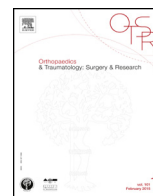




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Review article

Alignment options for total knee arthroplasty: A systematic review

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ARTICLE INFO

Article history:

Received 5 November 2016

Accepted 4 July 2017

Keywords:

TKA

Alignment

Kinematic alignment

Anatomic alignment

Adjusted technique

Restricted technique

ABSTRACT

In spite of improvements in implant designs and surgical precision, functional outcomes of mechanically aligned total knee arthroplasty (MA TKA) have plateaued. This suggests probable technical intrinsic limitations that few alternate more anatomical recently promoted surgical techniques are trying to solve. This review aims at (1) classifying the different options to frontally align TKA implants, (2) at comparing their safety and efficacy with the one from MA TKAs, therefore answering the following questions: does alternative techniques to position TKA improve functional outcomes of TKA (question 1)? Is there any pathoanatomy not suitable for kinematic implantation of a TKA (question 2)? A systematic review of the existing literature utilizing PubMed and Google Scholar search engines was performed in February 2017. Only studies published in peer-reviewed journals over the last ten years in either English or French were reviewed. We identified 569 reports, of which 13 met our eligibility criteria. Four alternative techniques to position a TKA are challenging the traditional MA technique: anatomic (AA), adjusted mechanical (aMA), kinematic (KA), and restricted kinematic (rKA) alignment techniques. Regarding osteoarthritic patients with slight to mid constitutional knee frontal deformity, the KA technique enables a faster recovery and generally generates higher functional TKA outcomes than the MA technique. Kinematic alignment for TKA is a new attractive technique for TKA at early to mid-term, but need longer follow-up in order to assess its true value. It is probable that some forms of pathoanatomy might affect longer-term clinical outcomes of KA TKA and make the rKA technique or additional surgical corrections (realignment osteotomy, retinacular ligament reconstruction etc.) relevant for this sub-group of patients. Longer follow-up is needed to define the best indication of each alternative surgical technique for TKA. Level I for question 1 (systematic review of Level I studies), level 4 for question 2.

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1. Introduction

For decades, a stable knee with a neutrally aligned lower limb has been one of the primary goals of Total Knee Arthroplasty (TKA) because it was supposed to be important for successful clinical outcomes and implant survivorship [1]. Therefore, the aim of Mechanical Alignment (MA) technique for TKA is not to restore the constitutional patient-specific alignment [2] but rather to systematically create a “biomechanically friendly prosthetic knee” [1]. MA technique aims at frontally and axially aligning the femoral component with the Trans-Epicondylar Axis (TEA), which was believed originally to be the flexion-extension axis of the native knee, at creating a femorotibial joint line perpendicular to a neutral limb

mechanical axis, and at frontally aligned the extensor mechanism [1]. This implant positioning has been recommended in order to prevent patella instability, and to generate less and more evenly distributed between tibial compartments constraints in order to prevent accelerated polyethylene wear and early implant loosening. This concept defines the “systematic approach for TKA implantation” as the goal is not to restore the patient anatomy but rather to aim a “systematic goal” [1].

MA TKAs provide good long-term implant survivorship [3], but its functional outcomes are disappointing (high rates of dissatisfaction and residual symptoms) despite the many improvements in implants design and in precision of the surgery (navigation system, patient-specific instrumentation, robotics) [4,5]. Because many reports found the postoperative standing frontal limb alignment seems to be of poor value to predict the prosthetic knee loading during gait [6,7], the knee function, and the long-term TKA implants survivorship [8,9], interest in alternative more anatomical surgical techniques has recently re-emerged [10], with the hope

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they would improve knee kinematics and functional outcomes of TKA. This review aims at (1) classifying the different options to frontally align TKA implants; and (2) at comparing their safety and efficacy with the one from MA TKAs, therefore answering the following questions: do alternative techniques for implant positioning improve functional outcomes of TKA (question 1)? Is there any pathoanatomy not suitable for kinematic implantation of a TKA (question 2)?

2. Search strategy and criteria

A literature search was performed on 21st February 2017 with PubMed and Google scholar by one author (CR). Regarding the question 1, the search parameters used for PubMed database were: (“primary total knee arthroplasty” or “total knee arthroplasty” or “primary total knee replacement” or “total knee replacement” or “TKR” OR “TKA” or “knee replacement” or “knee arthroplasty”) and (“alignment” or “knee alignment” or “implant alignment” or “limb alignment” or “joint line alignment” or “positioning” or “implant positioning”) and (“randomized study” or “randomized” or “comparative study” or “comparative”), and the search parameters used for Google Scholar database were: (“primary total knee arthroplasty” or “total knee arthroplasty” or “primary total knee replacement” or “total knee replacement” or TKR or TKA or “knee replacement” or “knee arthroplasty”) and (“alignment”), with words occurring in the title of the article. Among the studies that were identified, we only included randomized clinical trial published in peer reviewed journals over the last 10 years in either English or French, and comparing clinical outcomes between primary MA TKA and an alternative surgical technique to position TKA implants. Because of the small number of eligible studies to answer the question 1, we judged non relevant any statistical analysis. Regarding the question 2, the search parameters used for PubMed and Google Scholar databases were: (“primary total knee arthroplasty” or “total knee arthroplasty” or “primary total knee replacement” or “total knee replacement” or “TKR” or “TKA” or “knee replacement” or “knee arthroplasty”) and (“kinematic alignment”). Only studies assessing clinical outcomes of KA TKAs and published in peer-reviewed journals over the last ten years in English or French were eligible.

3. Results

The Fig. 1 illustrates the flowchart of paper selection to answer the question 1. We found six eligible articles for question 1 [11–16] and thirteen for question 2 [5,12–23].

3.1. Classification of the different surgical techniques for TKA

Multiple alternative philosophies to implant TKA have challenged the conventional MA technique and are illustrated in Fig. 2.

3.1.1. Anatomic Alignment (AA) technique

The Anatomic Alignment (AA) technique, initially introduced in the 1980s by Hungerford and Krackow [24], can also be defined as a “systematic approach” as the technique aims a systematic oblique joint line (2–3° valgus) relative to the mechanical axis of the limb. The rational supporting this technique is the promotion of a better load distribution on the tibial component [25], and also a better patella biomechanics as it reduces the risk of lateral retinacular ligament stretching when knee flexes [26]. The technical challenge in the 1970s to precisely achieve bone cuts, with the risk of having a supposedly deleterious excessive (> 3°) varus of the limb or of the tibial implant positioning [9,27–29], has prevented the wide spread use of AA technique. Nowadays, this lack of surgical accuracy has

been overcome by 2 means: firstly by the use of precision tools for implant positioning (navigation system and robotic technology), and secondly by the development of TKA implant incorporating a 3° joint line obliquity in their design, which enables to obtain the effects of an AA technique by doing a MA bone cuts (= AA-like technique) [30]. Good mid to long-term results have been published with both techniques (AA and “AA-like”) [11,31].

3.1.2. Adjusted Mechanical Alignment (aMA) technique

The adjusted Mechanical Alignment (aMA) technique is an adaptation of the conventional MA technique with the goal to under-correct the constitutional frontal deformity (varus or valgus) to a maximum of 3° [32–35]. Slight to moderate constitutional deformity are preserved while more severe deformity are attenuated. The implant positioning adjustment is made on the femoral side as promoters of this technique aim to keep the tibial implant mechanically aligned [34,35]. Few non-comparative longitudinal studies reported very good functional outcomes and/or long-term survivorship for aMA-TKAs for varus and valgus knees.

3.1.3. Kinematic Alignment (KA) technique

The kinematic Alignment (KA) technique is a “true knee resurfacing” (fully anatomic positioning of TKA implants) and is the counterpart of the hip-resurfacing technique for the hip [36]. Like partial replacement techniques for knee, KA technique is a “patient specific” and “ligament sparing” (bone procedure) technique striving to restore the highly inter-individual variable native pre-arthritis limb and joint line alignments [2,37] and knee laxity [38,39] without the need of any complex preoperative assessment or planning. KA technique is a pure bone procedure with predictable “expected thickness of bone cuts”, and intraoperative ability to quality assurance check (caliper measurement) and correct them (varus-valgus recut instruments). KA is a new surgical technique for TKA, which uses new landmarks to set the 3D orientation of the femoral and tibial implants [36,40]. The only one similarity with the MA technique is the sagittal positioning of the femoral component, all the other steps are specific to KA technique (Table 1 and Table 2).

3.1.4. Restricted Kinematic Alignment (rKA) technique

The restricted Kinematic Alignment (rKA) technique [41]: some cautious authors have opted for a compromise when performing a TKA on patient having substantial coronal limb deformity or joint line obliquity [23]. Those authors use computational assisted surgery to assess limb and femoral and tibial components frontal alignment, and restrict their indication of “KA technique” for patients with a small constitutional frontal limb deformity ($\leq 3^\circ$) and a distal femoral or proximal tibial frontal joint line with less than 5° obliquity (= safe alignment zone) [23,42]. Otherwise, that is in approximately one third to half of cases, the authors perform bone cut adjustment to bring the patient in their safe zone of alignment, with substantial bone cut (tibial or/and femoral) adjustment needed in 17% of knees (822 out of 4800 osteoarthritic knees) [41]. Conversely with the previously mentioned aMA technique, the rKA technique follows the main technical principle of KA technique, which is to respect as much as possible the kinematic alignment of the femoral component, and adjustment of the coronal limb alignment and joint line obliquity is first made by fine-tuning the tibial component positioning.

3.2. Question 1

3.2.1. MAT KA vs. AA TKA ($\pm$ like)

We only found one randomized trial to answer this question. Yim et al. [11] compared 56 MA TKAs and 61 AA TKAs, all performed with the use of robotics. At a minimum of 2 years follow-up

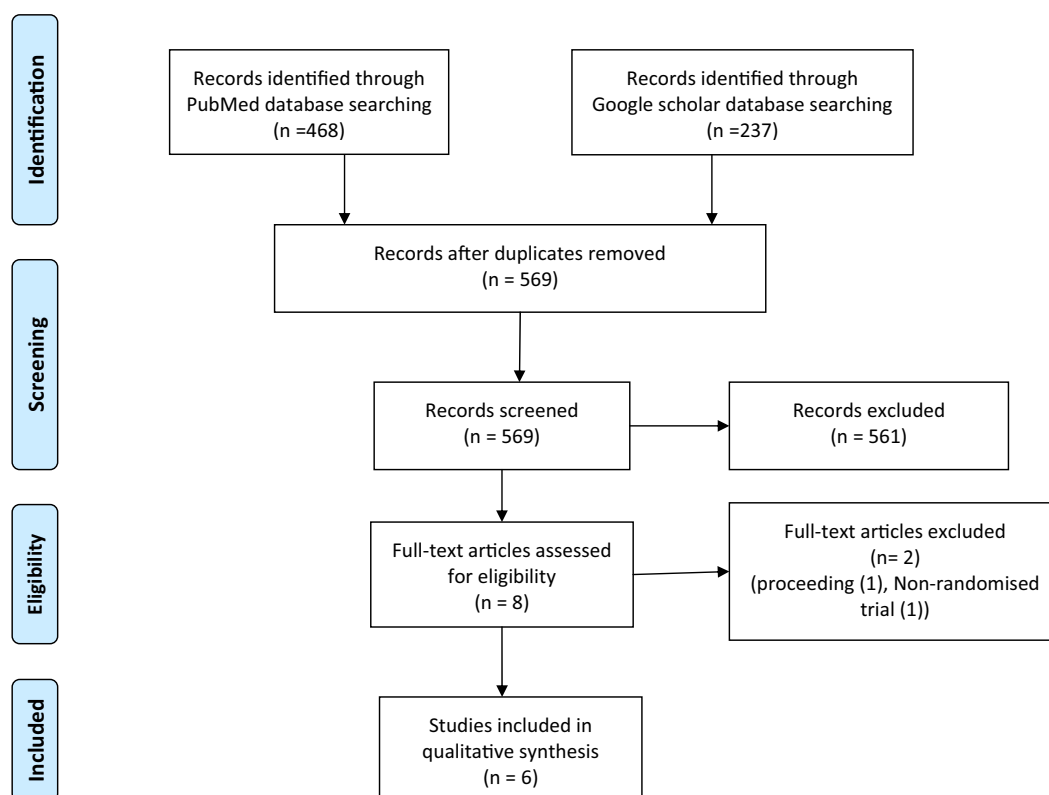


Fig. 1. Flow-chart.

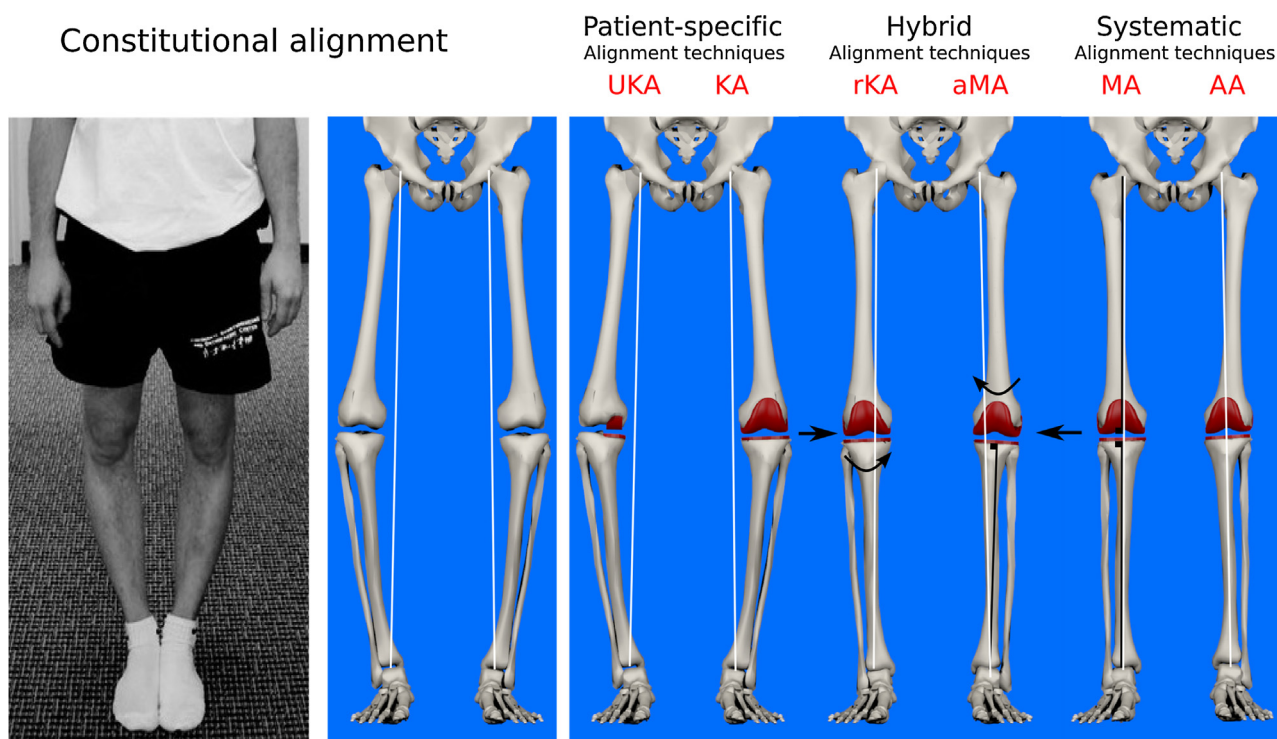


Fig. 2. Different philosophies for implanting a TKA. To illustrate this classification, a knee with severe constitutional varus deformity has been selected. MA: Mechanical Alignment technique; AA: Anatomical Alignment technique; aMA: adjusted Mechanical Alignment technique; rKA: restricted Kinematic Alignment technique, UKA: Unicompartmental Knee Arthroplasty.

Table 1
Technical differences between mechanic and kinematic alignment techniques.

	KA technique “patient specific approach”	MA technique “systematic approach”
F component sagittal rotational positioning (F distal cut)	Follow F bowing (3° flexion relative to the sagittal F mechanical axis)	Follow F bowing (3° flexion relative to the sagittal F mechanical axis)
F component frontal rotational positioning (F distal cut)	Parallel to the frontal femoral slope after correction for wear	Perpendicular to the femoral mechanical axis
F component horizontal rotational positioning (F anterior and posterior cuts)	Neutral rotation relative to PCL Measured resection technique only	External rotation relative to PCL Measured resection or gap-balancing techniques
F component anteroposterior translational positioning	Posterior referencing technique only (compromise done on the trochlear offset)	Posterior or anterior referencing techniques (compromise done on the flexion gap or on the trochlear offset)
F component mediolateral translational positioning	Centered on the notch	Centered on the notch or slightly lateralized to optimize patella tracking
T component frontal rotational positioning (Tcut)	Parallel to the frontal tibial slope after correction for wear (no attention is paid to the ankle)	Perpendicular to the tibial mechanical axis
T component sagittal rotational positioning (T cut)	Parallel to medial plateau slope	Between 2 and 7° posterior slope relative to the sagittal T mechanical axis
T component horizontal rotational positioning	Parallel to lateral plateau axis [no attention is paid to ATT)	Towards ATT
FT soft tissues balancing	No (goal is to restore constitutional knee laxity in flexion and extension)	Often (goal is to obtain rectangular symmetric flexion and extension gaps)
PF soft tissues balancing	No	Often

Table 2
Step-wise algorithms for balancing the Kinematically Aligned (KA) Total Knee Arthroplasty (TKA).

Tight in flexion and extension	Tight in flexion and well-balanced in extension	Tight in extension and well-balanced in flexion	Well-balanced in extension and loose in flexion	Tight medial and loose lateral in extension	Tight lateral and loose medial in extension
1st – use thinner liner 2nd – recut tibia and remove more bone	Increase posterior slope until natural A-P offset is restored at 90° of flexion	1st – remove posterior osteophytes 2nd – strip posterior capsule	1st – reduce tibial slope if excessive 2nd – add thicker liner and recheck if knee extends fully 3rd – if PCL is incompetent, consider PS implants or UC liner	1st – remove medial osteophytes 2nd – recut tibia in more varus and insert thicker liner	1st – remove lateral osteophytes 2nd – recut tibia in more valgus and insert thicker liner

The top row lists six different scenarios of non-balanced knee, and the bottom lists the corresponding corrective actions. Notice those corrections that require a recut of bone are performed by fine-tuning the proximal-distal translation and the varus-valgus and flexion-extension (slope) rotations of the tibial resection and not by recutting the femur.

they found no significant differences between groups regarding the Hospital for Special Surgery (HSS) and the WOMAC scores and knee flexion (93 [SD 8] and 19 [SD 2] and 125° [SD 11.5°] versus 95 [SD 5.5] and 20 [SD 2] and 129° [SD 11.5°], for AA group and MA group, respectively).

3.2.2. MA TKA vs. KA TKA

Four studies (229 KA TKAs) were eligible to answer this question (Table 3). At 1 or 2 years follow-up, two RCTs found better functional outcomes with KA-TKA [12,13] while two others found similar good functional score [14,15]. Overall, the KA technique has shown to enable a quicker recovery [16], to be likely to generate better functional outcomes (higher functional scores [12,13], higher rates of forgotten knee [13], lower rates of residual pain [13], and to be responsible for a similar reoperation/revision rates at early-term [12–15].

3.2.3. MA TKA vs. either rKA TKA or aMA TKA

We found no randomized trial having assessed this question.

3.3. Question 2

We found no evidence that severe (1) constitutional limb valgus or varus or (2) femorotibial joint line obliquity or (3) varus obliquity of the tibial plateau might affect clinical outcomes (functional score and implants survivorship) of KA TKA [13–15,19,23]. Howell et al. [19] specifically assessed this question and found no correlation between postoperative limb alignment (0.8° varus, ranged from 10°

valgus to 8.5° varus, 7% (15 patients) and 20% (42 patients) of limb with > 3° of varus or valgus, respectively) or tibial component alignment (mean 1.9° varus, ranged from –7° valgus to 7° varus) and clinical outcomes of 208 consecutives non-selected KA TKAs at mid-term (mean 6.3 years); the authors had 5 revisions (or pending), which all occurred in patients having a neutrally aligned KA TKA. Also, Calliess et al. [12] found no correlation between special pre-operative deformities and postoperative outcomes; however, the authors only included mild to moderate deformities (< 10° frontal limb deformity and < 4° tibial implant obliquity relative to the tibial mechanical axis) in their randomized trial. None of the other clinical reports assessed the correlation between clinical outcomes of KA TKAs and patient lower limb anatomy [13–15,23].

Literature shows patella instability after KA TKA ranges from 0% to 2.4% [13,14,16,17,19,23]. We found no evidence that pathoanatomies predisposing to patella instability might affect clinical outcomes of KA TKA; however, Howell et al. [19] had out of their 5 patients revised one case of patella instability affecting a patient with medical history of bilateral congenital patella instability. Nedopil et al. [17] found 13 patients with atraumatic patella instability (only 3 dislocations), which occurred at an average of 5 months out of 3212 consecutive non-selected KA TKAs, and did a case-control study to understand the factors predisposing to this complication. They only found sagittal rotational positioning of the femoral component (component flexion), but not the postoperative limb alignment nor the frontal/axial implant positioning, to correlate with the risk of patella instability. However, the authors did not assess the factors “preoperative (KA TKA) medical history of

Table 3

Eligible studies to answer the question 1 regarding comparison between Mechanical (MA) and Kinematic (KA) Aligned Total Knee Arthroplasty (TKA).

	Study design	Population	TKA design and cutting tool	Pathoanatomy excluded?	Postoperative limb and joint-line alignment for KA TKA	Collateral ligament release for KA group?
Dossett et al. [13,16]	Double blind RCT	KA group: 44 TKAs MA group: 44 TKAs	KA group: ShapeMatchTechnology™ (Otismed Stryker) MA group: conventional measured resection instruments, 3° external rotation of femoral component Both group: cruciate-retaining Vanguard™ TKA (Biomet, Inc. Warsaw, Indiana) with patella resurfaced	No	Hip Knee Ankle angle: 0.1 (SD 2.8) (range –7.7° to 8.5°) Tibial component alignment relative to tibial mechanical axis: 2.2° varus (SD 2.6°, range 4° valgus to 8.7° varus)	No
Calliess et al. [12]	RCT – not blinded	KA group: 100 TKAs MA group: 100 TKAs	KA group: ShapeMatch Technology™ (Otismed Stryker) MA group: conventional measured resection instruments, rotation of the femoral component was bony referenced to the transepicondylar line and the Whiteside's line with strict posterior referencing Both group: cruciate-retaining, cemented, fixed-bearing implant (Triathlon™; Stryker, Inc)	Preoperative varus–valgus deformity >10° Lateral distal femoral angle and/or medial proximal tibial angle outside 86°–94°	Hip Knee Ankle angle: 1° valgus (SD 3°) Tibial component alignment relative to tibial mechanical axis: 2° varus (SD 1°)	No
Young et al. [14]	Double blind RCT	KA group: 49 TKAs MA group: 50 TKAs	KA group: ShapeMatch Technology™ (Otismed Stryker) Ma group: computer navigated TKA. Posterior femoral cut made with navigation assistance parallel to the surgical epicondylar axis with Whiteside's line and 3° external rotation relative to the posterior condylar axis used as additional references Both group: cruciate-retaining, cemented, fixed-bearing implant (Triathlon™; Stryker, Inc)–selective patella resurfacing (grade 4 chondral loss on the patella or patellofemoralmaltracking)	Preoperative varus–valgus deformity > 15° Fixed flexion contracture > 15°	Hip Knee Ankle angle: 0.4° varus (SD 3°) range 11° varus to 6° valgus Tibial component alignment relative to tibial mechanical axis: 3° varus (SD 3°, range from 10° varus to 4° valgus). 31% of tibias were in ≥ 5° varus	Ligamentous release was performed If necessary to achieve symmetric ligament balance in both flexion and extension
Waterston et al. [15]	Double blind RCT	KA group: 36 TKAs MA group: 35 TKAs	KA group: ShapeMatch Technology™ (Otismed Stryker) MA group: conventional measured resection instruments Both group: cruciate-retaining, cemented, fixed-bearing implant (Triathlon™; Stryker, Inc) with patella resurfaced	Preoperative varus–valgus deformity >10° Fixed flexion contracture > 20°	Hip Knee Ankle angle: range from 172° to 195°	Not reported

Table 3 (Continued)

	Follow-up	Functional score	Odds ratio for pain-free knee	Postoperative ROM at last follow-up	Aseptic revision	Aseptic reoperations or Manipulation Under Anesthesia (MUA)	Other
Dossett et al. [13,16]	2 years	KA group: mean OKS 40 (SD 10.2, range from 15 to 48), mean WOMAC 15 (SD 20.3, range from 0 to 60, with 0 the best), mean combined KSS 160 (SD 31.9, range from 93 to 200) MA group: mean OKS 33 (SD 11.1, range from 13 to 48), mean WOMAC 26 (SD 22.6, range from 0 to 73), mean combined KSS 137 (SD 37.9, range from 64 to 200) → Difference Oxford Knee Score (OKS): 6.2 points (1.7 to 10.7) ($P=0.005$) → Difference WOMAC score: -10.7 (-19.8 to -1.5) ($P=0.005$) → Difference combined KSS: 23.3 (8.4 to 38.1) ($P=0.005$)	Odds ratio 3.2 (with OKS) to 4.9 (with WOMAC) favoring KA TKA	KA group: mean 121° (SD 10.4°) (range from 100° to 150°) MA group: mean 113° (SD 12.5°) (range from 80° to 130°) → Difference knee flexion 8.5° (3.6° to 13.4°) ($P=0.002$)	KA TKA: none MA TKA: 1 revision for knee instability	KA group: 1 evacuation of hematoma; 2 excision of lateral patella; reoperation for patellar subluxation; 2 MUA MA group: 1 evacuation of hematoma; 1 ORIF patella fracture; 1 excision of lateral patella	
Calliess et al. [12]	1 year	KA group: Mean combined KSS 190 (SD 18), mean WOMAC 13 (SD 16) MA group: Mean combined KSS 178 (SD 17), mean WOMAC 26 (SD 11) ($P=0.02$ and 0.001 for comparison for KSS and WOMAC, respectively)	Not reported	Not reported	KA group: 2 revisions for knee instability MA group: 1 revision for knee instability		Distribution of the results was broader for KA group in comparison with the MA group Several treatment failures were noted in KA group (i.e. poor outcome scores) Negative weak correlation between the deviation of the postoperative alignment from the initial preoperative KA plan and poor KSS in the KA group
Young et al. [14]	2 years	KA group: mean OKS 42 (SD 6, range from 19.0 to 48.0), mean WOMAC 88 (SD 14, range from 50.0 to 100.0) MA group: mean OKS 41 (SD 6, range from 19 to 48), mean WOMAC 85.5 (SD 17, range from 23 to 100) → Difference 1.0 (95% CI -3.5 to 1.4 , $P=0.4$) for OKS, and -3 (95% CI -9.1 to 3.2 , $P=0.6$) for WOMAC. Also no difference in KSS pain and function components, visual analog scale pain, WOMAC, or EQ-5D	Not reported	KA group: mean 119° (SD 11° , range from 80° to 150°) MA group: Mean 116° (SD 11° , range from 90° to 140°)	None	KA group: 1 patella dislocation at 3 weeks post-surgery, which was treated with a patella realignment procedure; 2 MUA MA group: 1 distal femoral fracture 3 months after TKA treated with a lateral locking plate; 1 recurrent hemarthroses which resolved after open debridement; 1 traumatic patella dislocation treated with open repair of the medial retinaculum and secondary patella resurfacing. The patient went on to develop recurrent patella instability, which was managed with a patella realignment procedure	
Waterston et al. [15]	1 year	Greater improvement in the mean "American Knee Society Score" in the kinematically aligned group at six weeks only Slight improvement in the mean physical component of the SF-36 in the KA group at six months postoperatively ($P=0.04$) Better peak torque in the quadriceps in the kinematically aligned group at six weeks and three months No significant difference in the mean KOOS, UCLA, and EQ-5D scores, and for the "time up and go" test, the two minute walking distance test and the timed up and down stairs test, mean range of motion, ability to kneel or walk across an uneven surface between the two groups at any time	Not reported	Ka group: Mean 118.5° (SD 12°) MA group: Mean 118.4° (SD 9.4°) → Difference: 0.1° (range from -6.1° to 6.2°) ($P=0.98$)	None	KA group: none MA group: 1 patient with quadriceps rupture	There was a trend towards the patients in the kinematically aligned group within 3° of their plan having forgotten their TKA (77% versus 45% ($P=0.10$))

RCT: Randomized Controlled Trial; TKA: Total Knee Arthroplasty; OKS: Oxford Knee Score; KSS: Knee Society Score; WOMAC: Western Ontario and McMaster Universities Arthritis Index.

atraumatic patella dislocation” or “preoperative patella maltracking/subluxation”.

4. Discussion

As Mechanically Aligned TKAs are still affected by disappointing functional outcomes despite the many improvements in implants design and surgical precision, revival of interest for alternative more anatomical surgical techniques for TKA has arisen: AA, aMA, KA, and rKA techniques. Only few comparative studies directly compared KA and MA TKAs; however, it seems that, regardless of patient constitutional knee anatomy, the KA technique for TKA enables a faster recovery and is likely to generate better functional outcomes during the early-term (≤ 2 years).

Before to interpret our results, it is important to acknowledge some limitations in the current study. Firstly, no study compared MA TKAs with aMA or rKA TKAs, making impossible to fully answer the question 1. Secondly, studies having compared MA and KA TKAs are at maximum 2 years of follow-up, which makes irrelevant the assessment of the impact of the alignment on implants' fixation and wear. Lastly, there is a lack of evidence regarding the impact of constitutional limb anatomy on KA TKA function and survivorship (question 2). However, it is likely that some forms of severe pathoanatomies might affect KA TKA and were not detected because patients with those deformities were not eligible to participate in the study [12,14,15] or because the follow-up was too short for a complication to happen.

4.1. Question 1

The better functional outcomes for KA TKAs might be explained by the fact that KA technique is almost a pure bone procedure (exceptional collateral ligaments release), which reliably position TKA implants [43–47]. This probably enables to reproducibly restore the patient-specific femorotibial joint obliquity and soft-tissue laxity allowing generation of better knee kinematics and potentially less knee balance related complications compared to MA TKA [48–52].

4.2. Question 2

Although clinical outcomes of KA TKA have been reported to be good with the patient's anatomy (mild to moderate frontal deformity) included in the published studies, it is likely that not all patients are suitable for kinematic alignment [14,23,25,49], because some native pathoanatomy may be inherently biomechanically inferior, predisposing to initial disease and then potentially to prosthetic complications if recreated.

4.2.1. Patients with severe ($\geq 5^\circ$) constitutional knee varus deformity

Most of the varus deformity of patients scheduled for TKA is related to articular surfaces wear (Figs. 3 and 4), and 7% to 40% of patients have a constitutional varus knee deformity $> 3^\circ$ [14,16,19,33,42,53]. Because the constitutional frontal alignment of a non-prosthetic (native) knee influences the dynamic medial tibial plateau loading during gait [54], and therefore the risk for developing OA [55], it is likely that restoring a severe constitutional varus with KA TKA would result in uneven and locally increased medial plateau loading, which would potentially increase the risk of tibia plateau collapse and implants' wear/loosening [25,49]. This has been confirmed by a finite element analysis done by Nakamura et al. [49]; compared to a MA TKA, the authors estimated the maximum stress on the tibial insert and on the tibial resection surface increases by 47% and 25%, respectively, if the KA TKA resulted in a limb with 6° varus. In a cohort of 208 consecutive

non-selected KA TKA at 6 years follow-up, Howell et al. [19] found 97.5% implant survivorship and no clinical impact for restoring a constitutional varus limb as high as 8.5° and implanting tibial component with up to 7° varus relative to the tibial mechanical axis. While this does not preclude occurrence of failures at longer-term, this good results might be the consequence of a few factors that can lower the risks of accelerated PE wear and early implant loosening: (1) the fact that the native or prosthetic (KA TKA) femorotibial joint line of patients with constitutional knee varus remains relatively parallel to the floor when standing and walking [46,56] which might be biomechanically beneficial by reducing deleterious shear stress, (2) the kinematic tibial cut is likely to result in a tibial resection surface having a better and more homogeneous bone quality when compared with a mechanical tibial cut, (3) the rare occurrence of femorotibial lift-off after KA TKA [48], likely to be the result of a reliable restoration of the constitutional knee laxity, which is likely to reduce stress on PE and implant fixation area, and (4) the new generation of polyethylene [57] can sustain much higher strain and are more wear-resistant.

4.2.2. Patients with severe ($> 5^\circ$) varus of the proximal tibial joint line

For a similar overall limb mechanical axis (HKA) there is a high inter-individual variability in joint line obliquity and frontal orientation of the proximal tibial joint line [2,37,58]. Therefore, a large amount of patients receiving a KA TKA, precisely 31% in the series of young et al. [14], have a tibial component implanted in severe ($> 5^\circ$) varus. The varus tilt of tibial component has been shown to correlate with the peak contact stresses, even if the overall limb alignment was neutral [59], and therefore there is a fear that restoring this constitutional tibial varus slope could generate tibial complication.

4.2.3. Patients with severe constitutional valgus knee

The incidence of valgus knee alignment $> 3^\circ$ in healthy Caucasian populations is inferior to 10% [2,58]. A valgus knee is often compared to a dysplastic hip as the pathoanatomy is believed needing correction to prevent complications such as patellar and femorotibial instability. While KA technique is probably suitable for slight to moderate constitutional valgus alignment [12,14,15,19], uncertainties remain for more severe valgus, notably when a MCL stretching, or disturbing knocking knees, or patella lateral subluxation are present.

4.2.4. Patient with a medical history of atraumatic patella instability or patella maltracking (subluxation)

The concern of patella instability would persist after KA TKA as abnormal anatomic parameters (high tibiofemoral torsion, high Q angle, trochlear dysplasia, and patella alta) would be reproduced. This concern is further accentuated by the fact KA TKA is currently performed with implants designed for MA technique, which frequently display a dysplastic trochlear shape and do not reproduce the patient-specific groove alignment [59–61]. Only one case of patella instability occurring in this context has been reported [19]; however, it is not clear if authors of other studies on KA TKA took those parameters into consideration when assessing the reason of patella instability [13,14,16].

4.2.5. Trochlea design of current implants design

So far, development and research on KA technique has been focused on the femorotibial joint. However, KA technique also aims at restoring the patient-specific patella kinematics, which would be best done by respecting the patellar ligaments integrity (except the approach) and reproducing the constitutional trochlea anatomy [62]. However, current TKA implants have been designed for implantation following MA technique principles and their trochlea aims at achieving a “biomechanically friendly goal”

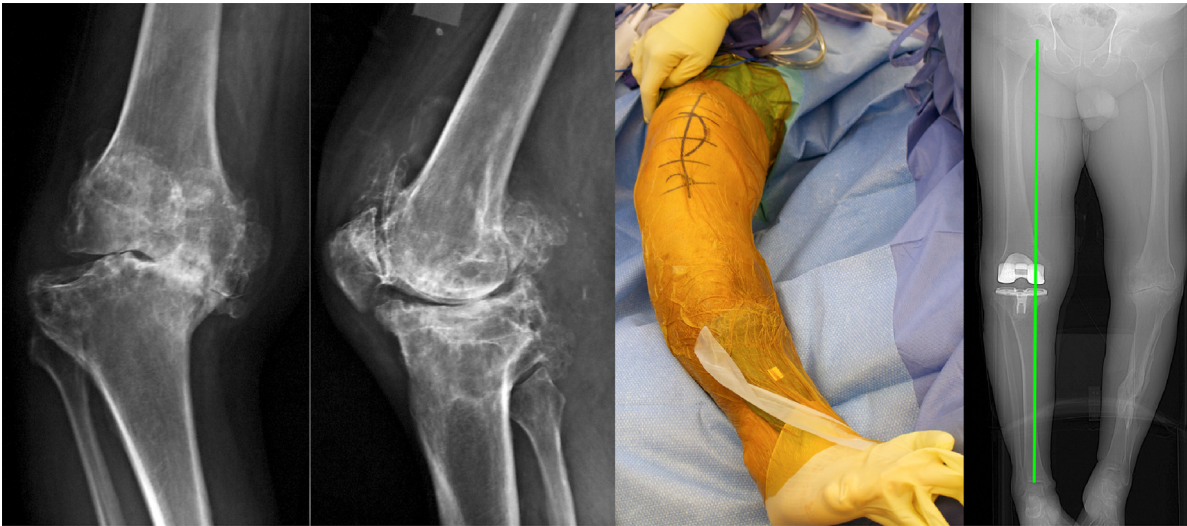


Fig. 3. Composite showing the preoperative radiographs of the knee with severe valgus deformity, intraoperative photograph of the severe valgus deformity and flexion contracture, and postoperative computer tomographic scanogram of the limb and axial views of the femoral and tibial components. The kinematically aligned total knee arthroplasty restored the native alignment and laxities of the knee without a release of the lateral collateral ligament in this patient with an intact posterior cruciate ligament.



Fig. 4. Composite shows the preoperative radiographs of a post-traumatic knee with a severe varus deformity, flexion contracture and chronic posterior cruciate ligament insufficiency; an intraoperative photograph of the varus deformity; and a postoperative computer tomographic scanogram of the limb and axial views of the femoral and tibial components. The kinematically aligned total knee arthroplasty restored the native alignment and laxities of the knee without a release of the medial collateral ligament and was performed with posterior cruciate ligament substituting implants because of the torn posterior cruciate ligament.

(early capture of the patella in early flexion and patella tracking not excessively constrained) rather than trying at reproducing the patient trochlear anatomy [61,63]. A computer simulation done by Ishikawa et al. [59] in a single knee model suggested the groove alignment resulting from KA technique could affect the

patellofemoral biomechanics mainly at a very early knee flexion when the patella engages the trochlea. Current mid-term evidence has not highlighted the incidence of patellofemoral catastrophic failure. Mid-term follow up of KA TKAs found patellar loosening and patellar instability to be low (0.9% and 0.4% to 1.4%, respectively)

Table 4
Advantages, evidence of clinical improvement, and potential concerns of the kinematic alignment technique for total knee arthroplasty (TKA) in comparison with the mechanical alignment technique.

Advantages	Clinical improvements	Potential concerns
Patient-specific implant positioning likely to restore the constitutional femorotibial alignment and laxity → Better femorotibial kinematics Higher surgical reproducibility	Faster recovery Better functional results: higher knee scores; less residual pain; higher flexion; more forgotten knee; higher patient satisfaction Easier revision of medial UKA to TKA	Severe constitutional varus or valgus deformities Severe tibial plateau varus Pathoanatomy favoring patella instability Trochlea design of current TKA implants

UKA: unicompartmental Knee Arthroplasty.

Knee types	1	2	3a	3b	3c	4
Complexity of procedure	Simple	Complex				
Description	After correction of articular wear there is no severe frontal pathoanatomy	After correction of articular wear there is a severe (constitutional or post-traumatic) frontal pathoanatomy				History of non traumatic patella instability
HKA after correction of articular wear	$\leq 5^\circ$ varus or valgus	$>5^\circ$ varus	$>5^\circ$ valgus with “tibia valga” present	$>5^\circ$ valgus without “tibia valga”	Valgus knee with severe MCL distension	
Possible alternative techniques for TKA	KA	rKA with tibial adjustment or “KA + realignment osteotomy” (KA ?)		rKA with tibial and femoral adjustment or “KA + realignment osteotomy” (prevent excessive joint line obliquity)	Not indicated	“KA + MPFL reconstruction” +/- lateral retinaculum release and VMO plasty +/- extensor mechanism realignment

Fig. 5. Algorithm for use of more anatomical surgical techniques for total knee arthroplasty. Alternative techniques of implant positioning are suggested and additional procedure(s) (osteotomy, ligament reconstruction, and so on) are recommended depending the type of pathoanatomy. KA: Kinematic Alignment technique; rKA: restricted Kinematic Alignment technique; MCL: Medial Collateral Ligament; MPFL: Medial Patello-Femoral Ligament; VMO: Vast Medial Oblique.

[17,19,23], and anterior knee pain to be 5 times less likely [13] compared to MA TKAs. These good outcomes are probably reflecting the high tolerance of the trochlear designs used in the reported studies, but could also be the consequence of a short follow up.

Advantages and potential concerns of the KA technique relative to the MA technique are listed in the Table 4. While the better functional outcomes of KA technique might lead to a reduction of the early revision rate, the abovementioned concerns could be responsible of an increased of it over longer term; the comparison of the survivorship between KA and MA TKAs is therefore far from being elucidated. The Fig. 5 illustrates a new surgical technique algorithm, which could help knee surgeons willing to use more anatomical techniques for TKA to choose the best option providing effectiveness and safety, and hopefully optimal outcomes.

5. Conclusion

Four alternative techniques to position a TKA are challenging the traditional MA technique: AA, aMA, KA, and rKA alignment techniques. The KA technique enables faster recovery and generally generates higher functional TKA outcomes in comparison to the MA technique. While there is no evidence, it is probable that some forms of severe pathoanatomy might affect longer-term clinical outcomes of KA TKA and make the rKA technique or additional surgical corrections (realignment osteotomy, retinacular ligament reconstruction etc.) relevant for this sub-group of patients. Also, the development of new implant specifically designed for KA technique in order to optimized outcomes of KA TKA might be relevant. Longer follow-up is needed to define the value and best indication of each alternative surgical technique for TKA.

Source of Funding

EA is funded by the Uren Foundation.

Disclosure of interest

Regarding this study, Stephen Howell is the promoter of the kinematic alignment technique and the developer of specific instrumentations for performing this technique. Outside the current study Charles Rivière declares being consultant for Depuy, Stephen Howell declares being consultant for Zimmer-Biomet, Pascal-André Vendittoli declares being consultant for Medacta, Stryker, and Microport. Justin Cobb declares being consultant for Biomet-Zimmer, Mathortho, and to perceive fee from Microport, and Sebastian Parratte declares being consultant for Zimmer-Biomet, Arthrex, Graftys, and Adler ortho.

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