EOR | volume 3 | march 2018
DOI: 10.1302/2058-5241.3.170022
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EFORT open reviews

Kinematic alignment technique for total hip and knee arthroplasty: the personalized implant positioning surgery

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- Conventional techniques for hip and knee arthroplasty have led to good long-term clinical outcomes, but complications remain despite better surgical precision and improvements in implant design and quality.
- Technological improvements and a better understanding of joint kinematics have facilitated the progression to 'personalized' implant positioning (kinematic alignment) for total hip (THA) and knee (TKA) arthroplasty, the true value of which remains to be determined.
- By achieving a true knee resurfacing, the kinematic alignment (KA) technique for TKA aims at aligning the components with the physiological kinematic axes of the knee and restoring the constitutional tibio-femoral joint line frontal and axial orientation and soft-tissue laxity.
- The KA technique for THA aims at restoring the native 'combined femoro-acetabular anteversion' and the hip's centre of rotation, and occasionally adjusting the cup position and design based on the assessment of the individual spine-hip relation.
- The key element for optimal prosthetic joint kinematics (hip or knee) is to reproduce the femoral anatomy.
- The transverse acetabular ligament (TAL) is the reference landmark to adjust the cup position.

Keywords: knee arthroplasty; hip arthroplasty; kinematic alignment technique; spine-hip syndrome; hip-spine syndrome; spine-hip relation; patient-specific surgery

Cite this article: *EFORT Open Rev* 2018;3:98-105.
DOI: 10.1302/2058-5241.3.170022

Introduction

In the 20th century, Sir John Charnley and Sir John Insall successfully introduced modern total joint replacements for hips (THA) and knees (TKA), respectively. In order to prevent implant fixation failure and accelerated polyethylene wear, it was initially recommended that implants were positioned in a 'biomechanically friendly' way, which disregarded most of the individual patient anatomy.[1-5] Therefore, knee implants were aligned perpendicular to the femoral and tibial mechanical axes[2,3] and the acetabular cup component was medialized as much as possible.[1,4,5] A few years later, Lewinnek et al[6] recommended that the acetabular cup was radiographically positioned with 40° inclination and 20° anteversion, as they found it reduced the risk of prosthetic hip dislocation.

While those initial surgical techniques made for popular and clinically successful total joint replacements, many complications have remained, most notably the functional limitations after TKA[7] and the persistence of frequent instability after THA.[8] In response to those complications, many improvements were developed in the field of joint replacement over the last few decades, moving away from these conventional methods of positioning to more personalized techniques, namely kinematically aligned (KA) THA[9] and TKA.[10]

This instructional review aims, in the first half, to outline the rationale and clinical outcomes of conventional implant-positioning surgical techniques for TKA and THA and then, in the second half, to describe the newly promoted more personalized techniques (kinematic alignment).

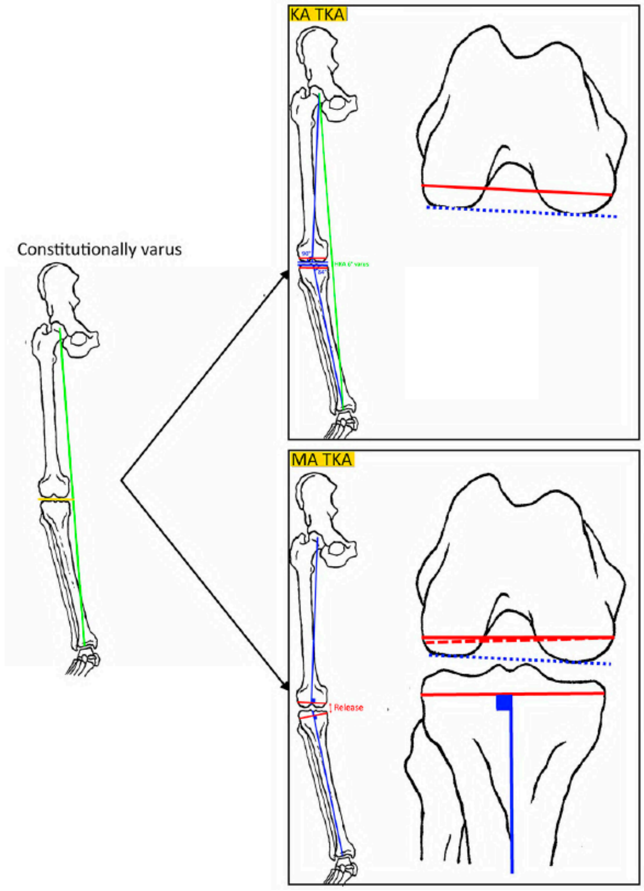

Fig. 1 Comparison between KA TKA and MA TKA. In KA TKA, the posterior femoral cut (red) is made parallel to the posterior condylar line (dotted blue). In comparison, in MA TKA, the femoral cut is made with 3° external rotation relative to the posterior condylar line (measured resection) or parallel to the tibial cut (dotted red – gap balancing) which is perpendicular to the mechanical axis of the tibia (solid blue).

Conventional techniques for hip and knee replacement: rationale and limitations

Conventional technique for TKA

For decades, knee components have been positioned following the concept of mechanical alignment (MA), where implants are aligned perpendicular to the femoral and tibial mechanical axes in order to create a straight lower limb with a prosthetic tibio-femoral joint line (TFJL) perpendicular to the overall limb mechanical axis (Fig. 1). Also, the femoral component is expected to be frontally and axially aligned with the trans-epicondylar axis, which then becomes the prosthetic flexion-extension axis, and the flexion and extension gaps are made, sometimes through the need for soft-tissue release, rectangular and identical in every knee[2,3] (Fig. 1). Every patient implanted with a MA TKA receives similar implant positioning, despite the fact that each patient has different constitutional knee anatomy (obliquity of the native TFJL, alignment of the native knee). This technique enables protection of each implant's fixation and surface bearing by reducing the knee adduction moment and by more evenly sharing the loading between medial and lateral tibial plateaus.[1] All of these things aim to optimize long-term implant survivorship. Also, it aligns the extensor mechanism, which reduces the risk of patella instability.[2,3]

Besides these biomechanical advantages, there remain some inconveniences related to the disregard for individual knee anatomy: first, changing the lower limb and joint line alignment often leads to the need for technically demanding, and therefore poorly reliable, soft-tissue balancing;[2,11] second, a high rate of lateral trochlea facet and distal condyle overstuffing, potentially responsible for clinically deleterious lateral retinacular stretching and patella maltracking;[12] and third, abnormal tibiofemoral (TF) and patella-femoral joint (PFJ) kinematics.[13] These drawbacks might explain why MA TKAs have remained overall functionally disappointing with high rates of residual symptoms (an average of 50%)[7] despite the many improvements in surgical precision and knee implant design.[14-17]

Conventional positioning for THA

For decades, it was recommended that the prosthetic hip centre of rotation be medialized relative to the native centre of rotation by medialization of the acetabular component and a compensatory increase of femoral offset (Fig. 2).[4,5] The rotation is mainly biomechanical, as this reduces the joint reaction force secondary to a reduction of the abduction moment from the abductors,[4,18] thus reducing the risk of early implant loosening and accelerated polyethylene liner wear. This concept has generated good long-term implant survivorship.[19]

Since 1978, the prosthetic cup orientation has been recommended to be at 40° inclination and 20° anteversion (Lewinnek box) relative to the anterior pelvic plane (Lewinnek plane), as this was shown to reduce the risk of prosthetic dislocation.[6] Because the native acetabular orientation varies in the population,[20,21] a similar prosthetic orientation for all patients is rarely likely to reproduce their constitutional acetabular anteversion, either anatomical or functional, and their functional cone of hip mobility (Fig. 2). As the soft tissues around the hip tend to limit the motion of the hip within its physiological cone of mobility,[22,23] this positioning (disregarding the individual acetabular anteversion) is likely not to be optimal and therefore sometimes generates complications such as articular impingement and prosthetic instability.[24,25]

Personalized techniques for total joint replacement: the kinematic revolution

Kinematic alignment technique for TKA

Following the results of a few studies suggesting that the standing post-operative limb alignment was of poor

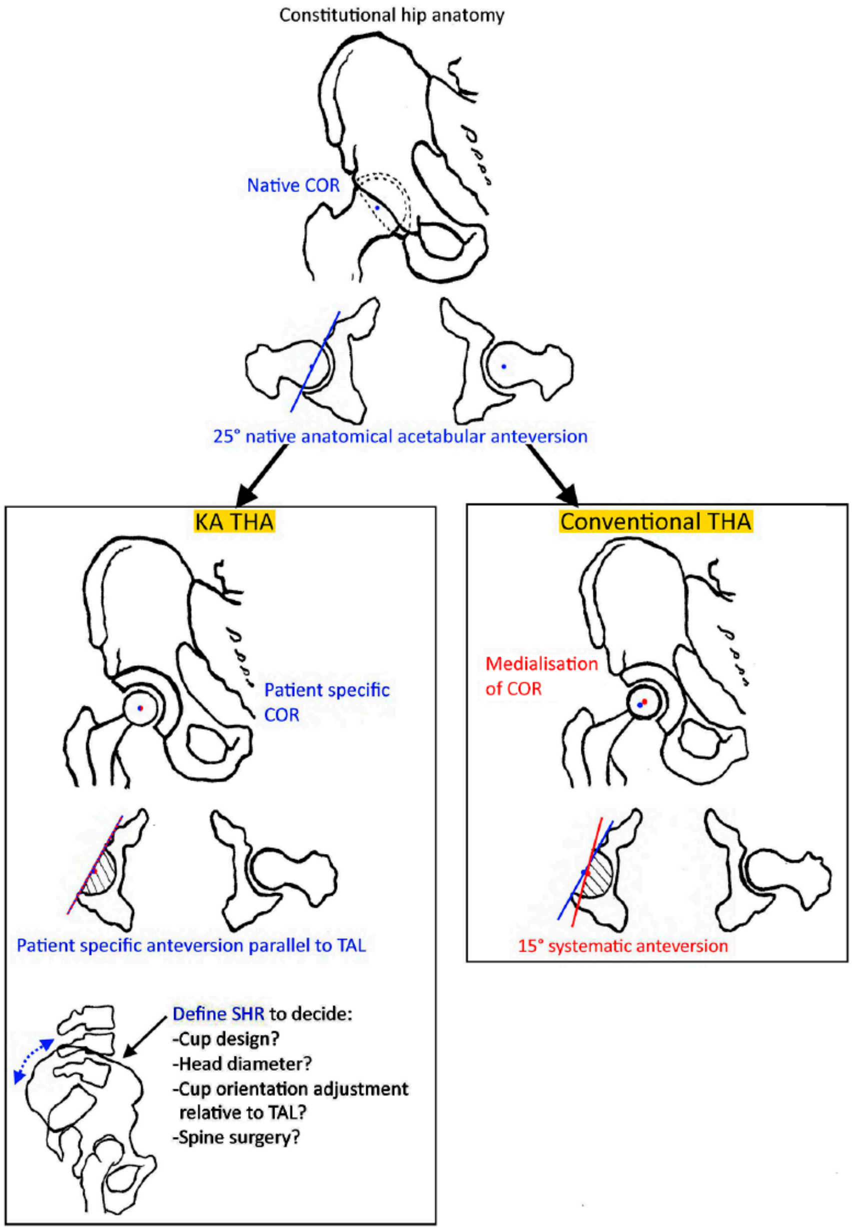

Fig. 2 Comparison between KA THA and conventional THA.

predictive value for clinical outcomes for patients with MA TKA,[26] the idea of preserving the constitutional knee alignment arose.

Since 2007, Howell et al have promoted the KA technique for TKA,[10] which aims at restoring the native three-dimensional (or constitutional) anatomy of the TFJL and at aligning the implants with the kinematic axis of the knee, namely the cylindrical (or trans-condylar) axis,[13] around which the tibia flexes and extends around the femur (Fig. 1). In simplistic terms, the KA technique is almost a true resurfacing of the TFJL, where implant thickness aims to replace the exact same amount of 'bone cartilage' removed and therefore to restore the highly variable individual native pre-arthritic (or constitutional) TFJL orientation[27,28] and soft-tissue laxity.[28-30] It is important to understand that the KA technique is not a modification of the MA technique, but rather a new surgical technique for TKA, with only the sagittal positioning of the femoral component shared with the MA technique. The KA technique, like the MA technique, can be performed with the use of navigation[31] or patient-specific instrumentation[32] or manual instrumentation.[33]

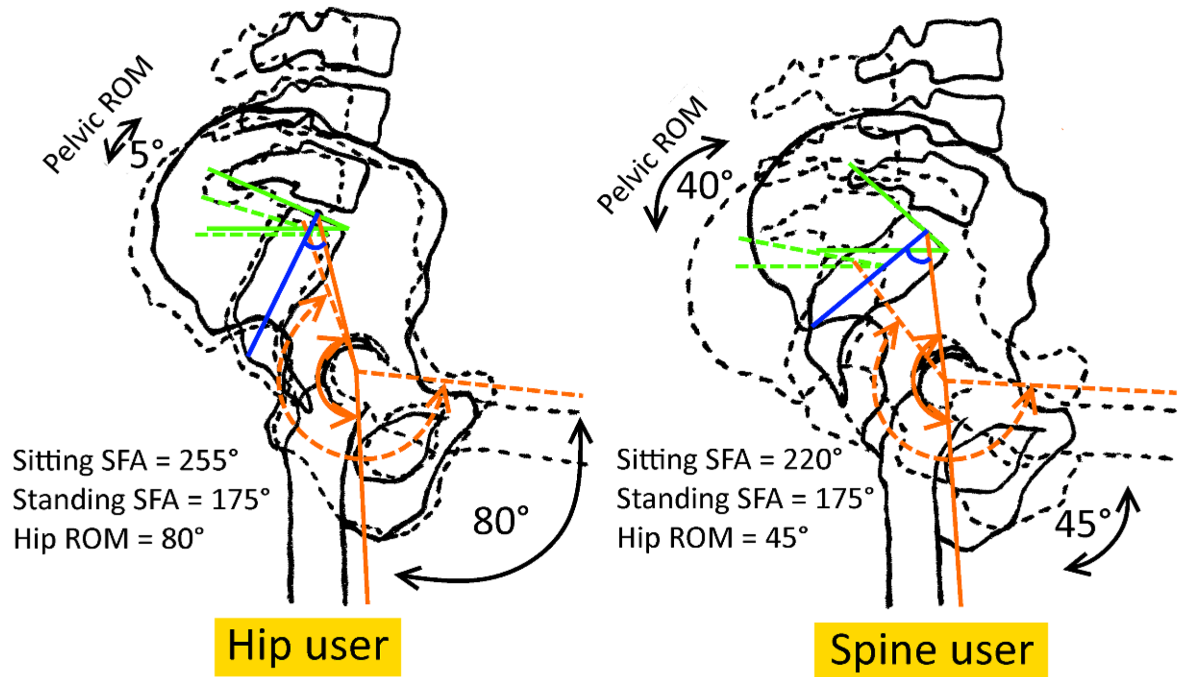

Fig. 3 Comparison between a 'hip' and 'spine' user's pelvic kinematics in standing (solid line) and sitting (dashed line). Note the differences in pelvic incidence (blue), sacral slope (green) and the sacro-femoral angle (orange).

Current evidence has shown this personalized technique performs better early on than the MA technique for TKA. Five randomized studies[32,34-38] have shown the KA TKA to provide faster recovery than MA TKA, and a meta-analysis[39] concluded that KA TKAs provide better functional outcomes and similar complication rates compared with MA TKA at two-year follow-up. Also, a prospective cohort study[40] and a systematic review[41] found the KA technique to generate excellent overall outcomes up until six years of follow-up. Longer-term outcomes are needed in order to define the best indication for the KA technique, as it is likely some patients would not benefit from restoration of their constitutionally extreme 'patho-anatomy'.[42]

Kinematic alignment technique for THA

Technological developments enabling more precise surgery (computer-assisted surgery, robotics[43]) and improvement in implant design and quality (wear-resistant surface bearings,[44] biological implant fixation) have enabled the progressive evolution of THA towards a more anatomical technique aiming to better restore the native hip centre of rotation[5] and acetabular anteversion (Fig. 2).[45,46] A technique for aligning the prosthetic cup parallel to the transverse acetabular ligament (TAL), and therefore allowing a personalized cup position, has recently been promoted with high safety and efficacy regarding dislocation risk.[45,46] However, despite more personalized cup positioning and improvements in implant tolerance (larger head-neck ratio design to prevent articular impingement, larger head to increase the jumping distance), prosthetic instability remains a concerning complication and one of the main causes of early revision after THA.[8,45]

There are two types of abnormal lumbopelvic sagittal kinematics which may influence complications after THA.[9] The first one is related to insufficient pelvic retroversion (Fig. 4) when sitting or squatting (type 1)[9,47-51,61] and the second (Fig. 5) is a consequence of ageing of the spine where the pelvis becomes progressively more retroverted when standing (type 2).[52,53] Patients with one of these aforementioned abnormal types of pelvic kinematics or an abnormally low pelvic incidence (< 35°) are therefore affected by a clinically deleterious lumbopelvic stiffness.[54-60] This generates aberrant functional acetabular orientation in sitting/squatting[9,47-51,61] or standing positions.[59,62] A compensatory effect by the use of a larger hip range of motion makes these patients 'hip users'[9] (Fig. 3). With THA, this lumbopelvic stiffness might be responsible for some complications such as prosthetic instability[9,55,57] and/or edge-loading.[50] Sagittal pelvic kinematics can be estimated in daily practice through standing and sitting lateral lumbopelvic images, either with conventional radiographs or EOS images[63-65] (EOS imaging system®, Biospace®, Paris, France).

The concept of KA THA[9] consists of restoring the constitutional hip anatomy (proximal femur anatomy and acetabular centre of rotation) and taking into account the

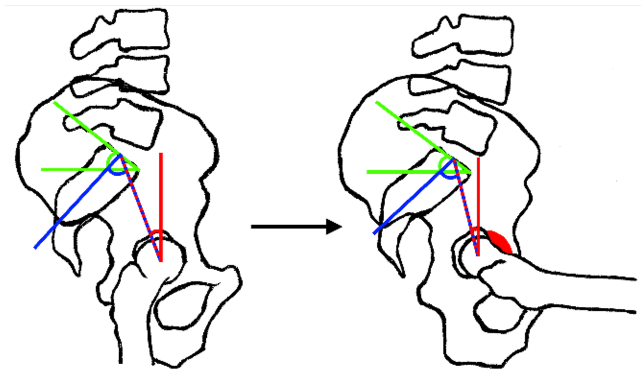

Fig. 4 Type 1 spine-hip syndrome. Note the lack of decrease in sacral slope (green) between standing (left) and sitting (right), contributing to femoroacetabular impingement (red). Pelvic incidence in blue and pelvic tilt in red.

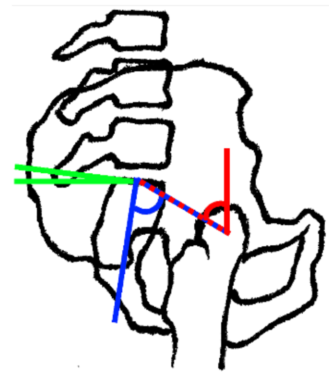

Fig. 5 Type 2 spine-hip syndrome. Ageing of the spine results in loss of lumbar lordosis and increased standing pelvic retroversion. Note the decrease in sacral slope (green) and increase in pelvic tilt (red). The pelvic incidence (blue) remains relatively fixed with age.

Table 1. Principles of the KA technique for THA

Principles of the KA technique for THA
Preoperatively:
1. Define the **individual SHR**
2. Consider **spinal surgery** before THA if evidence of sagittal imbalance
3. Consider the use of "high tolerance" implants for patients with normal SHR but a **high pelvic incidence** as they are at risk of developing SHS with ageing
Intra-operatively:
1. Restore the **proximal femur anatomy**
2. Restore the **native centre of rotation**
3. If normal SHR, restore native **acetabular anteversion**
4. If abnormal SHR, use "high tolerance" implants and adjust cup positioning relative to the **TAL**

Note: SHR, spine-hip relation; SHS, spine-hip syndrome; TAL, transverse acetabular ligament.

Table 2. THA considerations for 'spine' users compared with 'hip' users

Stiff LPC/'hip' user (e.g. low PI or abnormal LPC kinematics)	Flexible LPC/'spine' user (e.g. high pelvic incidence & normal LPC kinematics)
• Use tolerant implant (large diameter head or dual mobility cup) • Adjust cup position relative to the TAL in certain cases • Spine surgery or physiotherapy in certain cases	• No specific implant tolerance required • Consider the possibility of developing severe spine-hip syndrome with ageing

individual sagittal lumbopelvic kinematics in order to plan the implant design (cup and head size), the acetabular cup orientation (using the TAL[19,46]) and the need for spinal surgery to correct a severe sagittal imbalance (Table 1). The more stiff a lumbopelvic complex is, the more it seems sensible firstly to use a large diameter femoral head[24,25,66,67] or dual mobility cup with a mobile liner[68,69] which are more tolerant to articular impingement and edge loading, and second to adjust cup positioning relative to the TAL[19,46] in order to partially correct the abnormal functional cup positioning that would have resulted in anatomic positioning[9,58,59,61] (Table 2). To illustrate, it might be sensible to implant an elderly patient with severe abnormal type 2 pelvic kinematics with a dual mobility cup implanted with anatomic anteversion (parallel to the TAL) or maybe slightly reduced (Table 2). If the same type 2 kinematic abnormality was seen in a younger patient, it might be more reasonable to use a 36 mm diameter head and to adjust the cup using the TAL[19,46] with reduced anteversion and inclination (Table 2). Although more high-quality randomized controlled trials are needed to establish the safety and effectiveness of KA THA, in the author's (CR's) experience with $>$ 150 KA THAs, no adverse clinical or aberrant radiographic features in this cohort have been observed.

Conclusion

Both KA and conventional implant positioning have different advantages and disadvantages. The main advantage of conventional positioning is that it has a well-established, large evidence base regarding complications such as polyethylene wear in TKA[1,3] and dislocation in THA,[6] for example. However, the main disadvantage with conventional positioning is that it ignores individual variation in anatomy/kinematics, although it remains unclear whether restoring extreme native 'patho-anatomy' would be of benefit for every patient.[42] Even though KA TKA has shown promising early outcomes so far,[32,34-41] further research is still needed (for KA THA and KA TKA) to determine the true value and role of 'personalized' implant positioning.

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ICMJE CONFLICT OF INTEREST STATEMENT

C. Rivière declares being a consultant for Medacta, having received payment for lectures from Corin, activity outside the submitted work. S. Muirhead-Allwood declares royalties from Corin, DePuy, Zimmer, activity outside the submitted work. Mr Cobb declares board membership of Embody Orthopaedic; grants from Zimmer Biomet; lecture fees from Microport; patents from Imperial Innovations; royalties from Matortho; stock options from Embody Orthopaedic; travel expenses from Zimmer Biomet, activities outside the submitted work.

FUNDING STATEMENT

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

REFERENCES

1. **Monk AP, Van Oldenrijk J, Riley ND, Gill RHS, Murray DW.** Biomechanics of the lower limb. *Surgery* 2016;34:427-35.

2. **Whiteside LA.** Soft tissue balancing: the knee. *J Arthroplasty* 2002;17(suppl 1):23-7.

3. **Gromov K, Korchi M, Thomsen MG, Husted H, Troelsen A.** What is the optimal alignment of the tibial and femoral components in knee arthroplasty? *Acta Orthop* 2014;85:480-7.

4. **Terrier A, Parvex V, Rüdiger HA.** Impact of individual anatomy on the benefit of cup medialisation in total hip arthroplasty. *Hip Int*. 2016;26(6):537-42.

5. **Meermans G, Doorn JV, Kats JJ.** Restoration of the centre of rotation in primary total hip arthroplasty: the influence of acetabular floor depth and reaming technique. *Bone Joint J* 2016;98-B:1597-603.

6. **Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR.** Dislocations after total hip-replacement arthroplasties. *J Bone Joint Surg [Am]* 1978;60-A:217-220.

7. **Nam D, Nunley RM, Barrack RL.** Patient dissatisfaction following total knee replacement: a growing concern? *Bone Joint J* 2014;96-B(suppl A):96-100.

8. **Bozic KJ, Kurtz SM, Lau E, et al.** The epidemiology of revision total hip arthroplasty in the United States. *J Bone Joint Surg [Am]* 2009;91:128-33.

9. **Rivière C, Lazennec JY, Van Der Straeten C, et al.** The influence of spine-hip relations on total hip replacement: A systematic review. *Orthop Traumatol Surg Res* 2017;103:559-68.

10. **Stephen M, Howell MLH.** Kinematic alignment in total knee arthroplasty. In: Scott WN, ed. *Insall & Scott Surgery of the knee*. Fifth ed. New York: Elsevier, 2011:1255-69.

11. **Gu Y, Roth JD, Howell SM, Hull ML.** How frequently do four methods for mechanically aligning a total knee arthroplasty cause collateral ligament imbalance and change alignment from normal in white patients? AAOS Exhibit Selection. *J Bone Joint Surg [Am]* 2014;96:e101.

12. **Rivière C, Auvinet E, Aframian A, et al.** High rate of distal lateral trochlea facet overstuffing after mechanically aligned TKA: Clinically deleterious? *Orthop Traumatol Surg Res* 2017.

13. **Eckhoff DG, Bach JM, Spitzer VM, et al.** Three-dimensional mechanics, kinematics, and morphology of the knee viewed in virtual reality. *J Bone Joint Surg [Am]* 2005;87(suppl 2):71-80.

14. **Sassoon A, Nam D, Nunley R, Barrack R.** Systematic review of patient-specific instrumentation in total knee arthroplasty: new but not improved. *Clin Orthop Relat Res* 2015;473:151-8.

15. **Xie C, Liu K, Xiao L, Tang R.** Clinical outcomes after computer-assisted versus conventional total knee arthroplasty. *Orthopedics* 2012;35:e647-53.

16. **Chen JY, Chin PL, Tay DK, et al.** Functional outcome and quality of life after patient-specific instrumentation in total knee arthroplasty. *J Arthroplasty* 2015;30:1724-8.

17. **Mattei L, Pellegrino P, Calò M, Bistolfi A, Castoldi F.** Patient specific instrumentation in total knee arthroplasty: a state of the art. *Ann Transl Med* 2016;4:126.

18. **Charles MN, Bourne RB, Davey JR, et al.** Soft-tissue balancing of the hip: the role of femoral offset restoration. *Instr Course Lect* 2005;54:131-41.

19. **Hiddema WB, van der Merwe JF, van der Merwe W.** The transverse acetabular ligament as an intraoperative guide to cup abduction. *J Arthroplasty* 2016;31:1609-13.

20. **Thelen T, Thelen P, Demezon H, Aunoble S, Le Huec JC.** Normative 3D acetabular orientation measurements by the low-dose EOS imaging system in 102 asymptomatic subjects in standing position: analyses by side, gender, pelvic incidence and reproducibility. *Orthop Traumatol Surg Res* 2017;103:209-15.

21. **Fujita K, Kabata T, Maeda T, et al.** The use of the transverse acetabular ligament in total hip replacement: an analysis of the orientation of the trial acetabular component using a navigation system. *Bone Joint J* 2014;96-B:306-11.

22. **Safran MR, Lopomo N, Zaffagnini S, et al.** In vitro analysis of peri-articular soft tissues passive constraining effect on hip kinematics and joint stability. *Knee Surg Sports Traumatol Arthrosc* 2013;21:1655-63.

23. **Smith MV, Costic RS, Allaire R, Schilling PL, Sekiya JK.** A biomechanical analysis of the soft tissue and osseous constraints of the hip joint. *Knee Surg Sports Traumatol Arthrosc* 2014;22:946-52.

24. Banerjee S, Pivec R, Issa K, et al. Large-diameter femoral heads in total hip arthroplasty: an evidence-based review. *Am J Orthop (Belle Mead NJ)* 2014;43:506-12.

25. Miki H, Kyo T, Kuroda Y, Nakahara I, Sugano N. Risk of edge-loading and prosthesis impingement due to posterior pelvic tilting after total hip arthroplasty. *Clin Biomech (Bristol, Avon)* 2014;29:607-13.

26. Parratte S, Pagnano MW, Trousdale RT, Berry DJ. Effect of postoperative mechanical axis alignment on the fifteen-year survival of modern, cemented total knee replacements. *J Bone Joint Surg [Am]* 2010;92:2143-9.

27. Puthumanapully PK, Harris SJ, Leong A, et al. A morphometric study of normal and varus knees. *Knee Surg Sports Traumatol Arthrosc* 2014;22:2891-9.

28. Deep K, Picard F, Clarke JV. Dynamic knee alignment and collateral knee laxity and its variations in normal humans. *Front Surg* 2015;2:62.

29. Roth JD, Hull ML, Howell SM. The limits of passive motion are variable between and unrelated within normal tibiofemoral joints. *J Orthop Res* 2015;33:1594-602.

30. Roth JD, Howell SM, Hull ML. Native knee laxities at 0 degrees, 45 degrees, and 90 degrees of flexion and their relationship to the goal of the gap-balancing alignment method of total knee arthroplasty. *J Bone Joint Surg [Am]* 2015;97:1678-84.

31. Hutt JR, LeBlanc MA, Massé V, Lavigne M, Vendittoli PA. Kinematic TKA using navigation: surgical technique and initial results. *Orthop Traumatol Surg Res* 2016;102:99-104.

32. Waterson HB, Clement ND, Eyres KS, Mandalia VI, Toms AD. The early outcome of kinematic versus mechanical alignment in total knee arthroplasty: a prospective randomised control trial. *Bone Joint J* 2016;98-B:1360-8.

33. Howell SM, Roth JD, Hull ML. Kinematic alignment in total knee arthroplasty. Definition, history, principle, surgical technique, and results of an alignment option for TKA. *Arthropaedia* 2014;1:44-53.

34. Dossett HG, Swartz GJ, Estrada NA, LeFevre GW, Kwasman BG. Kinematically versus mechanically aligned total knee arthroplasty. *Orthopedics* 2012;35:e160-9.

35. Young SW, Walker ML, Bayan A, et al. The Chitranjan S. Ranawat Award: no difference in 2-year functional outcomes using kinematic versus mechanical alignment in TKA: a randomized controlled clinical trial. *Clin Orthop Relat Res* 2017;475:9-20

36. Calliess T, Bauer K, Stukenborg-Colsman C, et al. PSI kinematic versus non-PSI mechanical alignment in total knee arthroplasty: a prospective, randomized study. *Knee Surg Sports Traumatol Arthrosc* 2017;25:1743-8.

37. Matsumoto T, Takayama K, Ishida K, et al. Radiological and clinical comparison of kinematically *versus* mechanically aligned total knee arthroplasty. *Bone Joint J* 2017;99-B:640-6.

38. Dossett HG, Estrada NA, Swartz GJ, et al. A randomised controlled trial of kinematically and mechanically aligned total knee replacements: two-year clinical results. *Bone Joint J* 2014;96-B:907-13.

39. Courtney PM, Lee GC. Early outcomes of kinematic alignment in primary total knee arthroplasty: a meta-analysis of the literature. *J Arthroplasty* 2017;32:2028-32.

40. Howell SM, Papadopoulos S, Kuznik K, Ghaly LR, Hull ML. Does varus alignment adversely affect implant survival and function six years after kinematically aligned total knee arthroplasty? *Int Orthop* 2015;39:2117-24.

41. Lee YS, Howell SM, Won YY, et al. Kinematic alignment is a possible alternative to mechanical alignment in total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc* 2017;25:3467-79.

42. Rivière C, Iranpour F, Auvinet E, et al. Alignment options for total knee arthroplasty: a systematic review. *Orthop Traumatol Surg Res* 2017;103:1047-56.

43. Sugano N. Computer-assisted orthopaedic surgery and robotic surgery in total hip arthroplasty. *Clin Orthop Surg* 2013;5:1-9.

44. Kumar N, Arora GN, Datta B. Bearing surfaces in hip replacement - Evolution and likely future. *Med J Armed Forces India* 2014;70:371-6.

45. Archbold HA, Mockford B, Molloy D, et al. The transverse acetabular ligament: an aid to orientation of the acetabular component during primary total hip replacement: a preliminary study of 1000 cases investigating postoperative stability. *J Bone Joint Surg [Br]* 2006;88:883-6.

46. Meftah M, Yadav A, Wong AC, Ranawat AS, Ranawat CS. A novel method for accurate and reproducible functional cup positioning in total hip arthroplasty. *J Arthroplasty* 2013;28:1200-5.

47. Ng KC, Lamontagne M, Adamczyk AP, Rakhra KS, Beaulé PE. Patient-specific anatomical and functional parameters provide new insights into the pathomechanism of cam FAI. *Clin Orthop Relat Res* 2015;473:1289-96.

48. Lamontagne M, Kennedy MJ, Beaulé PE. The effect of cam FAI on hip and pelvic motion during maximum squat. *Clin Orthop Relat Res* 2009;467:645-50.

49. Bagwell JJ, Snibbe J, Gerhardt M, Powers CM. Hip kinematics and kinetics in persons with and without cam femoroacetabular impingement during a deep squat task. *Clin Biomech (Bristol, Avon)* 2016;31:87-92.

50. Pierrepont JW, Feyen H, Miles BP, et al. Functional orientation of the acetabular component in ceramic-on-ceramic total hip arthroplasty and its relevance to squeaking. *Bone Joint J* 2016;98-B:910-6.

51. Rivière C, Hardijzer A, Lazennec JY, et al. Spine-hip relations add understandings to the pathophysiology of femoro-acetabular impingement: A systematic review. *Orthop Traumatol Surg Res* 2017;103:549-57.

52. Esposito CI, Miller TT, Kim HJ, et al. Does degenerative lumbar spine disease influence femoroacetabular flexion in patients undergoing total hip arthroplasty? *Clin Orthop Relat Res* 2016;474:1788-97.

53. Rousseau MA, Lazennec JY, Boyer P, et al. Optimization of total hip arthroplasty implantation: is the anterior pelvic plane concept valid? *J Arthroplasty* 2009;24:22-6.

54. Ochi H, Homma Y, Baba T, et al. Sagittal spinopelvic alignment predicts hip function after total hip arthroplasty. *Gait Posture* 2017;52:293-300.

55. DelSole EM, Vigdorchik JM, Schwarzkopf R, Errico TJ, Buckland AJ. Total hip arthroplasty in the spinal deformity population: does degree of sagittal deformity affect rates of safe zone placement, instability, or revision? *J Arthroplasty* 2017;32:1910-7.

56. Barry JJ, Sing DC, Vail TP, Hansen EN. Early outcomes of primary total hip arthroplasty after prior lumbar spinal fusion. *J Arthroplasty* 2017;32:470-4.

57. Perfetti DC, Schwarzkopf R, Buckland AJ, Paulino CB, Vigdorchik JM. Prosthetic dislocation and revision after primary total hip arthroplasty in lumbar fusion patients: a propensity score matched-pair analysis. *J Arthroplasty* 2017;32:1635-40.

58. Gu M, Zhang Z, Kang Y, et al. Roles of sagittal anatomical parameters of the pelvis in primary total hip replacement for patients with ankylosing spondylitis. *J Arthroplasty* 2015;30:2219-23.

59. Stefl M, Lundergan W, Heckmann N, et al. Spinopelvic mobility and acetabular component position for total hip arthroplasty. *Bone Joint J* 2017;99-B(suppl A):37-45.

60. Sariali E, Klouche S, Mamoudy P. Investigation into three dimensional hip anatomy in anterior dislocation after THA. Influence of the position of the hip rotation centre. *Clin Biomech (Bristol, Avon)* 2012;27:562-7.

61. 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.

62. McCarthy TF, Alipit V, Nevelos J, Elmallah RK, Mont MA. Acetabular cup anteversion and inclination in hip range of motion to impingement. *J Arthroplasty* 2016;31(suppl):264-8.

63. 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.

64. Lazennec JY, Brusson A, Rousseau MA. Hip-spine relations and sagittal balance clinical consequences. *Eur Spine J* 2011;20(suppl 5):686-98.

65. Lazennec JY, Brusson A, Rousseau MA. Lumbar-pelvic-femoral balance on sitting and standing lateral radiographs. *Orthop Traumatol Surg Res* 2013;99(suppl):S87-S103.

66. Cinotti G, Lucioli N, Malagoli A, Calderoli C, Cassese F. Do large femoral heads reduce the risks of impingement in total hip arthroplasty with optimal and non-optimal cup positioning? *Int Orthop* 2011;35:317-23.

67. Malik A, Maheshwari A, Dorr LD. Impingement with total hip replacement. *J Bone Joint Surg Am* 2007;89:1832-42.

68. Vielpeau C, Lebel B, Ardouin L, Burdin G, Lautridou C. The dual mobility socket concept: experience with 668 cases. *Int Orthop* 2011;35:225-30.

69. Ko LM, Hozack WJ. The dual mobility cup: what problems does it solve? *Bone Joint J* 2016;98-B(suppl A):60-3.