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Original article

Kinematic alignment versus conventional techniques for total hip arthroplasty: A retrospective case control study

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ABSTRACT

Background: Residual complications of conventionally implanted hip components have only been partially reduced by improved implant design and higher surgical precision, and their occurrence is poorly predicted by the radiographic standing/supine cup orientation. This has raised awareness that conventional techniques may not aim for the correct component orientation target, and the lumbo-pelvic kinematics, which influences the functional acetabular orientation, may be of interest to further improve THA clinical outcomes. This has led to the development of the Lumbo-Pelvic kinematic alignment (KA) technique for THA that aims to anatomically position and kinematically align hip implants (acetabular and femoral, total and resurfacing components), in order to optimise prosthetic hip biomechanics and hopefully improve prosthetic function, patient satisfaction, and components' lifespan. Therefore, we conducted a case control investigation to assess the early-term safety and efficacy of this new technique by answering the following questions: does the KA technique for THA: (1) better restore the native hip anatomy, (2) generate a different radiographic supine cup position, and (3) improve clinical outcomes in comparison to the conventional mechanical alignment technique?
Hypotheses: Using KA technique allows there is no statistically significant difference between the pre to postoperative differential for acetabular medial and vertical offsets, femoral offset, and leg length.
Methods: We led a case control retrospective study with prospectively collected clinical data. Forty-one consecutive unselected KA-THAs performed with manual instrumentation were paired with 41 mechanically aligned THAs. The 1-year clinical outcomes and radiographical measurements were compared.
Results: Compared to the mechanical alignment technique, the KA technique resulted in a more anatomical restoration of the prosthetic hip centre of rotation with a lower delta pre- to post-operative horizontal acetabular offset (1.47 mm for KA versus −5.1 mm for MA, $p = 0.001$), and with 74% of KA versus 50% of MA cups ($p = 0.044$) being within 15% of native anatomy for the horizontal acetabular offset. In addition, the KA technique resulted in a higher cup anteversion ($22^\circ \pm 7^\circ$ vs $15^\circ \pm 8^\circ$, $p < 0.001$) but similar cup inclination ($41^\circ \pm 6^\circ$ vs. $42^\circ \pm 7^\circ$, $p = 0.25$), a similar proportion of cups within the Lewinnek zone (65% vs. 70%, $p = 0.8$), similar excellent functional outcomes (delta Oxford score pre- to follow-up of 24.3 and 23.5 points for KA and MA groups, respectively, $p = 0.88$), similar patient satisfaction scores of 95.4/100 and 89.5/100 for KA and MA groups, respectively, and the same absence of aseptic complications.
Conclusion: The KA technique for THA has been demonstrated to be safe, efficacious, and not inferior to the conventional MA technique at early-term. As the concept of the KA technique for THA is only at an early stage, its influence on mid to long-term clinical outcomes remains to be determined and further refinements of the concept are yet to be made.
Level of evidence: III; case-control retrospective study.

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1. Introduction

Many techniques for implanting hip components have succeeded over the last 60 years, progressively improving the clinical outcomes of THA to an acceptable level [1]. The initial and gold standard technique, namely mechanical alignment (MA), aims to achieve set biomechanical parameters, whilst disregarding most of the individual hip anatomy [2,3]. Minimisation of both joint reaction forces and the risk of dislocation was attempted by medialising the prosthetic hip centre of rotation (COR) [3,4] and by systematically (similarly implanted between patients) orienting components [5,6], respectively. Subsequently, concepts of combined anteversion [7] and of anatomical hip reconstruction (patient-specific constitutional acetabular and neck anteversion) [4,8–12] were successfully promoted. Furthermore, the concept of functional cup positioning (pelvic tilt adjusted cup implantation) [13,14], the goal of which is to achieve a more reliable supine or standing radiographical cup position, thus improving the standing components' interaction, has been drawing interest. All the afore-mentioned techniques for implanting hip components have led to good long-term clinical outcomes despite some remaining complications, primarily related to the poor interaction of components [1,15–17]. Interestingly, those complications have only been partially reduced by improved implant design [1,15] and higher surgical precision from technological assistance [18], and their occurrence is poorly predicted by the radiographic standing/supine cup orientation [5,6,17,19,20]. While the former suggests those techniques may not aim for the right components' orientation target, the latter raises the point that standing/supine cup orientation is insufficient to estimate the full picture of the component interaction during activities of daily living (ADLs). This has raised our awareness that sitting component interaction [21–24], and therefore the lumbo-pelvic kinematics (influencing the functional acetabular orientation) [21,25–27], may be of interest to further improve clinical outcomes of THA. This has led to the development of the lumbo-pelvic kinematic alignment (KA) technique for THA [21,28].

The KA technique for THA was initially described in 2017 [21,28] to account for inter-individually variable lumbo-pelvic kinematics between standing and sitting [21,29–31]. The technique was inspired by initial work from Laffargue et al. [32] on considering the hip kinematics for guiding the cup implantation. With the KA technique, patients with an abnormally stiff lumbo-pelvic complex will be implanted with a high tolerance (for risks of edge loading and articular impingement) cup design [33–35], plus or minus adjustment of their cup orientation by making a slight deviation from their native anatomy. By restoring the constitutional anatomy, physiological soft-tissue balance is reproduced, thus probably preventing imbalance-related complications (stiffness, pain, instability symptoms), and favouring the patient-specific physiological joint kinematics [3,4,11,36]. It is hoped this will result in improved functional outcomes and patient satisfaction. As the restoration of the native proximal femur anatomy and centre of rotation are key to producing physiological prosthetic hip kinematics [3,4,11,36], adjustment of component position primarily concerns the cup. The KA technique for THA aims to improve the early to long-term hip component lifespan through improving the individual functional interaction of components during activities of daily living (ADLs). The need for this is heightened given we are now implanting younger, high-demand patients with a longer life expectancy, who are at a higher risk of revision surgery [1]. If accurate component alignment could be achieved in all patients, the THA revision burden would hopefully be significantly reduced.

As there is no clinical data regarding this new KA technique, we initiated a case control investigation to assess its value and aimed with this pilot study to determine its early-term safety and efficacy. This study aimed to answer the following questions: does the KA technique for THA (1) better restore the native hip anatomy, (2) generate a different radiographic supine cup position, and (3) improve clinical outcomes in comparison to the MA technique? We therefore tested the hypotheses: There is no statistically significant difference between (1) the pre to postoperative differential for acetabular medial and vertical offsets, femoral offset, and leg length, regardless of the technique for implanting components (KA or MA), (2) the KA and MA radiographic cup orientation, and (3) patient reported outcomes measures (PROMs) for KA and MA patients.

2. Patients and Methods

2.1. Patients

We led a retrospective case-matched study using prospectively collected data (patient registry) on 1164 consecutive osteoarthritic adult hip patients having undergone a primary THA, either kinematically or mechanically aligned, in our centre between March and December 2017. Forty-one consecutive KA-THA patients (KA group - case), with a minimum of 1-year of follow-up, were selected and matched in a 1:1 ratio for age, gender, body mass index and preoperative functional scores with MA-THA patients (MA group – control). Demographic data and preoperative PROMs for each group are illustrated in Table 1. As this pilot study was an audit of practice, no ethical approval was required.

3. Methods

Experienced, fellow-trained surgeons performed all operative procedures using manual instrumentation (free-hand technique), following digital preoperative templating. All patients received a similar pre and post-operative rehabilitation protocol. Details regarding the procedure (approach, implant design and fixation) are shown in Table 1.

Conventional mechanical surgical technique (MA technique): Patients were positioned in lateral decubitus and MA-THA was performed either through a posterior or lateral approach. The acetabulum was reamed medially until reaching the quadrilateral bone, and the cup was impacted with 40° inclination and 15° anteversion relative to the table plane. The proximal femur reconstruction aimed to restore femoral length and medial offset, in addition to approximately 15° of prosthetic neck anteversion relative to the posterior condylar line.

Lumbo-pelvic Kinematic alignment surgical technique (KA technique): The surgical procedure followed a precise step-wise execution, as illustrated in Fig. 1. Femoral reconstruction aimed to be anatomic, following a modified calliper technique as described by Hill et al. [39], inter alia. After the individual preoperative spine-hip relationship (SHR–simplified Bordeaux classification, Table 2) was defined via clinical examination and analysis of lateral lumbo-pelvic standing and sitting radiographs as illustrated in Fig. 2 [21,31], the choice for cup design and orientation was determined following algorithms illustrated in Table 3 and Fig. 3. In short, cup orientation adjustment was made when selecting a more tolerant implant (larger head neck ratio, dual mobility) was considered insufficient to compensate for the poor lumbo-pelvic kinematics (subsequent suboptimal cup functional orientation if anatomically aligned), and this was at the discretion of the surgeon (CR). When an adjustment was deemed necessary, the goal was to achieve a compromised cup orientation preventing aberrant component interaction in standing and sitting positions, thus generating a fair functional component interaction. The extent of adjustment required was determined using the following published principles: the average posterior pelvic tilt from standing to sitting for patients

Table 1
Descriptive data of the kinematically aligned (KA) and mechanically aligned (MA) patients.

Variable	KA patients (n = 41)	MA patients (n = 41)	p-value
Sex, male (number)	17	17	0.823
Age, years (mean ± SD)	68 ± 10	67 ± 9	0.682
BMI, kg/m^2 (mean ± SD)	27.5 ± 5	29.5 ± 6	0.061
Contralateral hip, prosthetic (number)	7	8	1.000
Preoperative OHS, score (mean ± SD)	18.7 ± 9	18.9 ± 7.8	0.948
Preoperative EQ-5D index, score (mean ± SD)	0.36 ± 0.32	0.41 ± 0.3	0.465
Preoperative EQ-5D, VAS (mean ± SD)	64 ± 25	66 ± 21	0.583
Follow-up duration, months (mean ± SD)	8.2 ± 2.9	7.5 ± 2.9	0.258
Implanted side, right (number)	21	22	1.000
Fixation, cementless/hybrid (number)	36/4	16/25	< 0.001[a]
Approach, posterior/direct anterior/lateral (number)	28/13/0	23/4/14	< 0.001[a]
Surface bearing, full ceramic/ceramic on polyethylene/metal on polyethylene/dual mobility (number)	25/4/2/10	12/21/8/0	< 0.001[a]
Head size, 36/32/28 for dual mobility cup (number)	24/7/10	26/15/0	< 0.001[a]
Cup size, mm (mean ± SD)	52.5 ± 2.5	52.2 ± 3.4	0.771
Duration before discharge, days (mean ± SD)	3.8 ± 1.5	3.8 ± 1.6	0.943

BMI: body mass index, OHS: oxford hip score [37], EQ-5D; euro quality of life 5 dimensions [38], VAS: visual analogic score.
[a] Expresses a significant difference.

Successive steps for free-hand kinematic implantation of THA components:

1. Check for correct pelvis positioning when installing the patient on the surgical table
2. Measure the constitutional femoral length and offset before performing the neck cut
3. Cut the femoral neck perpendicular to it
4. Quality-control check of neck cut → Recut if needed
5. Mark the TAL orientation on the skin
6. Ream the acetabulum evenly without excessive medialisation
7. Impact the cup as planned, relative to the TAL skin-mark (cup anteversion) and the vertical plane (cup inclination)
8. Quality-control check of cup position → Re-impact if needed
9. Broach the femur perpendicular to the neck cut plane and insert the trial stem
10. Quality-control check by measuring prosthetic femoral length and offset → fine-tuning if needed
11. Prosthetic reduction, check components' interaction, leg length, and joint laxity (piston test)
12. Implant final components

Fig. 1. Main surgical steps to achieve a kinematically aligned (KA) Total Hip Arthroplasty (THA). TAL: Transverse Acetabular Ligament.

Table 2
Simplified Bordeaux classification of spine-hip relationships and their diagnostic criteria. Pelvic Incidence (PI), Lumbo-Lordosis (LL), Sagittal Vertical Axis distance (SVA).

	Simplified Bordeaux Classification of Spine-Hip Relationship					
Lumbo-pelvic complex	Flexible	Increasing stiffness				
Spine-hip relationship	A	1	B	C	D	Fused spine
Diagnosis	Pelvic Incidence > 30° No standing PI-LL mismatch > 10° delta sacral-slope from standing to sitting	PI < 30°	No standing PI-LL mismatch < 10° delta sacral-slope from standing to sitting	Standing PI-LL mismatch Normal SVA	Standing PI-LL mismatch Abnormal SVA	Instrumented or biologically fused spine

is approximately 20° [30,40,41], for every 10° of pelvic tilt there is a change of cup orientation by approximately 7° (anteversion) and 3°(inclination) [14], and the normal standing Sacral Slope is equal to 75% of Pelvic incidence [29,30].

3.1. Methods of assessment

Patients were assessed both before and 1 year after surgery. Pre and post-operative complications and patient reported outcomes measures (PROMs) were recorded, including patient satisfaction regarding the outcome of the THA (100 points visual analogic scale), Oxford Hip Score (OHS) [37], and Euro quality of life–5 dimensions (EQ-5D index and EQ-5D VAS for general health status) [38].

Preoperatively, all patients undertook routine radiographic imaging including a calibrated antero-posterior standing pelvis view and a lateral cross-leg view of the osteoarthritic hip; KA patients received additional standing and sitting lateral lumbo-pelvic radiographs. Postoperatively, all patients had a supine pelvic radiograph and a lateral view of the prosthetic hip. Radiographic measurements, including pre and post-operative hip anatomical parameters (acetabular horizontal and vertical offsets, femoral offset, and limb-length), the preoperative spino-pelvic parameters (pelvic incidence, sacral slope, lumbar lordosis L1-L5, and sacro-femoral angles) in standing and sitting positions, and the supine cup anteversion and inclination, were made using TraumaCad software (Brainlab, Cambourne, Cambridge, UK), as illustrated in Fig. 4. The preoperative anatomical hip parameters were measured on the contralateral healthy hip when the osteoarthritic hip was excessively degenerated and considered unreliable to estimate the native anatomy.

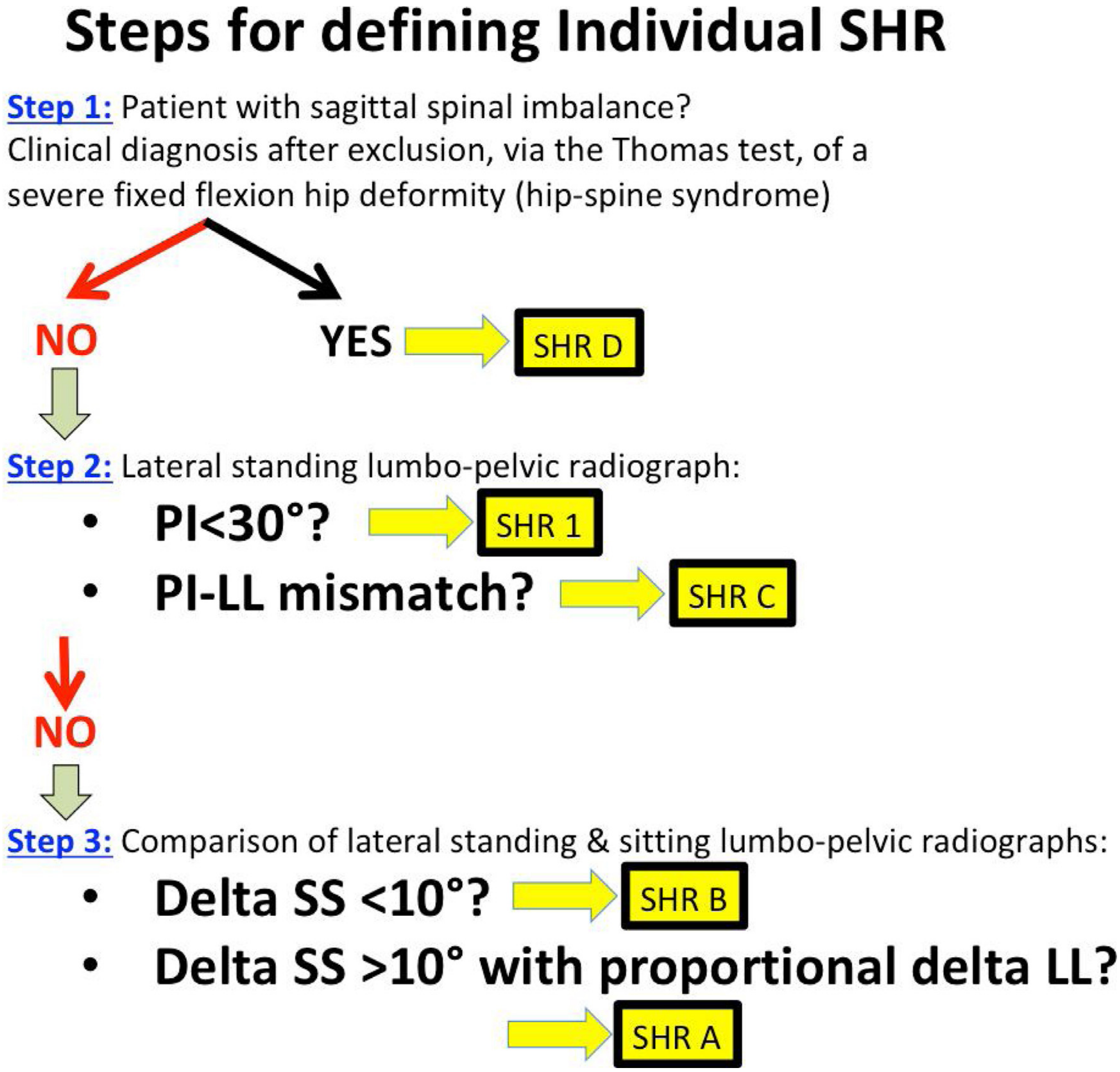

Fig. 2. Algorithm for defining the individual spine-hip relationship (SHR) according to the Bordeaux classification. PI: pelvic incidence, LL: lumbar lordosis, SS: sacral slope.

Table 3
Algorithm for adjusting the cup orientation to compensate for the individual Spine-Hip Relationship.

	Simplified Bordeaux Classification of Spine-Hip Relationship					
Spine-hip relationship	A	1	B	C	D	Fused spine
Cup anteversion adjustment	None (cup parallel to TAL)	Increased cup anteversion by 3.5° (relative to TAL) for every 10° of lack of pelvic retroversion when sitting (normal pelvic retroversion when sitting = 20°)		Reduced cup anteversion by 3.5° (relative to TAL) for every 10° of excessive standing pelvic retroversion (normal standing sacral slope = 75% of pelvic incidence)		Idem B or C, depending on position of fusion and residual flexibility
Cup inclination adjustment	None (radiographic target: 40°)	Don't change your free-hand technique for cup inclination as the additional cup anteversion will increase the radiographic cup inclination (radiographic target: 40° to 50°)				

TAL: Transverse Acetabular Ligament.

3.2. Statistics

Descriptive statistics were used and quantitative analyses were performed on a per protocol basis and confined to data derived from the period of follow-up. Continuous variables were expressed as mean ± standard deviation, and categorical data with absolute frequencies and percentages. Paired t-tests were performed to compare pre- and post-operative anatomical parameters, and clinical outcomes between KA and MA-THAs. The Chi-square test was used for discrete variables. The level of significance was set at 0.05 after adjustment. The proportion of prosthetic hips with anatomical parameters restored within 15% of native anatomy, considered to have negligible influence on function, has been calculated. Two independent assessors (CM and CYH) computed the cup positioning, and the inter-observer reliability of cup inclination and anteversion measurements was tested by using the intraclass

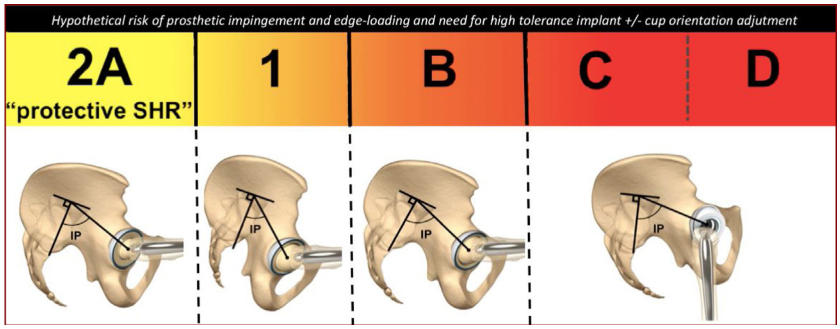

Fig. 3. Simplified Bordeaux classification of spine-hip relationship (SHR) with types 2A, 1, B, C, and D. The risks of poor functional component interaction and the need for cup adjustment (design and orientation) are estimated.

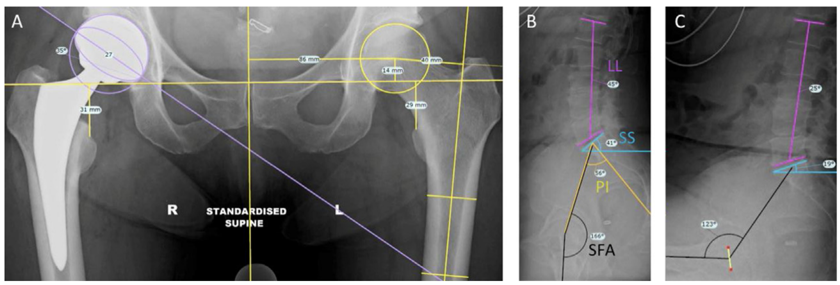

Fig. 4. Radiographical parameters measured with Traumacad. A. Anterior-posterior pelvic radiograph demonstrating a 27° cup anteversion and 35° cup inclination, a 2 mm limb length discrepancy (31 mm–29 mm), a 40 mm native femoral offset, and a 14 mm and 86 mm for the vertical and horizontal native centre of rotation offsets, respectively. Lateral lumbo-pelvic standing (B) and sitting (C) radiographs demonstrating preoperative spino-pelvic parameter measurements, including pelvic incidence (PI), sacral slope (SS), L1L5 lumbar lordosis (LL) and sacrofemoral angle (SFA). With a normal PI at 56°, no PI-LL mismatch when standing, and a 22° (41–19) SS reduction from standing to sitting, the patient is having a normal SHR type 2A. Patient flexed by 71° (=360-123-166) his hips in order to sit.

Table 4
Table illustrating preoperative spino-pelvic parameters and supine cup orientation of the whole group of KA patients, depending on their spine-hip relationship (SHR).

SHR type (Number of patients)	all KA patients (*n* = 34)	SHR A (*n* = 17)	SHR 1 (*n* = 1)	SHR B (*n* = 4)	SHR C (*n* = 7)	SHR D (*n* = 5)
Pelvic Incidence (°)	51 (29 to 84)	50 ± 10	29	57 ± 19	57 ± 10	48 ± 13
Lumbar Lordosis – Pelvic Incidence	5 (−31 to 43)	−2 ± 5	2	3 ± 3	13 ± 31	19 ± 6
Standing sacral slope (°)	36 (11 to 70)	39 ± 7	27	42 ± 19	35 ± 5	24 ± 11
Delta sacral slope (°)	21 (2 to 47)	23 ± 11	5	6 ± 3	32 ± 9	12 ± 7
Standing Lumbar Lordosis (°)	47 (5 to 79)	52 ± 10	27	54 ± 17	44 ± 25	28 ± 15
Delta Lumbar Lordosis (°)	19 (−9 to 66)	25 ± 11	9	4 ± 9	24 ± 30	5 ± 7
Delta Sacro Femoral Angle (°)	59 (28 to 91)	56 ± 14	70	85 ± 6	42 ± 13	71 ± 8
Bearings (32,36,Dual mobility)	6,20,8	5,12,0	0,1,0	1,3,0	0,4,3	0, 0, 5
Approach (direct anterior, mini-posterior)	10,24	5, 12	0,1	2,2	3,4	0,5
Supine cup inclination	40.6 ± 5.9 (25 to 52)	41 ± 3 (35 to 48)	41	43 ± 11 (28 to 52)	36 ± 6 (25 to 43)	42 ± 7 (32 to 50)
Supine cup anteversion	21.6 ± 7.5 (11 to 38)	21 ± 6 (11 to 30)	17	28 ± 7 (17 to 34)	24 ± 10 (11 to 38)	22 ± 6 (16 to 32)
Number of cup adjusted (%)	12/34 (35%)	0 (0%)	1/1 (100%)	4/4 (100%)	2/7 (29%)	5/5 (100%)

Results are expressed as mean ± Standard deviation (range).

correlation coefficient (ICC). The resulting ICC indicated excellent agreement for both cup inclination (ICC 0.97–CI: 0.95–0.98) and anteversion (ICC 0.93–CI: 0.89–0.96). Using the two-tailed hypothesis test at an alpha level of 0.05 and a power of 80%, it was found that 37 patients per group were required to detect a 3(±4) point difference in the OHS [37]. In order to account for 10% of missing data, we recruited 41 patients per group. All the statistical computations were two-tailed and were performed with SPSS™ Statistics 18 statistical software (IBM, Armonk, NY, USA).

4. Results

For KA patients, according to the simplified Bordeaux classification, 17 patients had a flexible (SHR A) and 17 a stiff (1 SHR 1/4 SHR B/7 SHR C/5 SHR D/no fusion) lumbo-pelvic complex. The preoperative spino-pelvic parameters, details regarding the surgical procedure, and the supine cup orientation for KA patients from the whole cohort of each sub-group of SHR are illustrated in Table 4. None of the patients with a flexible lumbo-pelvic complex (SHR A) had an adjustment of the cup orientation (kinematic and anatomical cup positioning were matching), while 12/17 (70%) patients with a stiff lumbo-pelvic complex did (kinematic and anatomical cup positioning were not matching). Five patients with SHR type C because of a slight spine degeneration (standing sacral slope > 50% of the pelvic incidence) had their cup anatomically implanted without adjustment because it was considered the cup tolerance would be sufficient to palliate this slightly abnormal SHR. Consequently, only 12/34 (35%) KA cups were adjusted.

Both Table 5 and Fig. 5 illustrate the comparison between native and prosthetic (KA and MA) anatomical hip parameters. Seven

Table 5
omparison of pre and post-operative radiological parameters for kinematically aligned (KA) and mechanically aligned (MA) patients.

Variable		KA patients ($n = 34$)	MA patients ($n = 34$)	*p* value
Vertical acetabular offset	Preoperative native	14.8 ± 2.8	15.1 ± 3.9	
	Postoperative	15.2 ± 3.2	16.8 ± 4.3	
	Δ pre to post	0.35 ± 2.56	1.71 ± 3.34	0.065
	p value	0.43	0.005[a]	
Horizontal acetabular offset	Preoperative native	31.4 ± 5.8	33.5 ± 4.9	
	Postoperative	30 ± 4.2	28.4 ± 3.9	
	Δ pre to post	−1.47 ± 4.31	−5.09 ± 4.47	0.001
	p value	0.06	< 0.001[a]	
Femoral offset	Preoperative native	36.4 ± 7.6	37.6 ± 7.9	
	Postoperative	37.6 ± 7.1	39.6 ± 6.3	
	Δ pre to post	1.12 ± 4.54	2 ± 6.8	0.531
	p value	0.16	0.1	
Limb length	Preoperative native	−0.12 ± 2.06	−0.21 ± 1.55	
	Postoperative	−0.29 ± 2.38	−0.06 ± 1.52	
	Δ pre to post	−0.18 ± 1.09	0.15 ± 1.37	0.285
	p value	0.35	0.54	

[a] Significant difference.

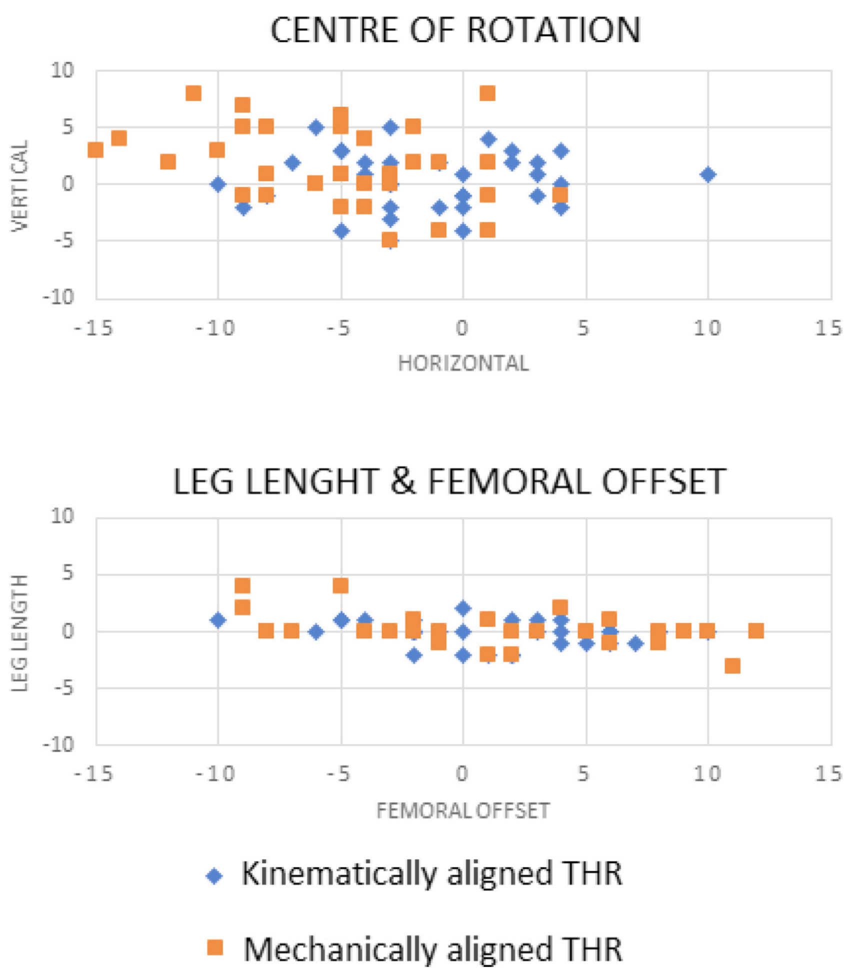

Fig. 5. Comparison of anatomical restoration of centre of rotation (above graph) and leg length and femoral offset (below graph) between treatment groups, as assessed on radiographs. Every dot represents the difference between preoperative (constitutional) and postoperative (prosthetic) values. None of the measured anatomical parameters differ between the KA prosthetic reconstructions and the native hips. In contrast, MA reconstructions resulted in a more medial ($p < 0.001$) and proximal ($p = 0.005$) prosthetic COR when compared to the native hip. THR: Total Hip replacement.

postoperative radiographs in each group (7 matched pairs) were excluded from the radiographic analysis because the coccyx was not centred on the symphysis (rotation of the pelvis in the transverse plane), thus affecting the quality of our measurements. None of the measured anatomical parameters differ between the prosthetic KA-THAs and the native hips. In contrast, MA-THA resulted in a more medial ($p < 0.001$) and proximal ($p = 0.005$) prosthetic COR when compared to the native hip. When comparing KA and MA acetabular reconstructions, the delta pre- to post-operative was different for the horizontal acetabular offset (respectively 1.47 ± 4.3 versus −5.1 ± 4.5, $p = 0.001$) but similar for the vertical acetabular offset (respectively 0.35 ± 2.6 vs. 1.7 ± 3.3, $p = 0.065$). Anatomical

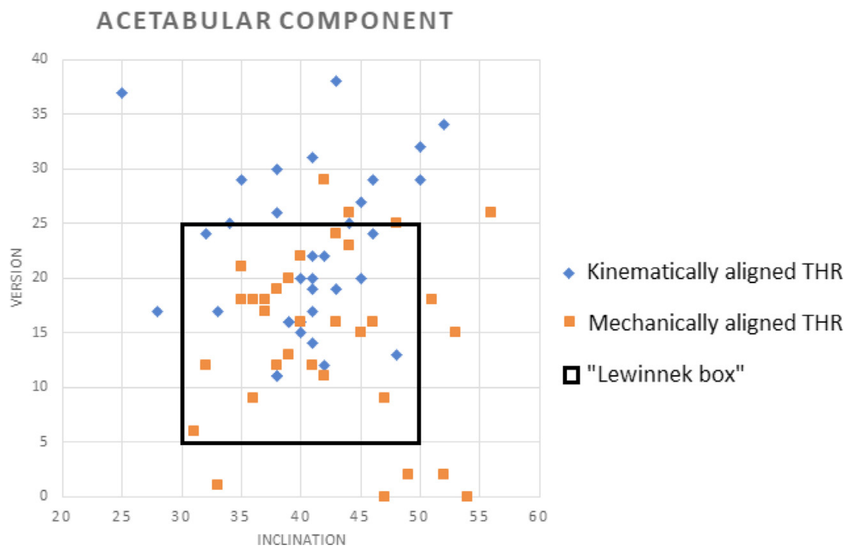

Fig. 6. A scatter plot showing the dispersion of the supine cup inclination and anteversion angles between KA and MA patients. KA cups were more anteverted ($p < 0.001$) but had similar inclination ($p = 0.25$). A similar proportion of KA (22/34 – 65%) and MA (24/34 – 70%) cups are matching the Lewinnek zone ($p = 0.8$).

Table 6
Comparison of pre and post-operative Patient Reported Outcome Measures (PROMs) for each treatment group.

Variable		Preoperative ($n = 78$)	Postoperative ($n = 78$)	Δ pre to postoperative	*p* value
OHS [37]	KA patients	18.8 ± 9.13	43.1 ± 5.3	24.3 ± 8.71	< 0.001[a]
	MA patients	19.13 ± 7.74	43.1 ± 6.43	23.5 ± 8.21	< 0.001[a]
	p value	0.858	0.608	0.624	–
EQ-5D index [38]	KA patients	0.37 ± 0.32	0.79 ± 0.23	0.4 ± 0.28	< 0.001[a]
	MA patients	0.42 ± 0.3	0.77 ± 0.31	0.29 ± 0.31	< 0.001[a]
	p value	0.466	0.990	0.489	–
EQ-5D VAS [38]	KA patients	63.65 ± 25.32	76.39 ± 20.11	13.17 ± 21.28	0.001[a]
	MA patients	67.1 ± 20.74	79.72 ± 17.17	8.75 ± 20.1	0.020[a]
	p value	0.498	0.675	0.168	–
Outcome satisfaction	KA patients	–	95.4 ± 6.95	–	–
	MA patients	–	89.51 ± 23.15	–	–
	p value	–	0.138	–	–

Results are expressed in mean ± standard deviation. KA: kinematically aligned, MA: mechanically aligned, Δ: difference, OHS: Oxford Hip Score [37], EQ-5D: euro quality of life - 5 dimensions [38], VAS: visual analogic score.
[a] Expresses a significant difference.

restoration (within 15% of native anatomy for horizontal and vertical acetabular offsets, and for femoral offset) was achieved for 26/34 (76%), 21/34 (62%), 24/34 (71%) and 17/34 (50%), 15/34 (44%), 17/34 (50%) KA and MA patients, with $p = 0.044$, $p = 0.224$ and $p = 0.137$ respectively.

Fig. 6 illustrates the supine radiographic cup positions for KA and MA-THAs. Table 4 shows the preoperative spino-pelvic parameters and postoperative cup orientations for KA patients depending on their SHR. KA cups were more anteverted (22° ± 7° vs 15° ± 8°, $p < 0.001$) but with similar inclination (41° ± 6° vs 42° ± 7°, $p = 0.25$) when compared with MA cups. Considering the cup inclination, cup anteversion, and the combined cup orientation, respectively, 31/34 (91%), 23/34 (68%), and 22/34 (65%) for KA cups and 29/34 (85%), 26/34 (76%), and 24/34 (70%) for MA cups were matching the Lewinneck recommendations ($p = 0.71$, $p = 0.59$, and $p = 0.8$, respectively).

Table 6 and Figs. 7 and 8 illustrate the pre and post-operative clinical outcomes for KA and MA groups. Two MA patients (one who had a septic revision and another with missing 1-year PROMs despite multiple contact attempts) and their respective matched KA patients, were excluded from the PROMs analysis. KA and MA techniques for implanting a THA similarly generated high functional outcomes (OHS mean 43.1 ± standard deviation 5 (min 27, max 48) for KA group and 43.1 ± 6 (min 16, max 48) for MA group, $p = 0.608$) and general health status (EQ-5D index and EQ-5D VAS). KA patients had a slightly higher progression from the preoperative condition with delta scores 24.3 ± 9 versus 23.5 ± 8 ($p = 0.624$) for the OHS, 0.4 ± 0.3 versus 0.29 ± 0.3 ($p = 0.489$) for the EQ-5D index, and 13.2 ± 21.3 versus 8.8 ± 20.1 ($p = 0.168$) for the EQ-5D VAS. Patient satisfaction was also similar, averaging 95.4/100 ±6.9 (min 60, max 100) and 89.5/100 ± 23.4 (min 0, max 100) ($p = 0.138$) for KA and MA patients, respectively. Regarding complications, one patient in the MA group had a septic revision; no other complications (reoperation, dislocation, etc.) were recorded in either group. Both the KA and MA groups had 7 patients out of 40 (18%) that reached the highest mark for OHS (48), and 32/40 (80%) and 30/40 (75%), respectively, that reached the top 15% mark for OHS (≥41).

5. Discussion

Lumbo-pelvic KA technique for THA is a surgical technique which aims to anatomically position and kinematically align hip implants to optimise the prosthetic hip biomechanics, with the hope of improving prosthetic hip function, patient satisfaction, and implant survivorship. We found the early outcomes of free-hand KA-THA to be promising, with high prosthetic hip function and patient satisfaction, acceptable cup orientation, no catastrophic failure, and no inferior results when compared to conventional MA-THA. The KA technique for THA is likely to be safe and efficacious

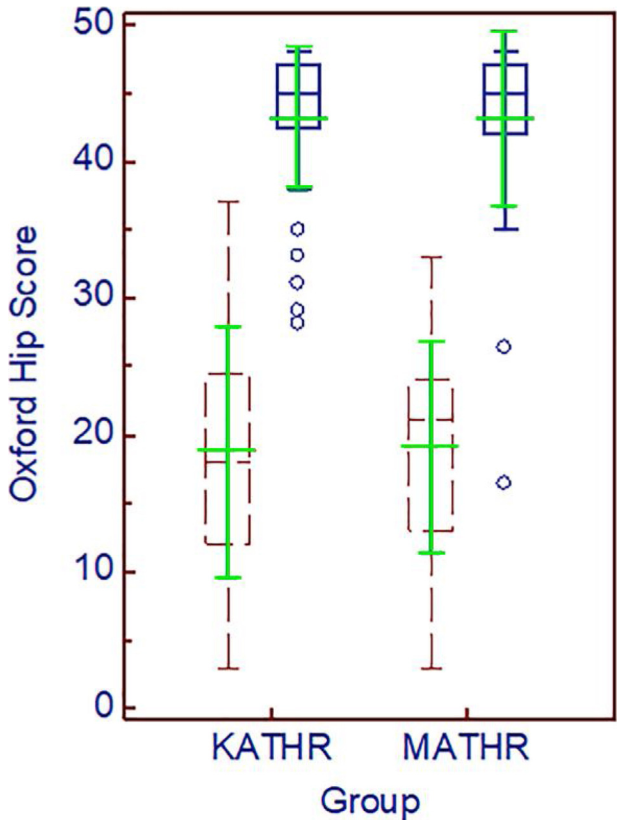

Fig. 7. Box plot illustrating the pre- (left) and post- (right) operative Oxford Hip Score for the kinematically (KA) and mechanically (MA) aligned groups. The mean values and standard deviation are shown in green colour. The median values, interquartile range, and extreme values of the score are displayed in brown (preop) and blue (postop) colours. The differences (absolute and delta values) observed between groups did not reach statistical significance. THR: Total Hip Replacement.

at early term. Several authors, listed in Table 7, have reported on methods for implanting THA that resemble our KA concept. Stefl et al. [42] planned a personalised cup position using CAS to execute their plan. The cup position was defined after considering the lumbo-pelvic complex kinematics and the femoral component anteversion, with the goal of having the cup within the Lewinnek safe zone on a standing pelvic radiograph. Spencer-Gardner et al. [43] reported on 100 THAs performed with the Optimized Positioning System™ (OPS™), aimed at anatomically restoring the proximal femur anatomy and kinematically positioning the cup. The functional components' interaction is estimated through a sophisticated process necessitating preoperative lateral lumbo-pelvic radiographs and low-dose pelvic CT scan; a software then computes the data and generates several recommendations for orienting the cup. Patient-specific instrumentation and a specific OPS™ navigation system with laser guidance is then used to execute the plan. Those techniques differ from our KA technique in that the component orientation planning requires complex calculations [43], the implantation of components requires technological assistance [42,43], and the components were not anatomically aligned in Stefl et al. [42] report.

We found that the KA technique acceptably restored the native hip anatomy (COR and proximal femur) to a better extent than the MA technique, with mean differences between native and KA prosthetic anatomical parameters being infra-millimetric. The better anatomical reconstruction with the KA technique is not surprising, as the KA technique aims at a "kinematic and almost fully anatomic" implantation, while the MA technique aims at a "biomechanically-friendly but partially anatomic" one. Our results are in line with studies having reported successful attempts for anatomically reconstructing the native hip centre of rotation and proximal femur anatomy [8,36]. The ability to perform a good biomechanical reconstruction may be due to the fact that the KA technique relies on intra-articular landmarks and simple quality control tools (ruler for reproducing femoral length and offset, neck cut and TAL for controlling femoral stem and cup anteversion, respectively), which are likely to contribute to an improved reproducibility of the prosthetic implantation [44].

With the exception of a higher KA cup anteversion, we found similar results for KA and MA cup supine orientation. This indicates that the KA technique, despite its philosophy of anatomically aligning cups plus kinematically adjusting approximately one third of them, does not generate aberrant cup positioning, and therefore is not likely to result in an unexpectedly high failure rate. There is no literature available to directly compare our cup orientation to, as this is the first clinical report about the KA technique for implanting THA. However, it is interesting to note that the cup orientation of

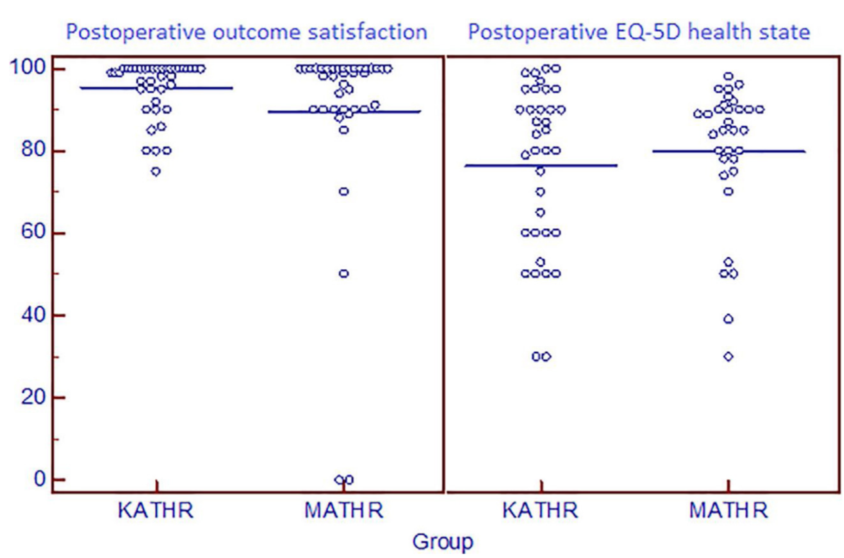

Fig. 8. Scatter plot showing the distribution of the postoperative outcome satisfaction (left graph) and EQ-5D Health status (right graph) scores for the kinematically (KA) and mechanically (MA) aligned groups. Both scores were captured via a visual analogic scale ranging from 0 to 100. The blue horizontal lines represent mean values. The differences observed between groups did not reach statistical significance. THR: Total Hip Replacement.

Table 7
Table illustrating the studies which have reported clinical data on patients having their total hip arthroplasty implanted with consideration of the lumbo-pelvic sagittal kinematics or spine-hip relationship status.

	Study design	Specific preop imaging to define individual SHR	Technique for implanting components	Number of THA (patients) and follow-up	Clinical outcomes	Cup anteversion	Cup inclination	Proportion cup within the safe zone
Stefl et al. [42]	Prospective study of radiographic outcomes	Standing and sitting lateral lumbo-pelvic radiographs	Femur first technique (combined anteversion concept) Cup orientation defined after consideration of femoral neck anteversion and lumbo-pelvic sagittal kinematics Mini-posterior approach Computed assisted navigation	160 THAs (151) 3 months to 1-year follow-up	3 dislocations within the first two months after surgery	From 17.2° to 20.7°	From 39.3° to 44.3°	90%
Spencer-Gardner et al. [43]	Prospective cohort	Standing, sitting, flexed seated, and step-up lateral lumbo-pelvic radiographs Low-dose pelvis CT scan	Acetabulum first technique Cup orientation defined by computation after considering acetabular anatomy and lumbo-pelvic sagittal kinematics Stem: anatomic alignment Posterior approach OPS™ navigation (for cup) and personalized cutting guide (for stem)	100 consecutive patients follow-up not reported	No dislocation	25.1° (9.6° to 36.3°)	41.8° (29.6° to 58.1°)	Not reported
Kinematic Aligned patients from the current study	Retrospective case-control study with prospectively collected data	Standing and sitting lateral lumbo-pelvic radiographs	Acetabulum first technique Cup orientation adjusted relative to native anatomy to account for the individual spine-hip relationship Stem: anatomic alignment Mini-posterior or direct anterior approach, depending on the individual spine-hip relationship. Manual instrumentation	41 consecutive unselected KA-THAs (41) 1 year follow up	Mean OHS 43.1 Mean patient satisfaction 95.4/100 No complication (dislocation, reoperation)	21.6° ± 7.5° (11° to 38°)	40.6° ± 5.9° (25° to 52°)	65%

OPS: Optimized Positioning System, OHS: Oxford hip Score, THA: Total Hip Arthroplasty.

our KA patients closely resembles that of THAs performed with the Optimised Positioning System^{TM} [43]; this technological tool also aims to anatomically position and kinematically align the acetabular component. The higher anteversion of KA cups may be explained by (1) the native acetabular anteversion (strictly followed for 24/34 (71%) KA patients) being higher overall than the amount of cup anteversion recommended with the MA technique [45,46], and (2) the fact that a lateral Hardinge approach has been performed in 12/34 (34%) of MA patients, thus potentially inciting the surgeons to voluntarily reduce the anteversion in the cup. Of note, this higher anteversion is unlikely to be the consequence of the kinematic cup adjustment we made for 10 KA patients, as the majority of those adjustments (6/10) were a reduction of the cup anteversion relative to the TAL. Nonetheless, trying to interpret the higher KA cup anteversion is probably not relevant, as the static supine cup orientation predicts neither the functionality of the cup orientation [2,6,19,21,24,26] nor the dynamic femoro-acetabular interplay [20,21], both being the main determinants in understanding the clinically sound functional components' interaction occurring during DALs.

We found similar clinical outcomes between the KA and MA techniques. With no aseptic complications, and high satisfaction and hip function, the early clinical outcomes of KA-THA can be considered to be excellent, and not inferior to those of the conventional gold standard MA-THA. The absence of prosthetic instability in either group raises the point that early prosthetic instability is becoming a rare complication with modern implants and expert surgeons. However, as some residual prosthetic instabilities are known to be the consequence of poor lumbo-pelvic kinematics [21,25,26,47,48], kinematically aligning hip components to compensate for poor SHR/lumbo-pelvic kinematics is likely to be a sound option for further improving prosthetic stability. In order to optimize prosthetic stability, KA patients had, in addition to kinematically aligned components, their cup design and surgical approach selected to adapt to their SHR/lumbo-pelvic kinematics; this defines the concept of "À La Carte" joint replacement. To illustrate, elderly patients with severe degenerated spines (SHR D) had a dual mobility cup implanted through a posterior approach in order to respect the integrity of anterior hip soft tissue and to release the frequently retracted posterior capsule. In contrast, generally younger type B patients were more likely to receive a 36 mm bearing diameter through a direct anterior approach that would respect the integrity of the posterior hip soft tissue.

It is important to acknowledge a few limitations of our methods that may affect the generalisation of our results. (1) Our study design to compare KA and MA techniques was suboptimal as it was not a randomized controlled trial, population samples were small, and various implants/approaches were used between the KA and MA groups. By respectively generating selection bias, increasing the risk of statistical error type 2, and confusion bias, this suboptimal study design may therefore affect the quality of our conclusions. However, the data from this audit is likely to be accurate as collection was prospective, and by waiting for higher levels of evidence our study provides a first insight (pilot study) into the value of the KA technique for THA. Additionally, performing KA implantation with the use of a variety of implants and approaches is sound when considering the concept of "À La Carte" (or personalised) joint replacement, where implant design, approach, and implant orientation are individually defined based on the patient age, level of demand, and SHR. (2) We used the OHS to compare functional outcomes between KA and MA patients, which is known to be suboptimal. The OHS is limited by a ceiling effect, which has been confirmed in our study with 80% and 75% of KA and MA patients, respectively, having reached the top 85% of the score. The OHS is therefore not suitable to distinguish between good and excellent procedures, and this may have prevented us capturing small functional performance differences between KA and MA patients. (3) With only 1 year of follow-up, our study did not allow us to assess the mid to long-term clinical value of KA-THA. The excellent clinical outcomes observed for the KA patients only confirm the early safety of this implantation and longer follow-up is required. (4) Our radiographic study in the supine position was suboptimal to perform complete assessment of the quality of the KA and MA implantations (cup and stem) as bi-dimensional images provide poor insight to the quality of the tri-dimensional reconstruction, and additionally the pelvic position when supine is often altered by tri-dimensional spine deformities. This explains why the stem anteversion was not measured. A tri-dimensional imaging tool, if not standing post-operative radiograph, would have generated more accurate data, but unfortunately was not possible for this audit. (5) As some asymmetry may exist between the native hips of an individual [49], the fact we used the contralateral healthy hip as a reference to radiographically assess the quality of the prosthetic hip biomechanics in some cases may have affected the quality of our results. However, this limitation is likely to be negligible, as native hip asymmetry has been shown to mainly affect the femoral neck anteversion, which has not been measured in our study.

6. Conclusion

The KA technique for THA has been demonstrated to be safe, efficacious, and not inferior to the conventional MA technique at early-term. As the concept of the KA technique for THA is only at an early stage, its influence on mid to long-term clinical outcomes remains to be determined and further refinements of the concept are yet to be made.

Disclosure of interest

Regarding this study, Charles Rivière has pioneered the kinematic technique for hip arthroplasty, written book chapters and presented this concept in conferences. Outside the current study Charles Rivière declares being a paid-consultant for Medacta and having been a paid-speaker for Corin Tornier, and Justin Cobb declares being consultant for Biomet-Zimmer, Mathortho, and to receive a fee from Microport. None of the other authors had conflict of interest related or outside the current study.

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Authors contribution

(1) The conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, (3) final approval of the version to be submitted, (4) statistics, (5) experimentation or surgery performance: Charles Rivière: 1 - 2 - 3–5; Tom Parsons: 1–2 - 3; Ciara Harman: 1–2–3; Loic Villet: 2–3; Justin Cobb: 2–3; Cedric Maillot: 1 - 2–3–4.

References

[1] Bayliss LE, Culliford D, Monk AP, Glyn-Jones S, Prieto-Alhambra D, et al. The effect of patient age at intervention on risk of implant revision after total replacement of the hip or knee: a population-based cohort study. Lancet 2017;389:1424–30.

[2] Lazennec JY, Thauront F, Robbins CB, Pour AE. Acetabular and femoral anteversions in standing position are outside the proposed safe zone after total hip arthroplasty. J Arthroplasty 2017;32:3550–6.

[3] Shoji T, Yamasaki T, Izumi S, Kenji M, Sawa M, et al. The effect of cup medialization and lateralization on hip range of motion in total hip arthroplasty. Clin Biomech 2018;57:121–8.

[4] Bonnin MP, Archbold PHA, Basiglini L, Fessy MH, Beverland DE. Do we medialise the hip centre of rotation in total hip arthroplasty? influence of acetabular offset and surgical technique. Hip Int 2012;22:371–8.
[5] Reina N, Putman S, Desmarchelier R, Sari Ali E, Chiron P, et al. Can a target zone safer than Lewinnek's safe zone be defined to prevent instability of total hip arthroplasties? Case-control study of 56 dislocated THA and 93 matched controls. Orthop Traumatol Surg Res 2017;103:657–61.
[6] Abdel MP, von Roth P, Jennings MT, Hanssen AD, Pagnano MW. What safe zone? The vast majority of dislocated that are within the lewinnek safe zone for acetabular component position. Clin Orthop Relat Res 2016;474:386–91.
[7] Dorr LD, Malik A, Dastane M, Wan Z. Combined anteversion technique for total hip arthroplasty. Clin Orthop Relat Res 2009;467:119–27.
[8] Archbold HA, Mockford B, Molloy D, McConway J, Ogonda L, Beverland D. The transverse acetabular ligament: an aid to orientation of the acetabular component during primary total hip replacement. J Bone Joint Surg Br 2006;88:883–6.
[9] Viste A, Chouteau J, Testa R, Chèze L, Fessy MH, Moyen B. Is transverse acetabular ligament an anatomical landmark to reliably orient the cup in primary total hip arthroplasty? Orthop Traumatol Surg Res 2011;97:241–5.
[10] Girard J, Lons A, Ramdane N, Ramdane N, Putman S. Hip resurfacing before 50 years of age: A prospective study of 979 hips with a mean follow-up of 5.1 years. Orthop Traumatol Surg Res 2018;104:295–9.
[11] Patel AB, Wagle RR, Usrey MM, Thompson MT, Incavo SJ, Noble PC. Guidelines for implant placement to minimize impingement during activities of daily living after total hip arthroplasty. J Arthroplasty 2010;25:1275–81.
[12] Shin YS, Suh DH, Park JH, Kim JL, Han SB. Comparison of specific femoral short stems and conventional-length stems in primary cementless total hip arthroplasty. Orthopedics 2016;39:311–7.
[13] 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.
[14] Maratt JD, Esposito CI, McLawhorn AS, Jerabek SA, Padgett DE, Mayman DJ. Pelvic tilt in patients undergoing total hip arthroplasty: when does it matter? J Arthroplasty 2015;30:387–91.
[15] Malkani AL, Ong KL, Lau E, Kurtz SM, Justice BJ, Manley MT. Early- and late-term dislocation risk after primary hip arthroplasty in the Medicare population. J Arthroplasty 2010;25:21–5.
[16] Hua X, Li J, Jin Z, Fisher J. The contact mechanics and occurrence of edge loading in modular metal-on-polyethylene total hip replacement during daily activities. Med Eng Phys 2016;38:518–25.
[17] Marchetti E, Krantz N, Berton C, Bocquet D, Fouilleron N, et al. Component impingement in total hip arthroplasty: Frequency and risk factors. A continuous retrieval analysis series of 416 cup. Orthop Traumatol Surg Res 2011;97:127–33.
[18] Ferguson RJ, Palmer AJ, Taylor A, Porter ML, Malchau H, Glyn-Jones S. Hip replacement. Lancet 2018;392:1662–71.
[19] Esposito CI, Gladnick BP, Lee Y, Lyman S, Wright TM, et al. Cup position alone does not predict risk of dislocation after hip arthroplasty. J Arthroplasty 2015;30:109–13.
[20] Mayeda BF, Haw JG, Battenberg AK, Schmalzried TP. Femoral-acetabular mating: the effect of femoral and combined anteversion on cross-linked polyethylene wear. J Arthroplasty 2018;33:3320–4.
[21] Rivière C, Lazennec JY, Van Der Straeten C, Auvinet E, Cobb J, Muirhead-Allwood S. The influence of spine-hip relations on total hip replacement: A systematic review. Orthop Traumatol Surg Res 2017;103:559–68.
[22] 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;97:1017–23.
[23] 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.
[24] Lum ZC, Coury JG, Cohen JL, Dorr LD. The current knowledge on spinopelvic mobility. J Arthroplasty 2018;33:291–6.
[25] Fessy MH, Putman S, Viste A, Isida R, Ramdane N, et al. What are the risk factors for dislocation in primary total hip arthroplasty? A multicenter case-control study of 128 unstable and 438 stable hips. Orthop Traumatol Surg Res 2017;103:663–8.
[26] Nam D, Riegler V, Clohisy JC, Nunley RM, Barrack RL. The impact of total hip arthroplasty on pelvic motion and functional component position is highly variable. J Arthroplasty 2017;32:1200–5.
[27] Esposito CI, Miller TT, Kim HJ, Barlow BT, Wright TM, et al. Does degenerative lumbar spine disease influence femoroacetabular flexion in patients undergoing total hip arthroplasty? Clin Orthop Relat Res 2016;474:1788–97.
[28] Rivière C, Lazic S, Villet L, Wiart Y, Allwood SM, Cobb J. Kinematic alignment technique for total hip and knee arthroplasty: the personalized implant positioning surgery. EFORT Open Rev 2018;3:98–105.
[29] Le Huec JC, Hasegawa K. Normative values for the spine shape parameters using 3D standing analysis from a database of 268 asymptomatic Caucasian and Japanese subjects. Eur Spine J 2016;25:3630–7.
[30] 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.
[31] Rivière C, Lazic S, Dagneaux L, Van Der Straeten C, Cobb J, Muirhead-Allwood S. Spine–hip relations in patients with hip osteoarthritis. EFORT Open Rev 2018;3:39–44.
[32] Laffargue P, Pinoit Y, Tabutin J, Giraud F, Puget J, Migaud H. Computer-assisted positioning of the acetabular cup for total hip arthroplasty based on joint kinematics without prior imaging: preliminary results with computed tomographic assessment. Rev Chir Orthop 2006;92:316–25.
[33] Ohmori T, Kabata T, Maeda T, Kajino Y, Taga T, et al. Increase in Safe zone area of the acetabular cup using dual mobility cups in THA. Hip Int 2017;27:361–437.
[34] McCarthy TF, Nevelos J, Elmallah RK, Chughtai M, Khlopas A, et al. The effect of pelvic tilt and femoral head size on hip range-of-motion to impingement. J Arthroplasty 2017;32:3544–9.
[35] Ezquerra L, Quilez MP, Pérez MÁ, Albareda J, Seral B. Range of Movement for Impingement and Dislocation Avoidance in Total Hip Replacement Predicted by Finite Element Model. J Med Biol Eng 2017;37:26–34.
[36] Takao M, Nishii T, Sakai T, Sugano N. Postoperative limb-offset discrepancy notably affects soft-tissue tension in total hip arthroplasty. J Bone Joint Surg Am 2016;98:1548–54.
[37] Dawson J, Fitzpatrick R, Carr AJ, Murray D. Questionnaire on the perceptions of patients about total hip replacement. J Bone Joint Surg Br 1996;78–B:185–90.
[38] Devlin NJ, Brooks R. EQ-5D and the EuroQol Group: past, present and future. Appl Health Econ Health Policy 2017;15:127–37.
[39] Hill JC, Archbold HAP, Diamond OJ, Orr JF, Jaramaz B, Beverland DE. Using a calliper to restore the centre of the femoral head during total hip replacement. J Bone Joint Surg Br 2012;94:1468–74.
[40] Ochi H, Homma Y, Baba T, Matsumoto M, Kaneko K. Sagittal spinopelvic alignment predicts hip function after total hip arthroplasty. Gait Posture 2017;52:293–300.
[41] Berliner JL, Esposito CI, Miller TT, Padgett DE, Mayman DJ, Jerabek SA. What preoperative factors predict postoperative sitting pelvic position one year following total hip arthroplasty? Bone Joint J 2018;100:1289–96.
[42] 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;99:37–45.
[43] Spencer-Gardner L, Pierrepont J, Topham M, Baré J, McMahon S, Shimmin AJ. Patient-specific instrumentation improves the accuracy of acetabular component placement in total hip arthroplasty. Bone Joint J 2016;98:1342–6.
[44] Grammatopoulos G, Alvand A, Monk AP, Mellon S, Pandit H, et al. Surgeons' accuracy in achieving their desired acetabular component orientation. J Bone Joint Surg Am 2016;98:e72.
[45] Archbold H, Slomczykowski M, Beverland D. The relationship of the orientation of the transverse acetabular ligament and acetabular labrum to the suggested safe zones of cup positioning in total hip arthroplasty. Hip Int 2008;18:1–6.
[46] Merle C, Grammatopoulos G, Waldstein W, Pegg E, Pandit H, et al. Comparison of native anatomy with recommended safe component orientation in total hip arthroplasty for primary osteoarthritis. J Bone Joint Surg 2013;95:e172.
[47] Dagneaux L, Marouby S, Lazic S, Maillot C, Canovas F, Rivière C. Dual mobility device reduces the risk of prosthetic hip instability for patients with degenerated spine: A case-control study. Orthop Traumatol Surg Res 2019;105, http://dx.doi.org/10.1016/j.otsr.2018.12.003 [In press].
[48] 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.
[49] Eckhoff DG, Jacofsky DJ, Springer BD, Dunbar M, Cherian JJ, et al. Bilateral symmetrical comparison of femoral and tibial anatomic features. J Arthroplasty 2016;31:1083–90.