Original Research

Abnormal Spinopelvic Motion and Spine Deformity are Associated With Native Femoral Retroversion in the Setting of Total Hip Arthroplasty

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ABSTRACT

Background: The effect of spinopelvic pathology on femoral version is unclear. This study investigated variability in native femoral anteversion in patients undergoing total hip arthroplasty (THA) and its relationship to the patient's underlying spinopelvic pattern.
Methods: A retrospective chart review was performed to include in the study all patients undergoing robot-assisted THA over a 3-year period. Native femoral version was measured for each patient using a preoperative computed tomography scan and categorized as excessive, normal, or retroverted. Additionally, a subset analysis was performed for all patients with sit-to-stand dynamic pelvic radiographs available, and cases were classified by spinopelvic pattern.
Results: A total of 119 patients were included in the study with a mean age of 68.6 years; 61 (51%) were female. The median femoral anteversion for the entire study group was $6.0°$ ($-32°$ to $40°$, interquartile range $13.5°$). Eleven patients (9.2%) had excessive femoral anteversion, 54 of the 119 (45.4%) had normal femoral version, and 54 of the 119 (45.4%) had native retroversion. Forty-two patients (35.3%) had sit-to-stand radiographs available and were subclassified by femoral version type and spinopelvic parameters. Welch's analysis of variance demonstrated a significant difference in femoral version among spinopelvic patterns ($F = 7.826$, $P = .003$), with Games-Howell post hoc analysis showing increased retroversion in deformity-stiff patients compared to deformity-normal mobility patients ($P = .003$).
Conclusions: This study demonstrates that native femoral retroversion is present in a significant number of patients undergoing THA and is more common in patients with stiff spine deformities. Based on this observation, currently available spinopelvic classification systems should be modified to account for native femoral version.
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Introduction

Femoral anteversion, also known as femoral version, is defined as the angle made by a line through the femoral neck and a line in reference to the condylar axis of distal femur (Fig. 1) [1]. Miller et al. report average native adult femoral anteversion to be $15°$ (normal range $5°$-$20°$) [2]. However, recent studies have shown a wide natural anatomic variation, with differences seen between males

and females [1,3,4]. Femoral anteversion has also been shown to be increased in dysplastic hips [5]. Our understanding and awareness of these variations has improved given the increasing use of preoperative computed tomography (CT) scans for technology-assisted total hip arthroplasty (THA) [4]. It is important that the orthopedic surgeon is aware of these large variations, as native femoral version is frequently used intraoperatively to assess femoral stem placement during THA [6]. Improper positioning of implants has the potential to diminish longevity and stability of the components [7].

It is now well-accepted that altered spinopelvic motion from lumbosacral pathology or surgical fusion can lead to instability following THA [8–10]. Heckmann and Lieberman reviewed the previously described classification systems and simplified them

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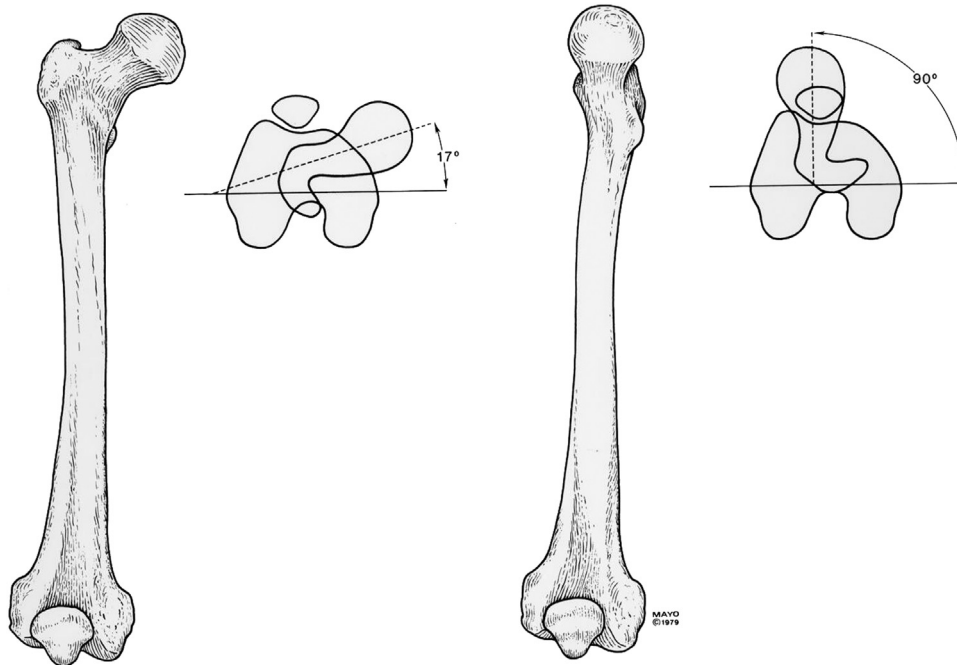*E-mail address:* deckey.david@mayo.edu

Figure 1. Illustration depicting the calculation of femoral version. Seventeen degrees of anteversion depicted on the left, and 90° of femoral anteversion depicted on the right.

based on sagittal alignment and motion [11]. They describe 4 different spinopelvic patterns based on standing and sitting lateral radiographs: (1) normal alignment and motion, (2) normal sagittal alignment but stiff, (3) sagittal deformity but normal motion, and (4) sagittal deformity and stiff. Spinopelvic stiffness is associated with increased age and compensatory femoral motion, which may result in impingement and dislocation in the setting of prosthetic hips [10]. It is unclear, however, how these spinopelvic patterns affect native femoral version. The goal of this study was to identify and classify variations in native femoral anteversion in relation to spinopelvic patterns in patients prior to undergoing THA.

Methods

Data collection

The study underwent institutional review board review and received exemption for minimal risk prior to beginning the study. No funding was received for this study. A retrospective chart review was performed to identify all consecutive patients who underwent planning CT scans prior to undergoing robot-assisted THA at a large academic institution over a 3-year period as a part of the Stryker MAKO protocol (Stryker Corp, Kalamazoo, MI). Preoperatively, 119 patients' femoral anteversion was calculated automatically for each patient by the preoperative planning software as the angle formed by the projection of the femoral neck axis and the posterior condylar axis in the transverse plane. Patients were then sub-classified into 3 groups based on their femoral anteversion, as previously described by Paley [12]: (1) type I, >20° or increased

Table 1
Demographics.

Variable	Median	Mean	Std. deviation	IQR	Minimum	Maximum
Age	69.0	68.6	11.3	11.0	23.0	91.0
BMI	28.3	28.6	5.9	8.1	15.6	45.1
Femoral version	6.0	6.0	11.5	13.5	-32.0	40.0

BMI, body mass index; IQR, interquartile range; Std. deviation, standard deviation.

femoral anteversion; (2) type II, 5°-20°, normal femoral anteversion; (3) type III, <5°, femoral retroversion.

Additionally, the lateral radiographs of all patients who had sit-to-stand dynamic pelvic radiographs were also evaluated and classified by spinopelvic pattern: [11] (1) no spine deformity and normal mobility; (2) no spine deformity but stiff; (3) spine deformity but flexible; (4) deformed and stiff. Spine deformity was defined as pelvic incidence, lumbar lordosis >10°, as previously described [8,11]. Pelvic stiffness was defined as sacral angle change of <10° from sitting to standing in sagittal radiographs [8,11]. Demographic factors, including age, sex, race, ethnicity, height, weight, body mass index, and preoperative diagnosis, were obtained via chart review.

Data analysis

Study data were collected and managed using Research Electronic Data Capture (REDCap) electronic data-capture tools hosted at our institution [13,14]. REDCap is a secure, Web-based software platform designed to support data capture for research studies, providing (1) an intuitive interface for validated data capture; (2) audit trails for tracking data manipulation and export procedures; (3) automated export procedures for seamless data downloads to common statistical packages; and (4) procedures for data integration and interoperability with external sources.

All analyses and statistical calculations were performed with Microsoft Excel (Microsoft Corp, Redmond, WA) and JASP [15] (JASP, Amsterdam, the Netherlands). Continuous variables were reported using descriptive statistics. Two group comparisons were performed with the Student t-test, and associations were evaluated with Pearson's correlation coefficient. Comparison of spino-pelvic classification groups with femoral version, and spinopelvic classification with age range, was performed with one-way analysis of variance (ANOVA). Normality checks for ANOVA were tested by plotting residuals and performing Levene's test of equality of variance with $P > .05$ assuming equal variance. Welch's ANOVA was used for any analyses demonstrating unequal variance, with Games-Howell post hoc analysis used for subgroup
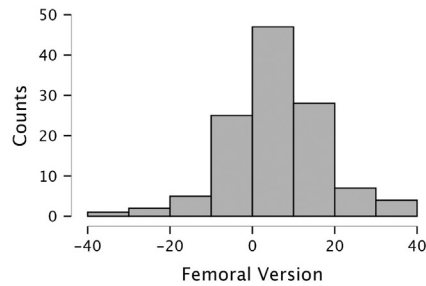
Figure 2. Femoral version distribution.

analyses. A P value of 0.05 was used as the cutoff for significance in all analyses.

Results

Overall, 119 patients were included in the study. The average age was 68.6 years (standard deviation ±11.3); 61 (51%) were female (Table 1). The median femoral anteversion was 6.0° ± 11.5° (−32° to 40°, interquartile range 13.5°) (Fig. 2). The median femoral anteversion stratified by ages <55, 55-64, and ≥65 years was 19° ± 17.5°, 5° ± 10.7°, and 5° ± 10.1°, respectively (Table 2). Using the femoral version classification system, 11 out of 119 (9%) patients had increased femoral version (>20°, type I), 54 (45%) had normal femoral version (5°-20°, type II), and 54 (45%) had native femoral retroversion (<5°, type III) (Table 3). No differences in retroversion were found based on sex or age.

Forty-two patients had sit-to-stand lateral radiographs available for subgroup analysis. These patients were then classified into subgroups based on femoral version type and spinopelvic parameters. Of the 42 radiographs available, 10 had no deformity and normal mobility, 22 had deformity but normal mobility, 7 had no deformity but were stiff, and 3 were deformed and stiff. All patients who were deformed and stiff had native retroversion, with a mean of −3.7° (−1 to −6, standard deviation ±2.5) (Table 4). Levene's test for equality of variance demonstrated $P = .035$; therefore, a Welch's ANOVA was performed to compare groups. A significant difference in femoral version between spinopelvic patterns was found (F = 7.826, P = .003) (Table 5), with Games-Howell post hoc analysis showing increased retroversion in deformity-stiff patients compared to deformity-normal mobility patients ($P = .003$) (Table 6).

Discussion

Although native femoral version is traditionally thought to be between 5° and 20° [2,12], recent studies have shown this to be highly variable in patients with degenerative joint disease of the hip and can therefore influence THA stability [3,16]. Spinopelvic pathology has also been implicated as a causative factor for dislocation following THA [10,17]. Our study found that nearly half of all patients undergoing THA had native femoral retroversion, and this

Table 3
Modified classification of spinopelvic parameters combined with femoral anteversion.

Type	Description	N (n)[a]	%[b]
Type I	Increased femoral anteversion (>20°)	2 (11)	4.8
1A	No spine deformity, normal mobility	1	2.4
1B	No spine deformity, stiff	0	0
1C	Spine deformity, normal mobility	1	2.4
1D	Spine deformity, stiff	0	0
Type II	Normal femoral anteversion (5°-20°)	17 (54)	40.5
2A	No spine deformity, normal mobility	2	4.8
2B	No spine deformity, stiff	2	4.8
2C	Spine deformity, normal mobility	13	31.0
2D	Spine deformity, stiff	0	0
Type III	Natively retroverted femur (<5°)	23 (54)	54.8
3A	No spine deformity, normal mobility	7	16.7
3B	No spine deformity, stiff	5	11.9
3C	Spine deformity, normal mobility	8	19.0
3D	Spine deformity, stiff	3	7.1

[a] Total number of patients, including those without sit-to-stand radiographs.
[b] Percent of patients with sit-to-stand radiographs.

was significantly more common in those who had a spinal deformity and stiffness. These findings are important because current classification systems of the spinopelvic relationship do not account for femoral version, and THA surgeons should be aware of this important association, particularly given previous literature that cites combined version as an important influencer of hip stability.

Femoral retroversion is associated with altered hip biomechanics. Satpathy et al. demonstrated that peak joint pressure was transferred posteroinferiorly in patients with femoral retroversion, thus increasing joint contact stress [18]. Posteriorly directed joint forces may contribute to instability and subsequent component wear. Indeed, Beck et al. found that the primary location of native cartilage wear in patients with femoral retroversion was in the posteroinferior acetabulum [19]. Biomechanical studies have also found that patients with native femoral retroversion typically hold the leg in increased external rotation relative to patients with native anteversion. This may portend anterior dislocation of the prosthetic joint, especially in those patients undergoing direct anterior THA [20]. This alteration in femoral alignment may also impact the ability of the surgeon to achieve appropriate femoral stem alignment [21]. Some surgeons may use 15° of anteversion as the target for femoral component position, rather than native femoral version. In these instances, the drastic change from 15° of retroversion to 15° of anteversion could lead to worse outcomes. Furthermore, femoral retroversion carries the risk of impingement of the femoral neck and acetabular rim and should be especially considered in THA patients with histories of femoroacetabular impingement, slipped capital femoral epiphysis, and malunited fracture [22]. Compensatory increases in acetabular anteversion in arthroplasty decrease impingement risk at the cost of increased

Table 2
Femoral version stratified by age.

	Age ranges (years old)		
	<55	55-64	≥65
No.	9	77	33
Median	19.0	5.0	5.0
Mean	17.4	4.5	6.3
Std. deviation	17.5	10.7	10.1
IQR	33.0	12.0	11.0
Minimum	−7.0	−32.0	−21.0
Maximum	40.0	33.0	26.0

IQR, interquartile range; No., number; Std. deviation, standard deviation.

Table 4
Averages of femoral version when subclassified by spinopelvic parameters.

	No deformity, normal mobility	Stiff w/o deformity	Deformity, normal mobility	Deformed and stiff
No.	10	7	22	3
Avg. femoral version	−0.8	−0.6	7.5	−3.7
Std. error of mean	4.5	2.4	1.7	1.5
Std. deviation	14.1	6.3	7.9	2.5
Minimum	−21.0	−8.0	−12.0	−6.0
Maximum	22.0	7.0	25.0	−1.0

Avg., average; No., number; Std. deviation, standard deviation; Std. error of mean, standard error of mean; w/o, without.

Table 5
Welch's ANOVA analyzing difference in femoral version between spinopelvic parameters.

Homogeneity correction	Cases	Sum of squares	df	Mean square	F	P	η^2
None	Classification	814.684	3.000	271.561	3.072	.039	0.195
	Residuals	3359.435	38.000	88.406			
Welch	Classification	814.684	3.000	271.561	7.826	.003	0.195
	Residuals	3359.435	12.874	260.942			

Type III sum of squares.

joint contact forces [23]. Subsequently risk of instability, wear, and dislocation is increased [7].

While femoral version and spinopelvic morphology have been shown to affect hip stability separately, we are unaware of previous studies that have established a relationship between them. Innmann et al. demonstrated preoperative spinopelvic characteristics can normalize after THA [24]. This study, however, excluded patients who had undergone previous spinal fusion. Lumbar-pelvic-femoral alignment mobility is known to impact THA stability and femoroacetabular dynamics [25]. A study by Esposito et al. demonstrated that decreased spinal mobility contributes to significantly increased femoroacetabular range of motion required for sit-to-stand motion [26]. Furthermore, studies now indicate that combined anteversion be utilized when determining adequacy of component positioning in THA [27—30]. This concept incorporates both acetabular version and femoral stem version in order that the lumbar-pelvic-femoral relationship is considered during implantation [31], with significantly increased rates of dislocation in more retroverted hips [7,32]. Our study showed that native femoral retroversion was relatively common and occurred more frequently in patients with spinopelvic deformity and stiffness. Future research is warranted to explore this relationship and its impact on THA outcomes.

To date, all previous literature has focused on the adjustment of acetabular component version in the setting of spinopelvic deformity. Our study provides evidence that adjustments to femoral version may be important in these cases. At a minimum, we should account for native femoral version in the cup adjustments. One could argue that these data suggest that we should be routinely obtaining preoperative planning CT scans. Preoperative CT scans have become commonplace in total shoulder arthroplasty. Given that this study was observational, we cannot make any definitive recommendations. Future studies should look to assess how femoral version and spinopelvic mobility affect outcomes. In cases where clinicians are not routinely obtaining preoperative CT scans, we recommend using the combined anteversion technique described by Ranawat [28] and validated by Dorr et al. [33].

This study is not without limitations. Of the 119 patients included in the study, spinopelvic imaging was available in only 42 (35%), as the protocol for routinely obtaining these radiographs was instituted in the latter half of the collection period. Although spinopelvic hypermobility has also been shown to have poorer post-THA outcomes, including dislocation and early wear due to hypermobility, we did not delineate between normal pelvic motion and hypermobility [34,35]. Further subclassification of nonstiff pelvic motion may have provided further detail on the relation of spinopelvic morphology with femoral anteversion. Finally, patients included in this study were within 1 year of surgery. While dislocation risk is highest in the 4- to 6-week postoperative range due to operative soft-tissue disruption, late dislocation is also associated with spinopelvic pathology [10,36].

Conclusions

Native femoral version is unique to each individual and must be considered when performing THA, as native femoral malalignment is associated with altered hip biomechanics and potential adverse outcomes following arthroplasty. This study demonstrates that femoral retroversion is significantly more common in patients with stiff spine deformities. Based on this observation, currently available spinopelvic classification systems should be modified to account for native femoral version. As both spinopelvic pathology and femoral retroversion are associated with THA component malalignment and postoperative outcomes, we propose an updated classification system to account for femoral version and its relation to spinopelvic morphology. Prospective, long-term follow-up studies would provide a better understanding of this relationship and its impact on THA outcomes.

Conflicts of interest

D. G. Deckey is in the editorial or governing board of Journal of Arthroplasty and is a board or committee member in the American Association of Hip and Knee Surgeons. All other authors declare no potential conflicts of interest.

For full disclosure statements refer to doi:10.1016/j.artd.2022.08.005.

Table 6
Games-Howell post hoc comparisons.

Comparison	Mean difference	SE	t	df	P_{Tukey}
No deformity normal mobility—stiff w/o deformity	−0.229	5.063	−0.045	13.262	1.000
No deformity normal mobility—deformity normal mobility	−8.345	4.772	−1.749	11.649	.344
No deformity normal mobility—deformed and Stiff	2.867	4.695	0.611	10.479	.926
Stiff w/o deformity—deformity normal mobility	−8.117	2.924	−2.776	12.575	.068
Stiff w/o deformity—deformed and stiff	3.095	2.796	1.107	7.983	.696
Deformity normal mobility—deformed and stiff	11.212	2.226	5.037	9.392	.003

SE, standard error of mean.

References

[1] Scorcelletti M, Reeves ND, Rittweger J, Ireland A. Femoral anteversion: significance and measurement. J Anat 2020;237:811—26.

[2] Miller MD, Thompson SR, editors. Miller's review of orthopaedics. 8th ed. Philadelphia: Elsevier; 2019.

[3] Pierrepont JW, Marel E, Baré JV, Walter LR, Stambouzou CR, Solomon MI, et al. Variation in femoral anteversion in patients requiring total hip replacement. HIP Int 2020;30:281—7.

[4] Marcovigi A, Ciampalini L, Perazzini P, Caldora P, Grandi G, Catani F. Evaluation of native femoral neck version and final stem version variability in patients with osteoarthritis undergoing robotically implanted total hip arthroplasty. J Arthroplasty 2019;34:108—15.

[5] Wells J, Nepple JJ, Crook K, Ross JR, Bedi A, Schoeneck P, et al. Femoral morphology in the dysplastic hip: three-dimensional characterizations with CT. Clin Orthop Relat Res 2017;475:1045—54.

[6] Bargar WL, Jamali AA, Nejad AH. Femoral anteversion in THA and its lack of correlation with native acetabular anteversion. Clin Orthop Relat Res 2010;468:527—32.

[7] Malik A, Maheshwari A, Dorr LD. Impingement with total hip replacement. J Bone Joint Surg Am 2007;89:1832—42.

[8] Ike H, Dorr LD, Trasolini N, Stefl M, McKnight B, Heckmann N. Spine-pelvis-hip relationship in the functioning of a total hip replacement. J Bone Joint Surg Am 2018;100:1606—15.

[9] Sultan AA, Khlopas A, Piuzzi NS, Chughtai M, Sodhi N, Mont MA. The impact of spino-pelvic alignment on total hip arthroplasty outcomes: a critical analysis of current evidence. J Arthroplasty 2018;33:1606—16.

[10] Heckmann N, McKnight B, Stefl M, Trasolini NA, Ike H, Dorr LD. Late dislocation following total hip arthroplasty: spinopelvic imbalance as a causative factor. J Bone Joint Surg Am 2018;100:1845—53.

[11] Heckmann ND, Lieberman JR. Spinopelvic biomechanics and total hip arthroplasty: a primer for clinical practice. J Am Acad Orthop Surg 2021;29: e888—903.

[12] Paley D. Principles of deformity correction. Berlin; New York: Springer; 2002.

[13] Harris PA, Taylor R, Minor BL, Elliot V, Fernandez M, O'Neal Lindsay, et al. The REDCap consortium: building an international community of software platform partners. J Biomed Inform 2019;95:103208.

[14] Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. J Biomed Inform 2009;42:377—81.

[15] JASP Team. Jasp (Version 0.16). https://jasp-stats.org/; 2021 [accessed 1.01.22].

[16] Hartel MJ, Petersik A, Schmidt A, Kendoff D, Nuchtern J, Rueger JM, et al. Determination of femoral neck angle and torsion angle utilizing a novel three-dimensional modeling and analytical technology based on CT datasets. PLoS One 2016;11:e0149480.

[17] Esposito CI, Carroll KM, Sculco PK, Padgett DE, Jerabek SA, Mayman DJ. Total hip arthroplasty patients with fixed spinopelvic alignment are at higher risk of hip dislocation. J Arthroplasty 2018;33:1449—54.

[18] Satpathy J, Kannan A, Owen JR, Wayne JS, Hull JR, Jiranek WA. Hip contact stress and femoral neck retroversion: a biomechanical study to evaluate

[19] Beck M, Kalhor M, Leunig M, Ganz R. Hip morphology influences the pattern of damage to the acetabular cartilage: femoroacetabular impingement as a cause of early osteoarthritis of the hip. J Bone Joint Surg Br 2005;87:1012—8.

[20] Dawson-Amoah K, Raszewski J, Duplantier N, Waddell BS. Dislocation of the hip: a review of types, causes, and treatment. Ochsner J 2018;18: 242—52.

[21] Karnezis IA. A technique for accurate reproduction of the femoral anteversion during primary total hip arthroplasty. Arch Orthop Trauma Surg 2001;121: 343—5.

[22] Noordin S, Lakdawala R, Masri BA. Primary total hip arthroplasty: staying out of trouble intraoperatively. Ann Med Surg 2018;29:30—3.

[23] Bourget-Murray J, Taneja A, Naserkhaki S, El-Rich M, Adeeb S, Powell J, et al. Computational modelling of hip resurfacing arthroplasty investigating the effect of femoral version on hip biomechanics. PLoS One 2021;16:e0252435.

[24] Innmann MM, Verhaegen JCF, Reichel F, Schaper B, Merle C, Grammatopoulos G. Spinopelvic characteristics normalize 1 Year after total hip arthroplasty: a prospective, longitudinal, case-controlled study. J Bone Joint Surg Am 2022;104:675—83. https://doi.org/10.2106/JBJS.21.01127.

[25] Mudrick CA, Melvin JS, Springer BD. Late posterior hip instability after lumbar spinopelvic fusion. Arthroplast Today 2015;1:25—9.

[26] Esposito CI, Miller TT, Kim HJ, Barlow BT, Wright TM, Padgett DE, et al. Does degenerative lumbar spine disease influence femoroacetabular flexion in patients undergoing total hip arthroplasty? Clin Orthop Relat Res 2016;474: 1788—97.

[27] McKibbin B. Anatomical factors in the stability of the hip joint in the newborn. J Bone Joint Surg Br 1970;52:148—59.

[28] Ranawat CS, Maynard MJ. Modern technique of cemented total hip arthroplasty. Tech Orthop 1991;6:17—25.

[29] Blumenfeld TJ. Pearls: clinical application of ranawat's sign. Clin Orthop Relat Res 2017;475:1789—90.

[30] Barrack RL. Dislocation after total hip arthroplasty: implant design and orientation. J Am Acad Orthop Surg 2003;11:89—99.

[31] Widmer K-H, Zurfluh B. Compliant positioning of total hip components for optimal range of motion. J Orthop Res 2004;22:815—21.

[32] Komeno M, Hasegawa M, Sudo A, Uchida A. Computed tomographic evaluation of component position on dislocation after total hip arthroplasty. Orthopedics 2006;29:1104—8.

[33] Dorr LD, Malik A, Dastane M, Wan Z. Combined anteversion technique for total hip arthroplasty. Clin Orthop Relat Res 2009;467:119—27.

[34] Grammatopoulos G, Gofton W, Jibri Z, Coyle M, Dobransky J, Kreviazuk C, et al. 2018 Frank stinchfield award: spinopelvic hypermobility is associated with an inferior outcome after THA: examining the effect of spinal arthrodesis. Clin Orthop Relat Res 2019;477:310—21.

[35] Sculco PK, Windsor EN, Jerabek SA, Mayman DJ, Elbuluk A, Buckland AJ, et al. Preoperative spinopelvic hypermobility resolves following total hip arthroplasty. Bone Joint J 2021;103-B:1766—73.

[36] Biedermann R, Tonin A, Krismer M, Rachbauer F, Eibl G, Stockl B. Reducing the risk of dislocation after total hip arthroplasty: the effect of orientation of the acetabular component. J Bone Joint Surg Br 2005;87:762—9.