The Journal of Arthroplasty xxx (2020) 1–5

Contents lists available at ScienceDirect

The Journal of Arthroplasty

journal homepage: www.arthroplastyjournal.org

Functional Anatomy of the Hip Joint

Nathanael Heckmann, MD [a], Taro Tezuka, MD [b], Russell J. Bodner, MD [c], Lawrence D. Dorr, MD [d, *]

[a] Department of Orthopaedic Surgery, Keck School of Medicine of USC, Los Angeles, CA
[b] Department of Orthopaedic Surgery, Yokohama City University, Yokohama, Japan
[c] Midwest Orthopedic Institute, Sycamore, IL
[d] Dorr Institute for Arthritis Research and Education, Pasadena, CA

ARTICLE INFO

Article history:
Received 9 April 2020
Received in revised form
23 July 2020
Accepted 27 July 2020
Available online xxx

Keywords:
spinopelvic imbalance
total hip arthroplasty
THA
dislocation
spine-hip relationship
functional safe zone

ABSTRACT

Background: The functional anatomy of the osteoarthritic hip joint in the sagittal plane has not been defined. The purpose of this study was to define the functional anatomy of the hip using clinical and radiographic analyses.
Methods: 320 hips had preoperative standing and sitting lateral spine-pelvis-hip X-rays. Radiographic pelvic measurements were pelvic incidence (PI) and sacral slope (SS), and hip measurements were anteinclination (AI) and pelvic femoral angle (PFA). Pelvic tilt (PT) was calculated as PI-SS. A triangle model was created from the clinical data that illustrates the functional motion of the hip during postural changes from standing to sitting.
Results: Pelvic motion was coordinated with hip motion, even with spinopelvic imbalance and stiffness. Pelvic motion (ΔSS) varied for all 5 types of imbalance, but pelvic motion (ΔSS) and acetabular motion (ΔAI) changed with a 1:1 ratio and inversely with femoral motion (ΔPFA) with a 1:1 ratio. The triangle model showed similar results with ΔSS, ΔPT, and ΔAI changing in a 1:1:1 ratio, and femur motion inversely changing with a 1:1 ratio.
Conclusion: The functional anatomy of the hip joint can be visually illustrated using a triangle model. Pelvic angles SS, PT, and AI change in unison, whereas femoral motion (ΔPFA) changes inversely with pelvic motion (ΔSS) in a 1:1 ratio. This coordinated mobility explains the limitations of the Lewinnek safe zone, which include only the acetabulum.

The function of the osteoarthritic (OA) hip joint has traditionally been described as the position of the acetabulum and measured by the Lewinnek safe zone [1]. Recent research has focused on the interrelationship of the spine-pelvis-hip complex as a coordinated functional unit that allows postural changes of the body [2–7]. Two schools of thought have emerged from this research. One group describes the spine as the initiator of function with spine anatomy measured [7,8]. The second group focuses on the hip as the initiator of motion with the anatomy of the hip being of greater importance for postural changes [3,4,6,9–11]. There has been little research on the relationship of the pelvic measurements to hip motion during function.

For hip surgeons, reconstructing the OA hip joint with total hip arthroplasty is a common surgery; therefore, it is also important to understand the interaction of the structural components, especially with degenerative changes of the spine (or surgical fusion) [5,6,9–16]. For these reasons, we studied the interrelated functional anatomy of the OA hip joint during postural changes from standing to sitting.

The purpose of our study is to describe the functional anatomy of the spine-pelvis-hip complex in OA hips and visually model the mathematical relationship of the anatomical components.

Methods

Radiographic Analysis

A retrospective analysis of prospectively collected data from 291 patients (320 hips) was performed. These patients had been used in

One or more of the authors of this paper have disclosed potential or pertinent conflicts of interest, which may include receipt of payment, either direct or indirect, institutional support, or association with an entity in the biomedical field which may be perceived to have potential conflict of interest with this work. For full disclosure statements refer to https://doi.org/10.1016/j.arth.2020.07.065.

* Reprint requests: Lawrence D. Dorr, MD, Dorr Institute for Arthritis Research and Education, 671 Bellefontaine Street, Pasadena, CA 91105.

https://doi.org/10.1016/j.arth.2020.07.065
0883-5403/

a previous publication for study of the functional safe zone [11]. All patients underwent preoperative standing and sitting lateral spine-pelvis-hip x-rays as described previously [5]. Using these lateral radiographs, the following measurements were obtained using preoperative measurements (Fig. 1):

1. Pelvic incidence (PI) is a static measurement of the anterior-to-posterior dimension of the pelvis that defines the physical and functional relationship of the femoral heads relative to the spine [17].
2. Sacral slope (SS) is used to assess the position of the spinopelvic junction, and the difference between standing and sitting values (ΔSS) is used to quantify pelvic motion between postural changes [4].
3. Pelvic femoral angle (PFA) is the angle of the femur in relationship to the sacrum and can be used to define femoral motion (ΔPFA) between postural changes [9,18].
4. Anteinclination (AI) is the sagittal position of the acetabulum [5].
5. Pelvic tilt (PT) is computed as PI-SS [17].

Data Analysis

Radiographs were measured for each postural position in each patient. Previous studies have defined 5 types of imbalance, and hips were categorized into these types [5,6,9–11]. The spinopelvic imbalance types are as follows:

1. The pelvis is fixed in posterior tilt (ie, the position of sitting, stuck sitting) during standing, which means the standing SS is <30°. This affects both AI and PFA of the hip. Patients with a low PI have this standing position 50% of the time, as their normal position [10,11].
2. The pelvis is fixed in anterior tilt (ie, the position of standing, stuck standing), which means sitting SS is >30° [10]. Fixed anterior hips with a standing SS ≥40° may have improved pelvic motion postoperatively; however, many patients with a standing SS of 30°-35° have spine stiffness in lordosis, which does not change postoperative (ie, surgical fusion [15]).
3. The pelvis and lumbar spine are kyphotic, which means sitting SS is <5° [10]. This can be caused by hip extension contracture or a high body mass index [2].
4. Stiff anterior occurs when the pelvis has decreased mobility (ΔSS ≤10°) and is fixed in an anteriorly tilted position (ie, a standing position) during sitting. It is pathologic if pelvic mobility is <5°, indicating a biological fusion between standing and sitting [10].
5. Stiff posterior occurs when the pelvis has decreased motion (ΔSS ≤10°) and is fixed in a posteriorly tilted position (ie, a seated position) during standing. Like stiff anterior, stiff posterior is pathologic if pelvic motion is <5°.

Hypermobility (ΔSS >30°) is a variant of normal OA hips unless associated with kyphosis. Routine hypermobility is the safest functional anatomy against impingement because it is associated with decreased femoral motion (ie, because of greater *pelvic* motion) [10]. Patients with pelvic hypermobility were included in Table 1 as part of the normal cohort.

Mathematical Relationships and the Triangle

Functional anatomy means the position of the spinopelvic complex in response to spatial changes of the hip joint (Fig. 1). To

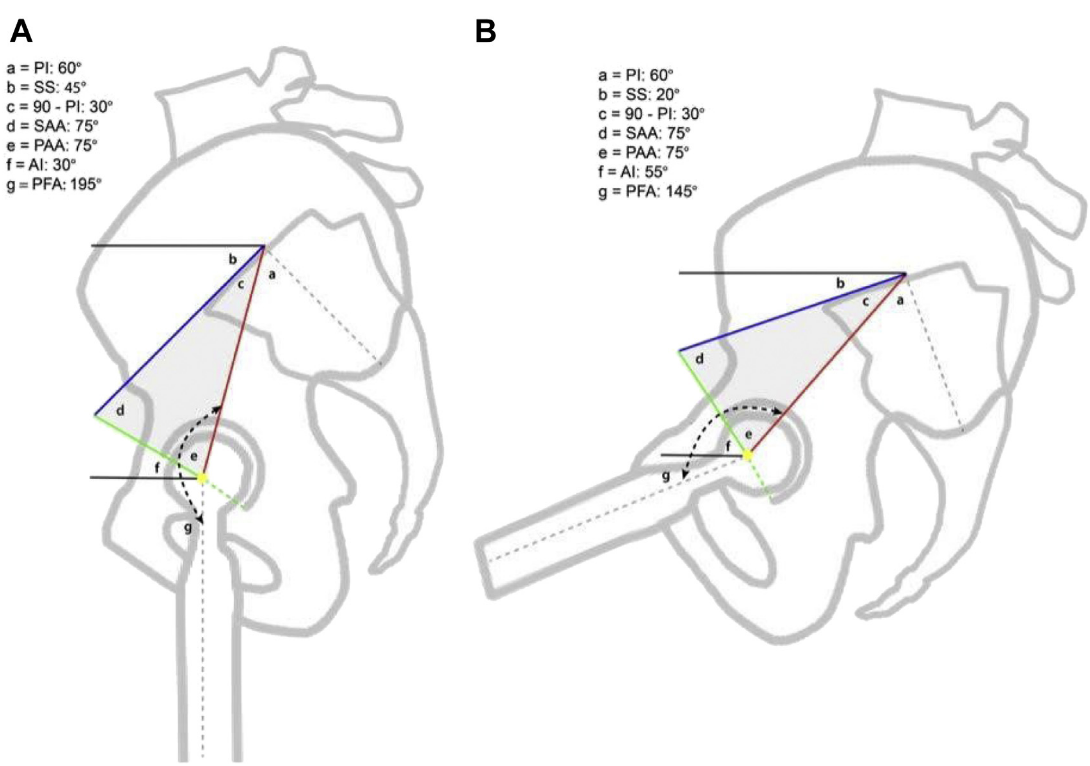

Fig. 1. (A) Mathematical triangle formed by angles (d), (e), and (c). (a) pelvic incidence (PI), (b) sacral slope (SS), (c) apex angle that is equal to 90°-PI, (d) sacroacetabular angle (SAA; angle d), links SS and the acetabulum (anteinclination [AI]), (e) pelvic acetabular angle (PAA; angle e), connects the pelvic tilt (PT) to AI, (f) AI, and (g) pelvic femoral angle (PFA), links femoral motion to the pelvis. (B) The sitting position. The triangle rotates with its fulcrum on the hip joint, and the extent of the rotation is determined by ΔSS (ΔSS = 25° in this illustration). This opens the acetabulum 25° when sitting (1:1 ratio of ΔSS:ΔAI). Femoral motion (g) in this example is 50° as shown by the ΔPFA. It is the hip that drives the rotation of the triangle back (ie, clockwise), tilting the pelvis posteriorly when sitting.

Table 1
Functional Anatomy Measurements.

Cohort	PI	Std SS	Sit SS	ΔSS	Std PT	Sit PT	ΔPT	Std PFA	Sit PFA	ΔPFA	Std AI	Sit AI	ΔAI
Overall ($n = 320$)	54 ± 10	38 ± 9	17 ± 10	21 ± 12	15 ± 9	37 ± 12	21 ± 12	185 ± 11	126 ± 15	60 ± 11	38 ± 11	57 ± 11	20 ± 11
Normal ($n = 234$)	55 ± 9	41 ± 7	16 ± 9	25 ± 11	15 ± 9	40 ± 11	25 ± 11	185 ± 11	126 ± 15	55 ± 16	36 ± 10	58 ± 11	23 ± 10
Fixed posterior ($n = 60$)	46 ± 9	25 ± 3	14 ± 9	12 ± 9	20 ± 10	33 ± 11	13 ± 10	188 ± 19	120 ± 14	68 ± 14	42 ± 10	54 ± 13	11 ± 12
Fixed anterior ($n = 26$)	62 ± 10	45 ± 5	35 ± 5	10 ± 6	17 ± 8	27 ± 9	10 ± 6	189 ± 11	114 ± 10	75 ± 15	38 ± 11	53 ± 9	14 ± 9
Kyphotic ($n = 36$)	47 ± 10	37 ± 9	−2 ± 6	38 ± 14	10 ± 11	50 ± 12	39 ± 14	178 ± 12	140 ± 17	38 ± 18	28 ± 14	65 ± 15	37 ± 15
Stiff posterior ($n = 27$)	48 ± 10	25 ± 4	21 ± 5	4 ± 3	23 ± 11	27 ± 11	4.6 ± 5	190 ± 11	114 ± 13	77 ± 9	43 ± 13	50 ± 12	6.5 ± 8
Stiff anterior ($n = 12$)	60 ± 10	42 ± 5	37 ± 6	5.0 ± 2	18 ± 8	24 ± 8	5.5 ± 3	193 ± 9	111 ± 10	82 ± 10	41 ± 9	50 ± 7	6.2 ± 2

Radiographic measurements of the preoperative bony anatomy. All values are expressed in degrees. The table shows an approximate 1:1:1 ratio of ΔSS, ΔPT, and ΔAI with ΔPFA changing inversely to changes in these pelvic measurements in a 1:1 ratio. Only 75 of 320 hips (23%) had a stiff pelvis or a kyphotic deformity requiring adjustment of the cup to compensate for pelvic imbalance [9,11].
PI, pelvic incidence; Std, standing; SS, sacral slope; Sit, sitting; PT, pelvic tilt; PFA, pelvic femoral anatomy; AI, anteinclination.

understand the relationship of the hip to the spinopelvic unit in the sagittal plane, a mathematical geometric triangle was constructed by one of the authors (R.J.B.) to visualize the quantitative relationship of the functional anatomy (Fig. 1). The pelvic components that comprise this triangle include PI, SS, AI, as well as PT. Femoral motion (ΔPFA) is included in the model. The triangle creates 3 fixed angles that link the acetabulum to the pelvis. The values of the 3 angles remain constant regardless of patient position and represent the patient's functional anatomy because it links the hip to the pelvis.

1. The sacroacetabular angle (SAA) formed by the long axis of the mouth of the acetabulum and the S1 end plate have been previously described [3,4] (Fig. 1; angle d).
2. The pelvic acetabular angle (PAA) formed by a line from the center of S1 to the hip and the long axis of the acetabulum (Fig. 1; angle e).
3. The superior apex angle (Fig. 1; angle c), which is the complementary angle of PI (eg, 90°-PI).

The functional anatomy of the OA hip is mathematically expressed by the shape and orientation of the triangle, which is based on the 2 following equations: PI = SS + PT [17] and SAA = SS + AI [4]. There is a geometric balance between the acetabulum and the pelvis if the motion of the triangle is 25° (ΔSS), and the SAA and PAA angles are equal so that an isosceles triangle exists. The apex angle is 90-PI (ie, for a PI of 45°, the apex angle is 45°). Once the triangle is modeled, it rotates in space over the arc of pelvic motion (ΔSS), which determines how many degrees the triangle pivots between functional (postural) positions (Fig. 2).

Results

Patient Demographics

The average age was 63 ± 11 years old with an average body mass index of 28 ± 5.6. Our cohort consisted of 171 females (53%) and 149 males (47%).

Radiographic Measurements

Normal OA hips had an average pelvic motion of ΔSS = 25° and femoral motion of ΔPFA = 55° (ΔPFA of normal hips is 50°-70° [3,4,9,19]). ΔSS and ΔAI have a 1:1 ratio (Table 1). Hips in Table 1 with fixed posterior or anterior tilt had stiffness of the *spine*, which limited pelvic motion (fixed SS above or below 30°) and required increased femoral motion (ΔPFA) compared with normal hips. Femur motion (ΔPFA) changes inversely in a 1:1 ratio with pelvic motion (ΔSS). For example, *stiff posterior* hips had a decrease in pelvic motion (ΔSS) of 21° and an increased femoral motion (ΔPFA) of 22° compared with normal hips (Table 1). Hips with a kyphotic deformity of the spine and pelvis had a low sitting SS of −2° with pelvic hypermobility (ΔSS = 38°) and a corresponding decrease in femur motion (ΔPFA = 38°).

Triangle Results

Hips were modeled using the clinical value of average pelvic motion (ΔSS = 21°) and acetabular measurements of standing AI = 33.5° and sitting AI = 54.5° with an SAA of 72.5° and PAA of 72.5°, which gave a balanced geometric triangle that moved posteriorly with sitting (Fig. 2; green triangle). In a pelvis with fixed posterior tilt, the triangle in the standing position is tilted posteriorly (Fig. 2; blue triangle). A pelvis that is *stiff* and posteriorly tilted has negligible pelvic motion (Fig. 2; red triangle). Kyphotic hips had pelvic

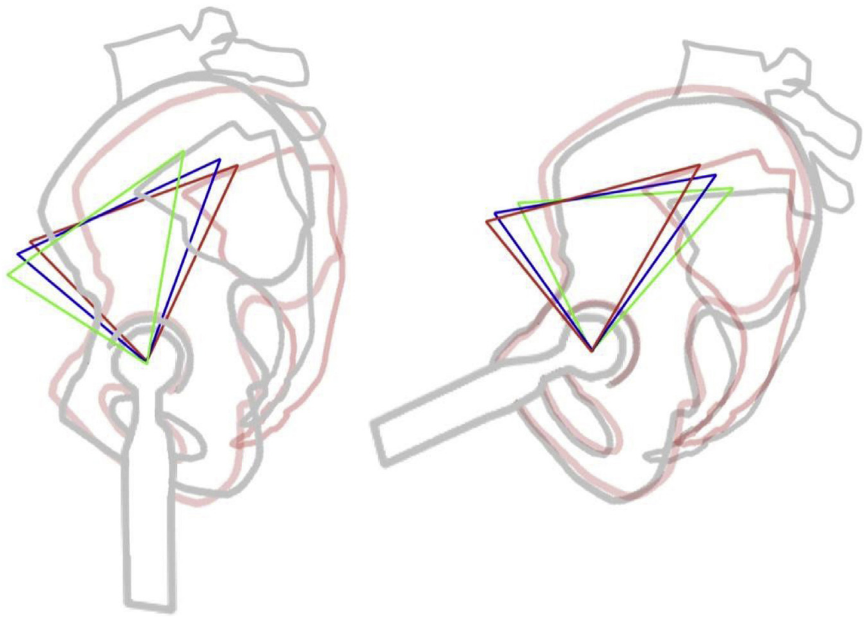

Fig. 2. Three different superimposed triangle positions illustrate the effect of different pelvic-hip positions on the functional anatomy: green represents the normal hip, blue represents a fixed posterior hip, and the red triangle is stiff posterior. All 3 triangles have a PI of 45°. The red triangle and associated red pelvis have minimal motion from standing to sitting. The blue and green triangles move posteriorly with AI and SS changing in a 1:1 ratio. Green triangle (normal osteoarthritic hip): standing/sitting SS = 35°/11° (ΔSS = 24°); standing/sitting PT = 10°/34°; standing/sitting AI = 33°/57°; and SAA/PAA = 68°/67°. Blue triangle (fixed posterior hip): standing/sitting SS = 25°/11° (ΔSS = 14°); standing/sitting PT = 20°/34°; standing/sitting AI 41°/55°; and SAA/PAA = 66°/69°. Red triangle (stiff posterior hip): standing/sitting SS 20°/15° (ΔSS = 5°); standing/sitting PT = 25°/30°; standing/sitting AI = 47°/52°; and SAA/PAA = 67°/68°.

hypermobility, which moves the triangle forward with standing (not included in Fig. 2).

For any given patient, the PI can be removed from determining the ratio of motion between the anatomic components because PI is a fixed anatomic parameter that remains constant throughout all postural changes. Thus, the ratio of motion for a patient with ΔSS = 25° is SS:PT:AI = 1:1:1 and does not require knowledge of the patient's PI. When there is imbalance, such as when the pelvis is fixed posteriorly, the ratio remains 1:1:1, but ΔSS changes the number of degrees all 3 anatomic components move. Three examples with a constant PI of 45° are illustrated in Figure 2.

Discussion

The hip joint is the fulcrum for the coordinated movement of the spine-pelvis-hip complex [3,10]. The clinical data and triangle in this study demonstrate that the function of the OA hip is a consequence of the coordinated motion of the interconnected anatomic components, which move as a singular anatomic structure in a 1:1:1 ratio. The function of the interrelated pelvic components is to accommodate changes in position of the acetabulum during postural change with a 1:1:1 ratio between AI, PT, and SS, whereas femur motion responds inversely in a 1:1 ratio (1° loss of pelvic motion corresponds to a 1° increase in femoral motion). The radiographic results, and the triangle model, support the notion that the functional anatomy of the OA hip coordinates pelvic movement with hip motion.

Degenerative disease may cause a decrease in motion of the anatomic hinges of the spine-pelvis-hip complex [9], either the posterior hinge (i.e. the lumbosacral junction) or the anterior hinge (i.e. the hip joint), which results in imbalance by increasing the compensatory motion of the opposite hinge [19,20]. The mobility measurement of the posterior hinge, ΔSS, decreases with degenerative disease of the spine and defines the magnitude of pelvic motion between standing and sitting, which corresponds to changes in the acetabular motion in a 1:1 ratio. The femur responds to stiffness of the acetabulum by increasing motion in a 1:1 fashion [9,11,19]. The visual mathematical triangle helps explain the excellent results in patients with a primary total hip arthroplasty using traditional cup angles because OA hips without severe stiffness have small changes in the hip functional anatomy (Fig. 2). When severe stiffness is present, from either biological or surgical fusion, the functional anatomy becomes clinically disrupted (Fig. 2; red triangle) [3,6,8,10,11,21].

The triangle confirms the clinical use of SS as a valid positional component of functional anatomy. For example, if the pelvis is fixed in posterior tilt but still has 15° of mobility, there are abnormalities in the structural position of the anatomy, but the acetabulum still opens with sitting (ie, tilts posteriorly) and closes with standing (ie, tilts anteriorly). However, if this same posterior pelvic imbalance is compounded by only 5° of pelvic motion (ΔSS = 5°), the hip joint is severely impacted because the acetabulum (AI) does not open (ΔSS = ΔAI), and femur motion (ΔPFA) must increase. Normal femoral flexion when sitting may be as high as 70°; so if normal pelvic motion of 20°-25° is reduced to 5°, the compensatory increase in hip flexion may increase the risk of impingement [9,19]. On average, femur flexion when standing up from a chair is 76°, sitting down is 62°, and picking up an object from the floor while sitting is 86°; so patients with decreased pelvic motion who must increase their hip motion are at high risk for bony impingement during these positions [22]. Femur flexion of 96° has been shown to cause impingement [23].

The limitations of this study are, first, the clinical data were obtained with static x-rays and not with dynamic motion analysis. However, the data available from the 2 radiographic positions can be interpolated to any postural position using the ratio between the different anatomic components. Furthermore, normal position and mobility cause no concern, whereas the most severe concern, pelvic stiffness, does not have pelvic mobility during postural change so hip position can be determined by the sum of the acetabulum (AI) and the femur (PFA), the combined sagittal index [9]. A second limitation is that the triangle model is mathematically derived from radiographic data, but the representation of the functional anatomy is consistent with our clinical data. Finally, the severity of hip osteoarthritis and amount of lumbar degenerative disease were not quantified for each patient. However, the effect of lumbar degenerative disease is expressed by ΔSS, and the effect of hip osteoarthritis is reflected by hip range of motion obtained during physical examination. From our clinical data, patients with normal pelvic mobility had hip motion of 87° on examination, whereas patients with stiff pelvic motion had hip motion of 92°. However, the specific effects of the severity of hip osteoarthritis on pelvic and hip motions will require further study.

Conclusion

The importance of these data is to provide an understanding of the entire spine-pelvis-hip complex involved in the functional motion of the OA hip joint. This functional anatomy explains why primary total hip arthroplasty has had a high success rate of >95% at 10 years [24,25] and longevity ≥30 years [26] because only hips with severe spinopelvic stiffness have increased risk of impingement. The functional anatomy also explains why the Lewinnek safe zone has not adequately predicted hip instability as it takes into account neither the loss of pelvic motion nor the corresponding compensatory increase in femoral motion [27].

Acknowledgments

The authors acknowledge Richard Lyon and Suzanne Edmonds who created the illustrations used in this manuscript.

References

[1] Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR. Dislocations after total hip-replacement arthroplasties. J Bone Joint Surg Am 1978;60:217–20.
[2] Esposito CI, Gladnick BP, Lee Y-Y, Lyman S, Wright TM, Mayman DJ, et al. Cup position alone does not predict risk of dislocation after hip arthroplasty. J Arthroplasty 2015;30:109–13.
[3] Lazennec J-Y, Brusson A, Rousseau M-A. Hip-spine relations and sagittal balance clinical consequences. Eur Spine J 2011;20(Suppl. 5):686–98.
[4] Lazennec JY, Riwan A, Gravez F, Rousseau MA, Mora N, Gorin M, et al. Hip spine relationships: application to total hip arthroplasty. Hip Int 2007;17(Suppl. 5):S91–104.
[5] Kanawade V, Dorr LD, Wan Z. Predictability of acetabular component angular change with postural shift from standing to sitting position. J Bone Joint Surg Am 2014;96:978–86.
[6] Phan D, Bederman SS, Schwarzkopf R. The influence of sagittal spinal deformity on anteversion of the acetabular component in total hip arthroplasty. Bone Joint J 2015;97-B:1017–23.
[7] Vigdorchik J, Eftekhary N, Elbuluk A, Abdel MP, Buckland AJ, Schwarzkopf RS, et al. Evaluation of the spine is critical in the workup of recurrent instability after total hip arthroplasty. Bone Joint J 2019;101-B:817–23.
[8] Buckland AJ, Puvanesarajah V, Vigdorchik J, Schwarzkopf R, Jain A, Klineberg EO, et al. Dislocation of a primary total hip arthroplasty is more common in patients with a lumbar spinal fusion. Bone Joint J 2017;99-B:585–91.
[9] 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.
[10] Stefl M, Lundergan W, Heckmann N, McKnight B, Ike H, Murgai R, et al. Spinopelvic mobility and acetabular component position for total hip arthroplasty. Bone Joint J 2017;99-B:37–45.
[11] Tezuka T, Heckmann ND, Bodner RJ, Dorr LD. Functional safe zone is superior to the Lewinnek safe zone for total hip arthroplasty: why the Lewinnek safe zone is not always predictive of stability. J Arthroplasty 2018;34:3–8.
[12] Offierski CM, MacNab I. Hip-spine syndrome. Spine 1983;8:316–21.
[13] Matsuyama Y, Hasegawa Y, Yoshihara H, Tsuji T, Sakai Y, Nakamura H, et al. Hip-spine syndrome: total sagittal alignment of the spine and clinical symptoms in patients with bilateral congenital hip dislocation. Spine 2004;29:2432–7.
[14] 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.
[15] Salib CG, Reina N, Perry KI, Taunton MJ, Berry DJ, Abdel MP. Lumbar fusion involving the sacrum increases dislocation risk in primary total hip arthroplasty. Bone Joint J 2019;101-B:198–206.
[16] Dorr LD, Malik A, Wan Z, Long WT, Harris M. Precision and bias of imageless computer navigation and surgeon estimates for acetabular component position. Clin Orthop Relat Res 2007;465:92–9.
[17] Legaye J, Duval-Beaupère G, Hecquet J, Marty C. Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. Eur Spine J 1998;7:99–103.
[18] Philippot R, Wegrzyn J, Farizon F, Fessy MH. Pelvic balance in sagittal and Lewinnek reference planes in the standing, supine and sitting positions. Orthop Traumatol Surg Res 2009;95:70–6.
[19] 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.
[20] Buckland AJ, Steinmetz L, Zhou P, Vasquez-Montes D, Kingery M, Stekas ND, et al. Spinopelvic compensatory mechanisms for reduced hip motion (ROM) in the setting of hip osteoarthritis. Spine Deform 2019;7:923–8.
[21] Bedard NA, Martin CT, Slaven SE, Pugely AJ, Mendoza-Lattes SA, Callaghan JJ. Abnormally high dislocation rates of total hip arthroplasty after spinal deformity surgery. J Arthroplasty 2016;31:2884–5.
[22] Sugano N, Tsuda K, Miki H, Takao M, Suzuki N, Nakamura N. Dynamic measurements of hip movement in deep bending activities after total hip arthroplasty using a 4-dimensional motion analysis system. J Arthroplasty 2012;27:1562–8.
[23] Larkin B, van Holsbeeck M, Koueiter D, Zaltz I. What is the impingement-free range of motion of the asymptomatic hip in young adult males? Clin Orthop Relat Res 2015;473:1284–8.
[24] Yukizawa Y, Dorr LD, Ward JA, Wan Z. Posterior mini-incision with primary total hip arthroplasty: a nine to ten year follow up study. J Arthroplasty 2016;31:168–71.
[25] Klasan A, Sen A, Dworschak P, El-Zayat BF, Ruchholtz S, Schuettler KF, et al. Ten-year follow-up of a cemented tapered stem. Arch Orthop Trauma Surg 2018;138:1317–22.
[26] Callaghan JJ, Bracha P, Liu SS, Piyaworakhun S, Goetz DD, Johnston RC. Survivorship of a Charnley total hip arthroplasty. A concise follow-up, at a minimum of thirty-five years, of previous reports. J Bone Joint Surg Am 2009;91:2617–21.
[27] Abdel MP, von Roth P, Jennings MT, Hanssen AD, Pagnano MW. What safe zone? The vast majority of dislocated THAs are within the Lewinnek safe zone for acetabular component position. Clin Orthop Relat Res 2016;474:386–91.