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Review article

Modern cup alignment techniques in total hip arthroplasty: A systematic review

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ABSTRACT

Introduction: A systematic review was conducted to assess the clinical and radiological outcomes of the alternative surgical techniques that consider the dynamic aspect of the acetabular orientation when aligning a cup (pelvic tilt-, lumbo-pelvic kinematics-, and spine-hip relationship-adjusted cup alignment techniques).
Method: Eight eligible articles reported the outcomes of total hip arthroplasty (THA) performed with alternative techniques. Clinical and radiological data were extracted. One study had a control group of patients who underwent conventional THAs (level III) while the seven other studies were level IV. Computer navigation system (CAS), Optimized Positioning System (OPS™), and manual instrumentation were used to align components in four, two, and two studies, respectively. A meta-analysis was not carried out because there was a lack of homogeneity between included articles regarding the method to position the cup and the nature of the reported data.
Results: THA performed with alternative techniques had an early dislocation rate ranging from 0 to 1.9%, no unexpected catastrophic failure, and acceptable radiographic cup orientations. One study compared kinematically and mechanically aligned THAs and found no dislocation in either groups, similar patient reported outcome measures (43 Oxford-12 Score for both groups), and similar proportions of cup in the Lewinnek zone (respectively 65% and 70%).
Discussion/conclusion: Alternative methods accounting for the functional acetabular orientation seem to be clinically safe and effective in the early-term, and generate acceptable cup orientation on radiographs. Their values compare to those of more conventional techniques for cup implantation remain to be determined. We developed a classification of the multiple methods for aligning an acetabular component.
Level of evidence: IV, systematic review of level III and IV studies.

1. Introduction

The mechanical alignment philosophy, defined half a century ago, is still considered to be the gold standard technique for implanting total hip arthroplasty (THA) components [1]. It focuses on achieving a set biomechanical goal, regardless of the patient's individual anatomy [1,2]. The hip centre of rotation is medialised [3,4] and components are systematically similarly implanted between individuals [5]. Following the marketing of cementless femoral implants and the increased awareness of the dynamic interplay between the acetabular and femoral components, the concept of combined femoro-acetabular anteversion has become popular [6]. These conventional techniques for implanting total hip components have led to good long-term clinical outcomes despite some residual complications, usually related to poor interaction of components. Interestingly, while this burden has been partially reduced with improvements in implant design and surgical techniques (e.g. hip resurfacing technique, muscle sparing approaches) [7–9], the higher surgical precision provided by technological assistance (e.g. computer assisted surgery, robotics) has not been a game-changer [10,11]. This suggests that these

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initial conventional techniques for implanting THA components (non-anatomic and kinematic) may target an inaccurate components alignment [12–15].

Component positioning and dynamic function are gaining recognition as significant factors in total hip arthroplasty stability and lifespan [16–20]. The individual lumbo-pelvic kinematics and spine-hip relationship, and their influence on the functional cup orientation, is being extensively studied [16–21]. Initial works focused on defining the amount of cup adjustment needed to accommodate the individual pelvic tilt, either in supine [22] or standing [23–25] position, thus defining the concept of pelvic-tilt adjusted cup positioning. More recently, attention has been directed towards the preoperative definition of the individual spine-hip relationship and lumbo-pelvic sagittal kinematics between standing and sitting positions, with the goal of refining the cup orientation and accommodating for the abnormal spine-hip relation [16,26] and lumbo-pelvic stiffness [27–30], respectively. The pelvic-tilt adjusted cup positioning technique primarily aims to improve the standing, and potentially the walking, components' interaction. In contrast, spine-hip relation- and lumbo-pelvic kinematics-adjusted cup positioning techniques aim to achieve a compromised optimal component interaction between standing and sitting positions, with the hope of preventing complications in both positions.

There is currently a paradigm shift in total hip replacement due to our improved awareness of the diversity between individuals regarding joint anatomy and kinematics, with a switch from the aforementioned conventional implantation techniques (mechanical alignment and combined anteversion techniques) that do not consider the functionality of the cup orientation, to those alternatives techniques which do (pelvic tilt- or lumbo-pelvic sagittal kinematics- or spine-hip relation-adjusted) [26]. A systematic review was therefore conducted to assess the clinical and radiographical values of those alternative techniques. Secondarily, we aimed to generate a classification of the multiple reported techniques for aligning a cup.

2. Method

2.1. Search strategy

A literature review was performed by two reviewers with use of the preferred reporting items for systematic review and meta-analysis (PRISMA) guidelines. In phase 1 of the search process, Medline (PubMed search engine), EMBASE, Cochrane and Google Scholar libraries were systematically searched in August 2018 using the following search terms: [("hip replacement" OR "hip arthroplasty" OR "total hip replacement" OR "total hip arthroplasty" OR "primary hip replacement" OR THR OR THA OR "hip prosthesis") AND (SHR OR "spine hip relation" OR "pelvic kinematics" OR "pelvic sagittal kinematics" OR "lumbo-pelvic kinematics" OR "spine ageing" OR "spine degeneration" OR "sagittal imbalance" OR "pelvis mobility" OR "pelvic range of motion" OR "spine flexibility" OR "lumbar flexibility" OR "spine stiffness" OR "instrumented spine" OR "fused spine" OR OPS OR "optimized positioning system" OR "kinematic alignment" OR "kinematic alignment technique" OR "adjusted cup positioning") AND ("radiographic study" OR "radiographic analysis" OR "Xray" OR "implant positioning" OR "implant position" OR "dislocation" OR "instability" OR "clinical outcomes" OR "complications")]. In phase 2, titles and abstracts were screened for their relevance. In phase 3, the full text of the selected studies was reviewed to assess for the inclusion criteria and methodological appropriateness with a predetermined question. In phase 4, the eligible studies underwent a systematic review process. The extracted data were then crosschecked for accuracy, and a third review author resolved any disagreement.

2.2. Eligibility criteria

Studies meeting the following criteria were included:

- articles written in English;
- full-text availability for the articles;
- human in vivo studies;
- reports of alternative techniques (pelvis-tilt adjusted, etc.) for implanting hip components;
- articles that document clinical and/or radiological outcomes.

2.3. Quality assessment and grading of the quality of the evidence

The methodological quality of the non-randomized studies was assessed using the Newcastle–Ottawa assessment scale.

2.4. Data extraction

The following data were extracted, when available, for each eligible article: study design, sample size, follow-up duration, method for aligning the cup, surgical approach, dislocation rate, functional outcomes, and radiographic cup orientation.

2.5. Statistics

A meta-analysis was not carried out as there was a lack of homogeneity between included articles regarding the method to position the cup and the nature of the reported data.

3. Results

3.1. Search results

Eight articles were included in the final analysis, seven being case series with level IV clinical evidence, [22,23,25,27,28,31,32] and one being a case–control study [33] (Fig. 1) with level III clinical evidence. The PRISMA flow diagram is illustrated in Fig. 1. Detailed characteristics of the included studies and their quality assessment are summarized in Tables 1 and 2, respectively.

3.2. Dislocation rate

No dislocation was reported in the single comparative study included in this review, which compared kinematically aligned versus mechanically aligned THAs [33]. Out of the other eligible studies, one reported a 1.9% rate of early positional dislocation (3/160 lumbo-pelvic kinematics adjusted THAs) [27], while the other prospective (100 lumbo-pelvic kinematics adjusted OPS^{TM}-[28] and 173 pelvic-tilt adjusted THAs [22,23]) and retrospective (78 pelvic-tilt adjusted THAs [25]) studies reported no dislocation.

3.3. Patient Reported Outcomes Measures (PROMs)

Similar early-term (one-year) PROMs (including Oxford Hip Score, EQ-5D, and patient outcome satisfaction) were reported between kinematically aligned and mechanically aligned THAs [33]. None of the other eligible studies reported on functional scores.

3.4. Radiographic cup orientation

Regarding the supine cup orientation, higher anteversion ($22^\circ \pm 7^\circ$ vs. $15^\circ \pm 8^\circ$), similar inclination ($41^\circ \pm 6^\circ$ vs. $42 \pm 7^\circ$), and

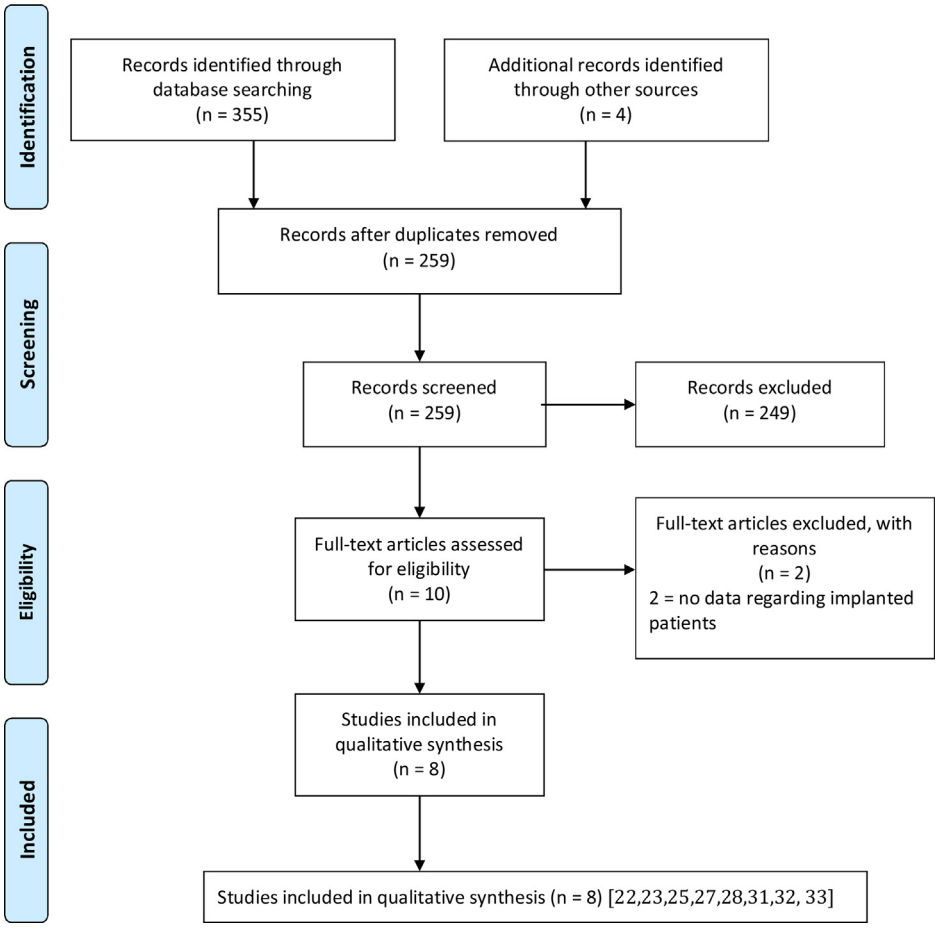

Fig. 1. PRISMA flow diagram for systematic review.

a similar proportion of cups oriented within the Lewinnek safe zone (65% vs. 70%) were reported between kinematically aligned (spine-hip relation adjusted cup) and mechanically aligned THAs, respectively [33]. Out of the other eligible studies, Spencer-Gardner et al. [28] (lumbo-pelvic kinematics adjusted OPS^{TM} cup) reported 25° (10° to 36°) and 42° (30° to 58°) for the supine cup anteversion and inclination, respectively. Meftah et al. [25] (pelvis-tilt adjusted cup) found a standing cup anteversion of 18° ± 5° (range 8°–29°) with only 2 cups outside the Lewinnek safe range for anteversion. Inaba et al. [23] (pelvis-tilt adjusted cup) found a supine cup anteversion of 17° ± 6° and inclination of 39° ± 4° and a standing cup anteversion of 21° ± 6° and inclination of 40.5° ± 4°. Ishida et al. [32] found that percentages of cup angles outside the "Lewinnek safe zone" were between 10% and 27% in the lying position, and 13% to 53% in the standing position, with these rates being significantly influenced by the amount of preoperative pelvic tilt. Finally Stefl et al. [27] (lumbo-pelvic kinematics adjusted cup) found a standing and sitting cup ante-inclination, as measured on postoperative lateral pelvic radiograph, of 30° ± 2.2° and 58° ± 1.6°, 40° ± 2.1° and 49° ± 2.1° and 33° ±1.7° and 61° ± 1.9° for hypermobile, biologically fused, and for kyphosis groups, respectively.

4. Discussion

4.1. Justification of the study

Given that a more comprehensive understanding of the functional acetabular cup orientation during activities of daily living would likely result in improved clinical outcomes following THA, we initiated this study to assess the clinical value (safety and efficacy) of alternative techniques for implanting a cup that consider the individual pelvic tilt or lumbo-pelvic sagittal kinematics or spine-hip relationship. The available evidence shows these new alternative methods are likely to be safe (no catastrophic clinical failure and acceptable radiographical positioning) and efficacious (high function and satisfaction). However, the available evidence did not enable us to compare their values to those from conventional techniques for implanting a cup.

4.2. Dislocation rate

THAs implanted with the alternative techniques had a very low dislocation rate ranging from 0 to 1.9%, which is similar to that observed when hip replacement is performed with an anti-dislocation therapeutic strategy (dual mobility cup design, muscle sparing direct anterior approach, and resurfacing hip replacement) [7–9] or a more conventional strategy (conventional implant design, approach, and technique for alignment MA, CA, or AA) but by expert surgeons [34]. Through aiming to improve the functional interaction of components on standing, pelvic-tilt adjusted cup positioning (functional alignment technique for cup positioning) could potentially reduce the risk of prosthetic instability occurring when standing. In contrast, by aiming to improve the functional interaction of components on standing to sitting [17], the lumbo-pelvic kinematics- and spine-hip relation-adjusted techniques may be pertinent in preventing instability for a wider range of positions occurring during activities of daily living.

Table 1
Eligible studies.

	Study design	Cup alignment method	Surgical planning	Surgical approach	Instrument	Sample size and FU duration	Dislocation and functional score	Cup orientation
Riviere et al. [33]	Retrospective matched case-control study	Spine-hip relation adjusted	Slight deviation from native acetabular anatomy = Kinematic alignment technique	KA group: mini-posterior or DAA MA group: posterior or lateral	Free-hand	41 consecutive KATHAs matched 1:1 with 41 MATHAs FU: 1-year	Dislocation: None Functional score: KATHA: OHS 43 (delta OHS 24), satisfaction 95.4%, MATHA: OHS 43 (delta OHS 24), satisfaction 89.5%	Cup anteversion on supine radiographs: KATHA: 22° MATHA: 15°
Spencer Gardner et al. [28]	Prospective cohort	Lumbo-pelvic kinematics adjusted	Computational planned functional supine targets via OPS Software: for inclination: 40° (32° to 45°), and for anteversion: 24° (13° to 30°)	Posterior	Personalized instrumentation and OPS™ navigation	100 consecutive THAs FU: not reported	Dislocation: None Functional score: not reported	Measured functional supine parameters: inclination: 42° (30° to 58°) anteversion: 25.1° (10° to 36°)
Pierrepont et al. [31]	Retrospective series of cases	Lumbo-pelvic kinematics adjusted	Computational planned stem anteversion and cup inclination/anteversion via OPS Software: case 1: 21° and 40°/20°, case 2: 18° and 34°/27°, case 3: 21° and 42°/13°	Mini-posterior or DAA	Patient-specific OPS instrumentation	3 THAs FU: not reported	Dislocation: not reported Functional score: not reported	Not reported
Stefl et al. [27]	Prospective radiographical study	Lumbo-pelvic kinematics adjusted	Adjustment for anatomical cup orientation (relative to APP) and combined anteversion depending on LCP flexibility: for normal LPC mobility: inclination 40°, anteversion 20° and combined anteversion from 25° to 45°, for hypermobile LPC: decreased, and for stiff stuck standing LPC: increased	Mini-posterior	Computed assisted surgery	160 THAs FU: 3 months to 1 year	Dislocation:3 early positional dislocations Functional score: not reported	Functional cup anteversion and inclination respectively on postoperative lateral standing and sitting pelvic radiograph: for hypermobile LPC group: 30° ± 2.2° and 58° ± 1.6° for biologically fused LPC group: 40° ± 2.1° and 49° ± 2.1° for kyphosis group: 33 ± 1.7° and 61° ± 1.9°
Babish et al. [22]	Prospective cohort	Pelvic tilt adjusted	Adjustment of a mechanical cup positioning	Lateral in supine	Computed assisted surgery	98 THAs FU: 1 year	Dislocation: None Functional score: not reported	Anatomical component orientation assessed by CT scan: 99% and 97% of anteversion and abduction matching the planned target (± 10°)
Inaba et al. [23]	Prospective cohort	Pelvic tilt adjusted	Adjustment of a cup orientation that was primarily defined to adapt the femoral neck anteversion (combined anteversion concept)	Lateral in lateral decubitus	Computed assisted surgery	75 THAs FU: 1 year	Dislocation: None Functional score: not reported	Functional supine parameters: inclination 39° ± 4° and anteversion 17° ± 6°; Functional standing parameters: inclination 40.5° ± 4° and anteversion 21° ± 6°
Ishida et al. [32]	Prospective cohort	Pelvic tilt adjusted	For patients with severe preoperative anterior pelvic tilts: no adjustment For patients with severe preoperative posterior pelvic tilts: reduced cup anteversion by several degrees to compensate posterior pelvic tilt	Lateral in lateral decubitus	Computed assisted surgery	149 THAs FU: not reported	Dislocation: 2 early positional anterior dislocation Functional score: increase in HHS and WOMAC	Proportions of cup angles outside the "Lewinnek safe zone": from 10% to 27% in the lying position and from 13% to 53% in the standing position
Meftah et al. [25]	Retrospective consecutive cases study	Pelvic tilt adjusted	Adjustment of the femoral neck anteversion that was primarily defined to adapt the acetabular anatomy (reverse concept)	Posterior	Free-hand	78 THAs FU: 5 to 22 months	Dislocation: None Functional score: not reported	Functional standing cup anteversion: 18 ± 5° (range, 8°–29°) with only 2 cups outside the safe zone Anatomic cup anteversion (relative to the APP): 18 ± 6° (range, 1.5°–36°)

THA: Total Hip Arthroplasty; KA: Kinematic Alignment; MA: Mechanical Alignment; OPS: Optimized Positioning System; FU: Follow Up; LPC: Lumbo-Pelvic Complex; APP: Anterior Pelvic Plane; OHS: Oxford Hip Score; DAA: Direct Anterior Approach

Table 2
This table illustrates the assessment of the methodological quality of the eligible studies. The Newcastle–Ottawa assessment scale for case-control and for cohort studies was used for assessing the quality of the included studies.

	Selection	Comparability	Exposure/Outcomes
Riviere et al. [33]	★★★★	★★	★★★
Spencer Gardner et al. [28]	★★★	Nil	★★★
Pierrepont et al. [31]	NA	NA	NA
Stefl et al. [27]	★★★	Nil	★★★
Babish et al. [22]	★★	Nil	★★★
Inaba et al. [23]	★★	Nil	★★★
Ishida et al. [32]	★★	Nil	★★★
Meftah et al. [25]	★★★	Nil	★★★

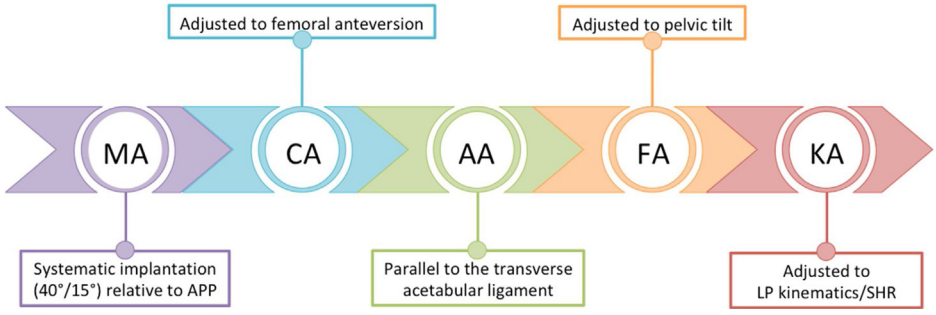

Fig. 2. Evolution of the techniques for aligning the acetabular component. MA: Mechanical Alignment, CA:Combined Anteversion, AA: Anatomical Alignment, FA: Functional Alignment; KA: Kinematic Alignment; APP: Anterior Pelvic Plane; LP: Lumbo-Pelvic; SHR: Spine-Hip Relationship.

4.3. PROMs

We were unable to provide an adequate answer to this question, as only one study reported the functional outcome scores. The prosthetic hip function and satisfaction were both excellent and similar between kinematically aligned (spine-hip relation adjusted) and mechanically aligned-THAs at 1-year follow up. Functionally aligning a cup primarily intends to improve the functional interaction of components, and therefore it is sensible not to expect increased functional performance from this. However, by restoring the constitutional proximal femur anatomy and native hip centre of rotation, the kinematic alignment technique for THA intends to create a more physiological prosthetic hip and consequently to improve prosthetic hip function and patient satisfaction [35]; this remains to be scientifically proven.

4.4. Radiographic cup orientation:

Overall, alternative techniques for cup alignment generated an acceptable radiographical supine and/or standing cup orientation. This was expected for the pelvic-tilt adjusted technique [22,23,25,32] as this method aims to reduce the number of outlying cups on supine or standing radiographic orientations. This was also expected for the lumbo-pelvic kinematics adjusted technique promoted by Stefl et al. [27], as the authors planned a cup implantation that targeted the Lewinnek safe zone and was executed by use of CAS. However, radiographic cup orientation for the kinematic alignment (spine-hip relationship adjusted cup orientation) technique for THA [33] and the lumbo-pelvic kinematics adjusted OPS™ THA [28] were more unpredictable, as the planned cup orientation is sometimes a compromise in order to improve the standing to sitting components' interaction in the case of lumbo-pelvic stiffness. To illustrate, for patients with SHR type B (subject with abnormal lumbo-pelvic kinematics type 1 but without radio-clinic signs of spine degeneration and with normal pelvis morphology, - i.e., normal pelvic incidence angle), the kinematically aligned cup will be implanted with a slight increase of the cup anteversion relative to the TAL, and with an inclination targeting 40° to 50° on standing pelvic radiograph.

4.5. Study limitations

It is important to acknowledge a few limitations of our methods that may affect the generalization of our results. Firstly, our eligible articles mainly reported on non-comparative studies, with a lack of homogeneity within the surgical techniques used for adjusting the cup position and the nature of the reported data. This has prevented us from performing a meta-analysis, and has affected the assessment of the value of those alternative techniques themselves, and to relate the values to those from more conventional methods of implantation. Secondly, quantitative functional outcomes were often missing, therefore we could not adequately define the influence of alternative techniques on functional performance. Lastly, the follow-up periods were too short to elucidate the longer-term clinical outcomes of THA components when performed with alternative techniques.

4.6. Classification proposal of cup aligning methods

Given the growing number of alternative techniques for implanting the acetabular component and the potential difficulty in distinguishing between them, we propose a classification system for the multiple methods of aligning a cup (Figs. 2 and 3):

Systematic mechanical technique [2–5]: gold standard and most popular technique. The hip centre of rotation is medialised in order to reduce stress on articular surfaces and the bone-implant interface; implants are also similarly positioned between patients with a recommended inclination of 40° ± 10° and anteversion of 15° ± 10°, relative to the anterior pelvic plane.

Femoral anteversion adjusted technique (=combined anteversion technique) [6]: the development of uncemented stems, with their propensity to closely recreate the native neck anteversion, has been responsible for the development of the concept of combined anteversion; the cup version being decided after the initial proximal femur reconstruction has been performed (femur first

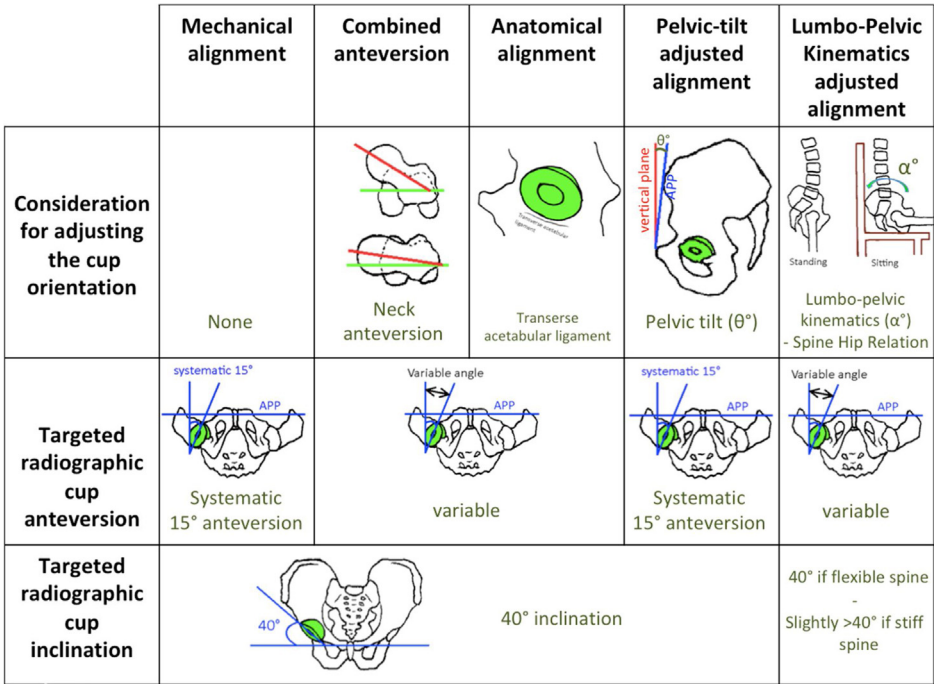

Fig. 3. This figure details the multiple methods for implanting a cup by highlighting for each the main parameter of consideration for adjustment of the cup orientation and the targeted cup anteversion and inclination. LP: Lumbo-Pelvic; APP: Anterior Pelvic Plane.

technique), with the aim of approximating a set combined anteversion.

Anatomical technique [7,34,36]: this technique aims to restore the native acetabular version by aligning the cup parallel to the transverse acetabular ligament.

Pelvic tilt adjusted techniques (functional alignment technique for cup positioning) [22,23,25,32]: the aim of this technique is to reduce the number of outliers in terms of cup position on supine [22] or standing [23,25] pelvic radiographs, by compensating for supine (relative to the horizontal plane) or standing (relative to the vertical plane) pelvic tilt, respectively. While technological assistance (e.g. tilt-adjusted navigation system) is usually needed [22,23,32], a free-hand technique is sensible for adjusting an anatomically positioned cup [25].

Lumbo-pelvic kinematics- and spine-hip relation- adjusted techniques (kinematic alignment technique for cup positioning): the aim is to reach a compromised, supposedly optimal, functional interaction of components between standing and sitting positions, or in other words, to prevent poor functional components' interaction (edge loading, articular impingement) from standing to sitting positions. Similar to the aforementioned pelvic tilt adjusted technique, technological assistance is needed for adjusting the cup positioning [27], unless the cup adjustment is a slight deviation from an anatomical cup positioning [26,33]. The recently promoted concept of the Lumbo-pelvic kinematic alignment technique [16,26,33] consists of adjusting the cup orientation by slightly deviating from the patient's native anatomy (transverse acetabular ligament [36]) in order to adapt to the individual spine-hip relationship. The Lumbo-pelvic kinematic alignment technique also promotes the anatomical reconstruction of the proximal femur anatomy and hip centre of rotation [37]. In other words, the kinematic alignment technique is a combination of both an anatomical hip reconstruction and a kinematic cup alignment technique. While the former enables a close-to-physiological peri-prosthetic soft-tissue balance for optimum prosthetic function and patient satisfaction, the latter could reduce the risk of poor dynamic component interaction during activities of daily living, optimising implant lifespan. By generating a component interaction that is the best compromise between the standing and sitting positions, kinematically aligned hip components hopefully prevent the occurrence of an aberrant component interaction during activities of daily living, which may be clinically advantageous. One could consider the Optimized Positioning System™ (Corin, Cirencester, UK) [28,31] to be a technological version of the KA technique for implanting THA components. It also aims, by way of 3D planning and technological implantation assistance, to restore most of the hip anatomy in addition to achieving a supposedly optimal cup position, which should reduce the risk of poor functional components' interaction.

5. Conclusion

From this literature review, alternative methods accounting for the functional acetabular orientation seem to be clinically safe and efficacious in the early-term, and generate acceptable radiographic cup orientation. Their value when compared to those of more conventional techniques for cup implantation could not be determined. We developed a classification for the multiple methods for aligning an acetabular component. Further research is needed to assess the value and to refine these alternative techniques.

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; Justin Cobb declares being consultant for Biomet-Zimmer, Mathortho, and to receive a fee from Microport.

The other authors declare that they have no competing interest.

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Authors contribution

Cedric Maillot: Conception and design of the study, drafting the article or revising it critically for important intellectual content, final approval of the version to be submitted. Ciara Harman: Conception and design of the study, drafting the article or revising it critically for important intellectual content, final approval of the version to be submitted. Loic Villet: drafting the article or revising it critically for important intellectual content, final approval of the version to be submitted. Justin Cobb: final approval of the version to be submitted. Charles Rivière: Conception and design of the study, drafting the article or revising it critically for important intellectual content, final approval of the version to be submitted.

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