et al. reported that IPI on the cup was influenced by the version difference between native acetabular and cup anteversions [16]. Weber et al. also reported that low cup anteversion was associated with an increased risk of cup protrusion [23].

There have been no reports in the literature describing the cup protrusion of THAs performed by the CA technique. In the present study, the resultant postoperative CA value was satisfactory and a safe zone of 25–50° was attained for 102 of 104 hips (98.1%); however, anterior protrusion of the cup appeared in 60 of 104 hips (57.7%). Further analysis of the comparisons between Group 1 (anterior protrusion +) and Group 2 (anterior protrusion −) revealed no significant difference between the groups for the postoperative CA value; however, in Group 1, preoperative femoral anteversion and postoperative radiographic stem anteversion were significantly higher, while postoperative cup anteversion was significantly lower. In addition, cases with a higher femoral anteversion of more than 53° met the extrusion criteria in this study. For these cases with stem anteversion of more than 53°, cup anteversion had to be placed to the retroversion in order to achieve optimal CA, and cup protrusion may appear more than the included cases.

This study has several limitations. First, Group 1 was defined as anterior cup protrusion of more than 3 mm on either the axial or sagittal view in the CT image. However, the definition of more than 3 mm was based on original protocol and lacks clear evidence. We could not clarify cup protrusion from bone boundary of less than 3 mm due to the metal artifacts in CT images. Previously, Ueno et al. described more precise data. Their CT image could be specialized to minimize metal artifacts and to accentuate bone boundary [17]. On the other hand, CT image in the present study is generally used for clinical examination. Measurement of the anterior cup protrusion from bone boundary was less accurate than that described by Ueno et al. [17]. In fact, it is possible that actual number of the cases with anterior cup protrusion could be more than 60 cases (57.7%) in the present study. Second, the focus was only on radiographic evaluation of the cup protrusion. Therefore, it was not possible to determine the relationship between the symptomatic iliopsoas impingement and cup protrusion. Third, the focus was on cup protrusion after THA due to the malpositioning of cup anteversion. It might be possible that other reasons, such as the oversized cup and lateralized cup position, could be combined with the malpositioning of cup anteversion [24].

In summary, the CA (stem-first) technique with image-free navigated THA could effectively achieve accurate CA. On the other hand, a large number of the cases revealed anterior cup protrusion due to the low cup anteversion. Therefore, we conclude that achievement of the optimal CA using the CA technique could be one of the major risk factors for anterior cup protrusion. Surgeons should consider anterior protrusion of the cup in cases with higher femoral anteversion in the CA technique.

Funding There is no funding source.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

1. Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR (1978) Dislocations after total hip-replacement arthroplasties. J Bone Joint Surg Am 60(2):217–220
2. Biedermann R, Tonin A, KrismerM Rachbauer F, Eibl G, Stöckl B (2005) Reducing the risk of dislocation after total hip arthroplasty: the effect of orientation of the acetabular component. J Bone Joint Surg Br 87(6):762–769
3. Jolles BM, Zangger P, Leyvraz PF (2007) Factors predisposing to dislocation after primary total hip arthroplasty. J Arthroplasty 17(3):282–288
4. Sugano N, Takao M, Sakai T, Nishi T, Miki H (2012) Dose CT-based navigation improve the long-term survival in ceramic-on-ceramic THA? Clin Orthop Relat Res 470:3054–3059
5. Nakashima Y, Hirata M, Akiyama M, Itokawa T, Yamamoto T, Motomura G, Ohishi M, Hamai S, Iwamoto Y (2014) Combined anteversion technique reduced the dislocation in cementless total hip arthroplasty. Int Orthop 38(1):27–32
6. Widmer KH, Zurfluh B (2004) Compliant positioning of total hip components for optimal range of motion. J Orthop Res 22(4):815–821
7. Yoshimine F (2006) The safe-zones for combined cup and neck anteversions that fulfill the essential range of motion and their optimum combination in total hip replacements. J Biomech 39(7):1315–1323
8. Amuwa C, Dorr LD (2008) The combined anteversion technique for acetabular component anteversion. J Arthroplasty 23(7):1068–1070
9. Dorr LD, Malik A, Dastane M, Wan Z (2009) Combined anteversion technique for total hip arthroplasty. Clin Orthop Relat Res 467(1):119–127
10. Dora C, Houweling M, Koch P, Sierra RJ (2007) Iliopsoas impingement after total hip replacement: the results of non-operative management, tenotomy or acetabular revision. J Bone Joint Surg Br 89(8):1031–1035
11. Henderson RA, Lachiewicz PF (2012) Groin pain after replacement of the hip: aetiology, evaluation and treatment. J Bone Joint Surg Br 94(2):145–151
12. Taher RT, Power RA (2003) Iliopsoas tendon dysfunction as a cause of pain after total hip arthroplasty relieved by surgical release. J Arthroplasty 18(3):387–388
13. Kingsley PC, Olmsted KL (1948) A study to determine the angle of anteversion of the neck of the femur. J Bone Joint Surg Am 30(3):745
14. Sugano N, Noble PC, Kamaric E (1998) A comparison of alternative methods of measuring femoral anteversion. J Comput Assist Tomogr 22(4):610–614
15. Cyteval C, Sarrabere MP, Cottin A, Assi C, Morcos L, Maury P, Taourel P (2003) Iliopsoas impingement on the acetabular component: radiologic and computed tomography findings of a rare hip prosthesis complication in eight cases. J Comput Assist Tomogr 27(2):183–188
16. Park KK, Tsai T-Y, Dimitriou D, Kwon Y-M (2016) Three-dimensional in vivo difference between native acetabular version and acetabularcomponent version influences iliopsoas impingement after total hip arthroplasty. Int Orthop 40(9):1807–1812
17. Ueno T, Kabata T, Kajino Y, Inoue D, Ohmori T, Tsuchiya H (2018) Risk factors and cup protrusion thresholds for symptomatic iliopsoas impingement after total hip arthroplasty: a retrospective case-control study. J Arthroplasty 33(10):3288–3296
18. Ranawat CS, Maynard MJ (1991) Modern techniques of cemented total hip arthroplasty. Tech Orthop 6(3):17–25
19. Fukunishi S, Nishio S, Fujihara Y, Okahisa S, Takeda Y, Fukui T, Yoshiya S (2016) Accuracy of combined anteversion in image-free navigated total hip arthroplasty: stem-first or cup-first technique. Int Orthop 40(1):9–13
20. Li H, Wang Y, Oni JK, Qu X, Li T, Zeng Y, Liu F, Zhu Z (2014) The role of femoral neck anteversion in the development of osteoarthritis in dysplastic hips. J Bone Joint Surg Br 96(12):1586–1593
21. Sugano N, Noble PC, Kamaric E, Salama JK, Ochi T, Tullos HS (1998) The morphology of the femur in developmental dysplasia of the hip. J Bone Joint Surg Br 80(4):711–719
22. Lachiewicz PF, Kauk JR (2009) Anterior iliopsoas impingement and tendinitis after total hip arthroplasty. J Am Acad Orthop Surg 17(6):337–344
23. Weber M, Woerner M, Messmer B, Grifka J, Renkawitz T (2017) Navigation is equal to estimation by eye and palpation in preventing psoas impingement in THA. Clin Orthop Relat Res 475(1):196–203
24. Odri GA, Padiolleau GB, Gouin FT (2014) Oversized cups as a major risk factor of postoperative pain after total hip arthroplasty. J Arthroplasty 29(4):753–756