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Evolution et évaluation de l'alignement dans les prothèses totales de genou

Elliot, Thomas Sappey-Marinier

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Elliot, Thomas Sappey-Marinier. Evolution et évaluation de l'alignement dans les prothèses totales de genou. Biomécanique [physics.med-ph]. Université de Lyon, 2022. Français. NNT : 2022LYSE1002 . tel-04217288

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N° d'ordre NNT : 2022LYSE1002

THESE de DOCTORAT DE L'UNIVERSITE DE LYON
opérée au sein de
l'Université Claude Bernard Lyon 1
Ecole Doctorale N° 162
(MEGA. Mécanique, Energétique, Génie civil et Acoustique)

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Soutenue publiquement le 11/01/2022, par :
Elliot, Thomas SAPPEY-MARINIER

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Devant le jury composé de :

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ARGENSON, Jean-Noël, Professeur des universités, Université Aix-Marseille – **Rapporteur**
EHLINGER, Matthieu, Professeur des universités, Université de Strasbourg – **Rapporteur**
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A nos Membres du Jury de Thèse,

Madame le Professeur Elvire SERVIEN,

Nous vous sommes reconnaissant de l'honneur que vous nous faites de présider ce jury de thèse. Nous mesurons la chance que nous avons de recevoir votre enseignement. Nous vous remercions de la confiance que vous nous accordez et des précieux conseils que vous nous donnez.

Soyez assurée de notre profond respect et de notre sincère reconnaissance.

Monsieur le Professeur Jean-Noël ARGENSON,

Nous vous remercions sincèrement d'avoir accepté d'être rapporteur et membre du jury de cette thèse. Merci pour l'intérêt et la considération que vous avez porté à ces travaux.

Nous sommes honoré de votre présence dans ce jury.

Soyez assuré de notre profond respect et de notre sincère gratitude.

Monsieur le Professeur Matthieu EHLINGER,

Nous vous remercions sincèrement d'avoir accepté d'être rapporteur et membre du jury de cette thèse. Merci pour l'intérêt et la considération que vous avez porté à ces travaux.

Nous sommes honoré de votre présence dans ce jury.

Soyez assuré de notre profond respect et de notre sincère gratitude.

Monsieur le Professeur Sébastien LUSTIG,

Nous vous remercions sincèrement de nous avoir confié ce travail et de nous avoir soutenu tout au long de celui-ci. Vos conseils, vos précieuses idées et vos encouragements nous ont permis d'achever ce travail. Nous vous sommes extrêmement reconnaissant d'être toujours disponible et présent. C'est un privilège pour nous de pouvoir travailler avec vous.

Soyez assuré de notre profond respect et de notre sincère reconnaissance.

Madame le Professeur Laurence CHEZE,

Nous vous sommes reconnaissant de l'honneur que vous nous faites en encadrant ce travail et en acceptant de le juger. Vous avez su nous guider sur le chemin de la recherche en biomécanique. Votre aide et vos conseils nous ont permis de réaliser ces différents travaux de recherche et nous vous en remercions.

Soyez assurée de notre profond respect.

Madame le Docteur Cécile BATAILLER,

Nous vous sommes reconnaissant de l'honneur que vous nous faites en acceptant de juger ce travail. Votre aide et vos conseils nous ont permis de réaliser ces différents travaux de recherche et nous vous en remercions. Nous sommes admiratifs de vos qualités de travail et de votre présence permanente.

Soyez assurée de notre profond respect et notre amitié.

Monsieur le Docteur Thomas NERI,

Nous vous sommes reconnaissant de l'honneur que vous nous faites en acceptant de juger ce travail. Nous aurions aimé suivre vos traces en Australie mais le destin en a décidé autrement. Nous sommes très heureux de pouvoir vous compter parmi notre jury de thèse.

Soyez assuré de notre profond respect et notre amitié.

Monsieur le Docteur Anthony VISTE,

Nous vous sommes reconnaissant de l'honneur que vous nous faites en acceptant de juger ce travail. Merci pour la considération et l'intérêt que vous avez porté à ces travaux. Nous vous remercions pour votre enseignement. Nous sommes heureux de vous compter parmi notre jury de thèse.

Soyez assuré de notre profond respect.

A l'équipe de la Croix-Rousse et du LBMC qui m'ont aidé à la réalisation de ce travail, soyez assuré de ma profonde gratitude.

A Sophie, mon amour, merci pour ton amour et ton soutien perpétuel,

A Mayeul, mon magnifique fils qui illumine mes journées,

A ma famille et ma belle-famille bien aimées,

A mes amis qui m'ont supporté et soutenu pendant ces années,

« Parfait est acceptable »

Résumé de thèse

La prothèse totale de genou (PTG) est une intervention fréquente en orthopédie. Lors de la réalisation de la PTG, l'objectif était d'obtenir un alignement mécanique (AM) systématique à 180°. Cette technique permet d'obtenir un membre rectiligne diminuant les contraintes articulaires et in fine améliorant la survie des implants. Malgré les avancées technologiques, les résultats des PTG restent imparfaits. Bien que la survie soit très bonne à long terme, jusqu'à 20% des patients ne sont pas satisfaits de leur prothèse.

Pour tenter d'améliorer ces résultats, de nouvelles propositions personnalisées d'alignement des implants ont été développées. Nous avons commencé par essayer de mieux comprendre l'alignement coronal fémoro-tibial d'une population arthrosique en montrant son importante variation individuelle et ses différences avec une population non arthrosique. Nous avons ensuite détaillé les différentes possibilités d'alignement personnalisé. Le but de l'alignement cinématique (AC) est de restaurer l'anatomie et l'équilibrage du genou pré-arthritique à partir de repères osseux. L'alignement fonctionnel, possible avec assistance robotique, adapte en peropératoire le positionnement des implants prothétiques selon l'anatomie et la laxité ligamentaire constitutionnelles. Nous avons réalisé une revue systématique comparant les résultats après PTG entre AC et AM. L'AC apparaissait comme une technique envisageable et alternative à l'AM. Une nouvelle classification radiologique CPAK d'AC a été décrite considérant l'alignement coronal et l'obliquité de l'interligne après PTG. Nous avons comparé l'alignement coronal obtenu avec cette méthode à des radiographies dynamiques en valgus compensant l'usure cartilagineuse et la laxité ligamentaire. Nous avons trouvé des résultats similaires indiquant que l'AC évalué avec la classification CPAK permettrait d'anticiper l'alignement fonctionnel sur l'espace en extension du genou.

Nous avons comparé les résultats cliniques après PTG en fonction de la restauration ou non des différentes catégories de la classification CPAK. Nous avons trouvé que l'AM ne restaure pas le phénotype du genou dans la majorité des cas. Aussi, nous avons montré moins de douleurs post opératoires lorsque l'interligne après PTG était maintenue par rapport au préopératoire. Enfin, la majorité des études présentant les résultats de PTG avec AC sont réalisées avec des prothèses à conservation du ligament croisé postérieur. Or, nous utilisons une PTG postéro-stabilisée (PS). Nous avons donc comparé les résultats entre AM et AC en utilisant une PTG PS par un système plot-came. Nous avons trouvé un risque augmenté de descellement

tibial aseptique dans le groupe cinématique potentiellement expliqué par des forces de cisaillement exercées sur le plot tibial.

Plusieurs études ont évalué le schéma de marche des patients afin d'obtenir un examen plus objectif sur la récupération fonctionnelle en post opératoire de prothèses de genou. L'objectif était d'évaluer la récupération d'un schéma de marche le plus proche possible de celui d'un genou natif. Nous avons initié une étude prospective randomisée comparant l'analyse de la marche chez des patients opérés de PTG type « medial-pivot » avec AM versus AC. Les objectifs étaient de comparer l'analyse de la marche, les résultats cliniques et radiologiques pour 52 PTG dans chaque groupe à un recul minimum de 12 mois.

Nous avons donc montré que l'AC permettait d'obtenir de bons résultats cliniques et radiologiques. L'AC déterminé à partir de repères osseux semble correspondre à l'alignement fonctionnel en extension. En revanche, l'assistance robotique nous a permis de réaliser que le comportement ligamentaire était différent en flexion et que l'AC ne permettait pas d'obtenir un bon équilibre ligamentaire en flexion dans tous les cas. L'évaluation du schéma de marche après PTG implantées avec assistance robotique selon l'alignement fonctionnel serait intéressante.

Mots clés

Prothèse totale de genou ; alignement mécanique ; alignement cinématique ; alignement personnalisé ; alignement fonctionnel ; analyse de la marche ; KneeKG.

Service de rattachement

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Abstract

Total Knee Arthroplasty (TKA) is a common orthopedic procedure. When performing a TKA, the aim was to achieve a systematic 180° mechanical alignment (MA). This technique results in a straight limb, reducing joint stress and ultimately improving implant survival. Despite technological advances, the results of TKA remain imperfect. Although long-term survival is very good, up to 20% of patients are not satisfied with their prosthesis.

In an attempt to improve these results, new personalized implant alignment proposals have been developed. We started by trying to better understand the coronal femoro-tibial alignment of an osteoarthritic population by showing its important individual variation and its differences with a non-osteoarthritic population. We then detailed the different possibilities of personalized alignment. The goal of kinematic alignment (KA) is to restore the anatomy and soft-tissue balance of the pre-arthritis knee using bony landmarks. Functional alignment, which is only possible with robotic assistance, adapts intraoperatively the positioning of prosthetic implants according to the constitutional anatomy and ligament laxity. We performed a systematic review comparing the results after TKA between KA and MA. KA appeared to be a feasible alternative technique to MA. A new CPAK radiological classification of KA was described considering the coronal alignment and the joint line obliquity following TKA. We compared the coronal alignment obtained with this method to distractive valgus stress radiographs compensating for cartilage wear and ligament laxity. We found similar results indicating that KA assessed with the CPAK classification would anticipate functional alignment for the knee extension space.

We compared clinical outcomes after TKA based on whether the different categories of the CPAK classification were restored. We found that MA does not restore the knee phenotype in most cases. Also, we showed less postoperative pain when the joint line obliquity after TKA was maintained compared to preoperatively. Finally, most studies presenting the results of TKA with KA are performed with prostheses that preserve the posterior cruciate ligament. However, we use a posterior-stabilized (PS) TKA. We therefore compared the results between MA and KA using a PS TKA with a plot-cam system. We found an increased risk of aseptic tibial loosening in the kinematic group potentially explained by shear forces exerted on the tibial plot.

Several studies have assessed patient walking in order to have a more objective examination of the functional recovery after TKA. The aim was to assess recovery by a gait pattern that resembles closely that of a native knee. We initiated a prospective randomized study

comparing gait analysis in medial-pivot TKA patients with MA versus KA. The objectives were to compare the gait analysis, clinical and radiological results for 52 TKRs in each group at a minimum follow-up of 12 months.

Thus, we showed that KA resulted in good clinical and radiological outcomes. The KA determined from bone landmarks seems to correspond to the functional alignment in extension. On the other hand, robotic assistance allowed us to realize that ligament behavior was different in flexion and that KA did not achieve good ligament balancing in flexion in all cases. The evaluation of the gait pattern after TKA implanted with robotic assistance according to the functional alignment would be interesting.

Table des matières

Résumé de thèse	11
Abstract	13
Table des matières	15
Abréviations	17
1. Préambule	19
2. Partie 1 – Introduction générale	21
2.1 La gonarthrose	21
2.2 La prothèse totale de genou	23
2.2.1. Généralités	23
2.2.2. Alignement mécanique « gold standard »	26
2.2.3. Résultats PTG avec un alignement mécanique	27
2.3 Les nouveautés technologiques et idéologiques en arthroplastie du genou	28
2.3.1 Article 1 – Les nouvelles technologies en arthroplastie du genou	28
2.3.2 Article 2 – Description de l’alignement coronal d’une population arthrosique	49
2.3.3. Article 3 – Revue systématique des alignements personnalisés en arthroplastie du genou	63
2.3.4 Article 4 – Revue systématique comparant alignement cinématique et mécanique à un recul minimum de 2 ans	78
2.3.5 Article 5 – L’alignement cinématique correspond à l’alignement fonctionnel sur l’espace en extension: analyse consécutive de 749 genoux en varus à l’aide de radiographie en stress	92
2.4 La marche humaine	106
2.4.1. Définition de la marche.....	106
2.4.2 Le cycle de marche.....	106
2.5 L’analyse de la marche	108
2.5.1 Principe et déroulement de l’examen d’analyse de la marche	108
2.5.2 Analyse de la marche chez un patient présentant une gonarthrose	113
3. Partie 2 – Etudes de recherche clinique	115
3.1 Article 6 – Résultats cliniques après PTG selon la restauration de l’alignement coronal et de l’obliquité de l’interligne	115

3.2 Article 7 – Comparaison des résultats cliniques entre alignement cinématique restreint et alignement mécanique avec une PTG postéro-stabilisée.....	129
3.3 Etude préliminaire afin d'évaluer si l'alignement cinématique permettait d'équilibrer le genou en extension et en flexion.....	141
4. Partie 3 – Protocole de recherche.....	144
4.1 Protocole de l'essai clinique randomisé	144
4.1.1. Type d'étude	144
4.1.2. Hypothèse	144
4.1.3. Critères d'inclusion et d'exclusion	144
4.1.4. Méthodologie.....	145
4.1.5. Comité d'éthique	146
4.2 Avancée du protocole de recherche.....	146
5. Partie 4 - Discussion générale	147
5.1 Evolution de l'alignement dans les PTG	147
5.2 Limitations de ce travail	148
5.2.1 Analyse radiographique	148
5.2.2 Suivi des études.....	149
5.2.3 Retard inclusion protocole de recherche	149
5.3 Conclusions générales	150
6. Références	152
7. Communications orales – Poster.....	175
7.1 Communications orales.....	175
7.2 Posters	179

Abréviations

AC : alignement cinématique
ACL : anterior cruciate ligament
AF : alignement fonctionnel
aHKA : arithmetic HKA
AFM : angle fémoral mécanique
AM : alignement mécanique
ATM : angle tibial mécanique
BMI : body mass index
CAS : computer-assisted surgery
cHKA : constitutional HKA
CPAK : Coronal Plane Alignment of the Knee
CR : conservation du ligament croisé postérieur / cruciate retaining
ECRP : essai contrôlé randomisé prospectif
FJS : forgotten joint score
FMA : femoral mechanical angle
HKA : angle Hip-Knee-Ankle
HKS : hip knee shaft angle
HSS : Hospital for Special Surgery knee score
IKS : International Knee Society score
IMC : indice de masse corporelle
JLCA : joint line convergence angle
JLO : joint line obliquity
JLOA : joint line orientation angle
KA : kinematic alignment
KOOS JR : knee injury and osteoarthritis outcome score junior
KSS : knee society score
LCM : ligament collatéral médial
LDFA : lateral distal femoral angle
LLR : long leg radiographs
LSV : lateral stress valgus angle
MA : mechanical alignment

mFTA : mechanical femorotibial angle
MPTA : medial proximal tibial angle
NA : not applicable
NEU : neutral
NS : not significant
OIA : obliquité de l'interligne articulaire
OKS : Oxford knee score
PRCT : prospective randomized controlled trial
PRISMA : preferred reporting items for systematic reviews and meta-analyses
PS : postéro-stabilisé / posterior-stabilized
PSI : patient-specific instrumentation
PTA : patellar tilt angle
PTG : prothèse totale de genou
PUC : prothèse unicompartmentale
RE : rotation externe
rKA : restricted kinematic angle
ROM : range of motion
SD : standard deviation
TKA : total knee arthroplasty
TMA : tibial mechanical angle
TS : tibial slope
UCLA : University of California at Los Angeles activity score
UKA : unicompartmental arthroplasty
VAL : valgus
VAR : varus
vcHKA : valgus corrected HKA
WOMAC : Western Ontario and McMaster Universities Osteoarthritis index

1. Préambule

La prothèse totale de genou (PTG) est une intervention fiable et très répandue. Aujourd'hui plus de 100 000 PTG sont réalisées en France et ce nombre ne fait qu'augmenter (1). Traditionnellement, au cours des quatre dernières décennies, le meilleur résultat pour une PTG a été observé avec le concept d'alignement mécanique (AM) visant à obtenir un axe de jambe neutre (angle fémoro-tibial mécanique de 180°). Les facteurs de satisfaction d'un patient après PTG sont multiples et complexes. De multiples dessins d'implants et des outils de planification préopératoire et d'assistance opératoire sophistiqués ont été proposés. Certains ont contribué à l'amélioration des résultats cliniques (2,3). Cependant, les résultats décevants, avec jusqu'à 20 % de patients insatisfaits après une PTG AM (4), et une meilleure compréhension de la biomécanique du genou ont suscité des discussions sur des concepts d'alignement alternatifs qui respectent davantage l'anatomie constitutionnelle du patient (5,6).

Les premières études évaluant ces nouveaux objectifs de positionnement semblent encourageantes. En effet des résultats cliniques similaires ont été montrés entre les différents concepts d'alignement avec des scores cliniques peu discriminants (7). Afin d'évaluer ces concepts d'alignement personnalisé, des scores plus pertinents ont été développés et utilisés tels que le Forgotten joint score (8). Cependant l'impact clinique et fonctionnel de l'utilisation de ces nouveaux concepts d'alignement reste incertain. L'une des évaluations possibles et intéressantes concerne l'analyse de la marche. En effet la marche constitue une fonction simple de la vie quotidienne, qui peut être analysée facilement et fournir des données intéressantes sur les résultats cliniques des prothèses de genou selon les différents concepts d'alignement.

L'objectif principal de cette thèse était donc d'investiguer l'évolution de l'alignement dans les prothèses totales de genou et d'évaluer le retentissement clinique d'un alignement personnalisé lors de la pose de prothèses totales de genou, comparé à un alignement mécanique.

L'hypothèse générale était qu'une prothèse totale de genou réalisée selon un alignement personnalisé permettrait d'améliorer les résultats cliniques sans augmenter le risque de complications, ni diminuer la survie de l'implant.

Cette thèse sera partagée en plusieurs parties. Premièrement, nous réaliserons un bref rappel sur l'arthrose du genou, la prothèse totale de genou et les nouvelles technologies et idéologies dans la pose de prothèse de genou, ainsi que sur la marche humaine et l'analyse de la marche. Cette partie présentera les résultats de plusieurs études : une revue sur les nouvelles technologiques, une étude décrivant l'alignement coronal fémoro-tibial d'une population arthrosique et la comparant à une population non arthrosique, une revue systématique sur les différents alignements personnalisés, une revue systématique comparant les résultats cliniques et radiologiques après PTG à 2 ans minimum entre alignement mécanique et cinématique et une étude comparant l'alignement cinématique à des radiographies en stress en valgus à partir de 749 dossiers.

La seconde partie rapportera les résultats de deux études cliniques. Une première étude comparant les résultats cliniques entre restauration ou non de l'alignement coronal et de l'obliquité de l'interligne après PTG. Une deuxième étude comparant les résultats cliniques et radiologiques entre alignement cinématique restreint et mécanique avec une PTG postéro-stabilisée.

La troisième partie portera sur le protocole général de l'étude randomisée, contrôlée initiée.

Et enfin nous conclurons cette thèse avec une discussion plus générale sur les limites de ces travaux et sur des pistes de travaux à venir.

2. Partie 1 – Introduction générale

2.1 La gonarthrose

L'arthrose du genou appelée aussi gonarthrose est la forme d'arthrose la plus fréquente. Elle est trois fois plus fréquente que l'arthrose des hanches. En effet, parmi les personnes âgées de 60 à 70 ans, 20 à 30% souffrent de gonarthrose et au-delà de 80 ans la prévalence est de 40 à 50%.

L'arthrose est l'usure du cartilage présent au niveau des surfaces de glissement. Elle débute en général sur une petite partie de l'articulation puis s'étend avec une vitesse variable à l'ensemble de l'articulation. Avec la disparition du cartilage, les zones osseuses se retrouvent directement en contact, le glissement articulaire devient alors difficile et douloureux. Progressivement l'os se déforme ainsi que l'articulation. Des becs osseux (appelés ostéophytes) apparaissent et contribuent à l'enraidissement douloureux du genou rendant de par ce fait la marche de plus en plus difficile. (*Fig. 1*)

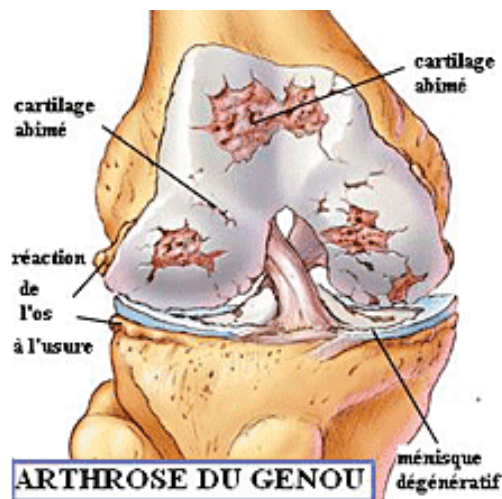


Figure 1 : Schéma de l'arthrose du genou

Il existe une classification radiologique en quatre stades de l'arthrose du genou : la classification de Ahlbäck. (*Figure 2*)

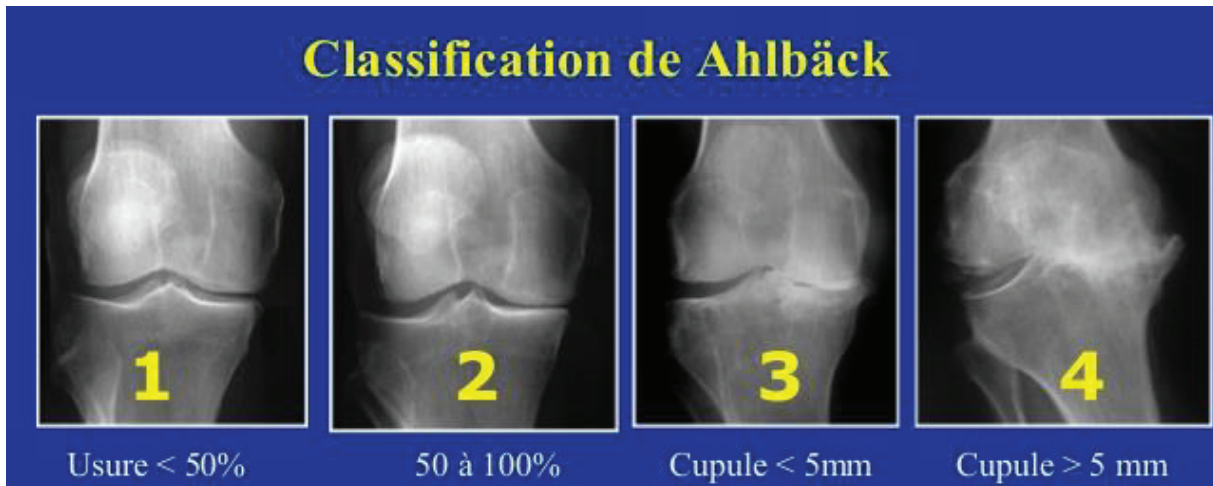


Figure 2 : classification radiologique de la gonarthrose

Le principal symptôme de la gonarthrose est la douleur :

- Type mécanique : s'aggrave au cours d'un effort et se calme au repos
- Vive lors d'une marche prolongée, sur la descente des escaliers ou sur un terrain accidenté

On observe une diminution des amplitudes articulaires et une raideur (flessum). La douleur s'accompagne fréquemment d'une raideur matinale et d'un gonflement du genou, lors des crises d'arthrose. Dans 2/3 des cas, la gonarthrose est bilatérale.

Les facteurs de risque sont :

- Antécédents de traumatisme ou fracture fémoro-tibiale
- Surutilisation chronique du genou, notamment lors d'activités professionnelles nécessitant de porter des charges lourdes ou de s'agenouiller à maintes reprises
- Anomalie du genou : axe des genoux en varus ou valgus
- Surpoids ou obésité

Il n'existe à ce jour pas encore de traitement médical efficace pour guérir de l'arthrose. Seul un traitement symptomatique peut être proposé par des antalgiques et des anti-inflammatoires. De plus, il existe les infiltrations articulaires soit de viscosupplémentation par de l'acide hyaluronique ou une infiltration d'anti inflammatoire locale (Altim) afin de « sécher » le genou en cas d'inflammation lors d'une crise d'arthrose.

En cas de gonarthrose, certains conseils peuvent aider à ralentir la progression de l'usure du cartilage :

- Diminuer l'activité physique en cas de crises (utilisation d'une canne, réduire les activités sportives)
- Perdre quelques kilos
- Pratiquer une activité physique régulière **adaptée** : marche modérée, natation...

Malheureusement lorsque l'arthrose devient trop avancée et que le patient ne supporte plus les douleurs, une chirurgie du genou doit être envisagée. La prise en charge chirurgicale de l'arthrose du genou fait appel, hormis les gestes arthroscopiques et le nettoyage articulaire, à trois types d'intervention : ostéotomies, prothèse unicompartmentale (PUC) et prothèse totale de genou (PTG).

L'analyse complète des antécédents du patient, de ses plaintes fonctionnelles, de ses motivations, associée à l'examen clinique et radiologique systématique, permettent d'éclaircir ce choix.

2.2 La prothèse totale de genou

2.2.1. Généralités

La prothèse totale de genou reste une des interventions les plus pratiquées en chirurgie orthopédique. En effet plus de 100 000 interventions ont été réalisées en 2019, en France. Ceci est expliqué d'une part par un vieillissement de la population et l'accroissement de la durée de vie, d'autre part les besoins fonctionnels accrus des patients même à des âges avancés, enfin l'apparition d'arthrose précoce secondaire soit à un surmenage physique chez des sportifs de haut niveau, soit à la progression de l'obésité au sein de la population générale, augmentant les contraintes articulaires et l'usure cartilagineuse (1).

Le but de la prothèse totale du genou est d'enlever les zones d'os et de cartilage qui sont usées, et de les remplacer par des pièces artificielles ayant les mêmes formes. Ces pièces sont en métal fait de différents alliages (chrome, cobalt, titane...) et sont articulées entre elles par une pièce en polyéthylène.

Une prothèse totale de genou se compose de plusieurs parties afin de remplacer l'articulation fémoro-tibiale et l'articulation fémoro-patellaire, que l'on retrouve toutes assemblées sur la figure 7 :

- Une pièce fémorale métallique est fixée au fémur avec ou sans ciment (*Figure 3*)

- Une pièce tibiale comprenant une quille d'encrage dans le tibia dont la fixation se fait avec ou sans ciment, préférentiellement avec ciment, (*Figure 4*) et une partie en polyéthylène rotatoire ou fixe afin de faire le lien entre les deux pièces de la prothèse. (*Figure 5*)
- Une pièce rotulienne également en polyéthylène dont la fixation osseuse se fait par ciment chirurgical. (*Figure 6*)



Figure 3 : pièce fémorale



Figure 4 : pièce tibiale



Figure 5 : insert polyéthylène



Figure 6 : insert rotulien

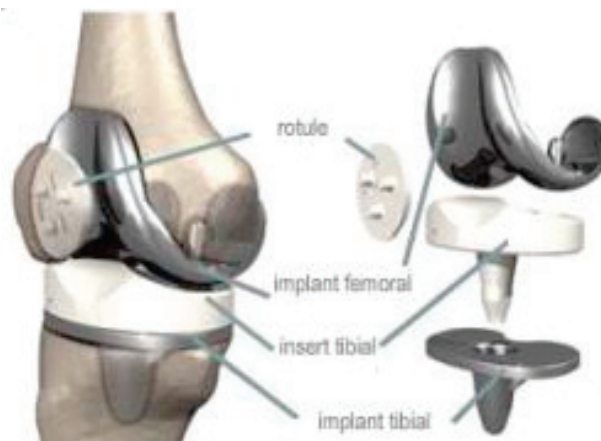


Figure 7 : assemblage des différentes parties d'une prothèse totale de genou

La mise en place d'une prothèse totale de genou doit obéir à deux règles intangibles :

- Les coupes osseuses pour le rétablissement des axes

- L'équilibrage des ligaments, qui est tout aussi crucial. En effet, un défaut peut, s'il est important, avoir des conséquences sur le résultat : instabilité liée à une laxité ou raideur due à la persistance d'une rétraction.

Lors d'une chirurgie de PTG, la prothèse doit pouvoir fonctionner aussi bien en extension qu'en flexion (*Figure 8*). Ainsi, les espaces créés par les coupes osseuses, se doivent d'être identiques en flexion et en extension.

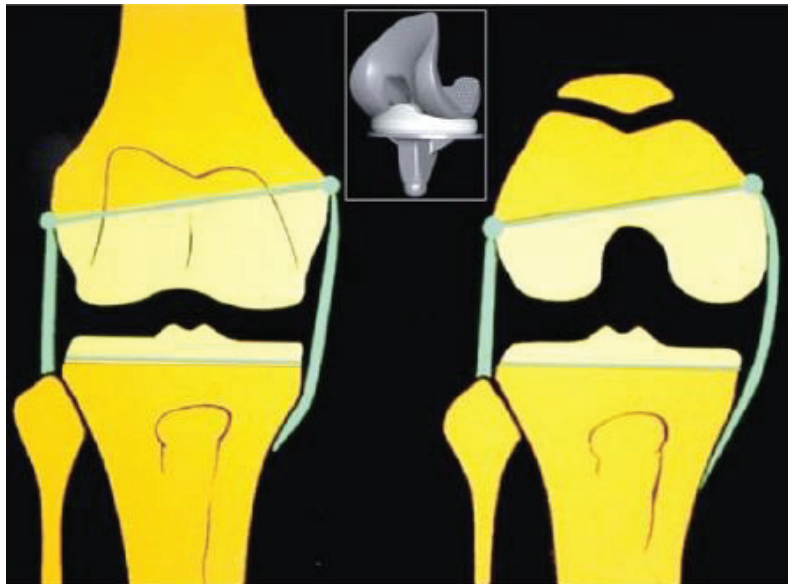


Figure 8 : Coupes osseuses et équilibrage ligamentaire : obtention d'un espace identique en flexion et en extension

Afin de rétablir les axes, plusieurs coupes osseuses sont nécessaires. L'un des défis de la PTG consiste à exécuter des coupes osseuses rigoureuses dans le plan frontal, le plan sagittal et le plan axial pour corriger la déformation sous-jacente. Trois principales coupes sont réalisées : les coupes fémorales distale et postérieure et la coupe proximale du tibia (9) (*Figure 9*).

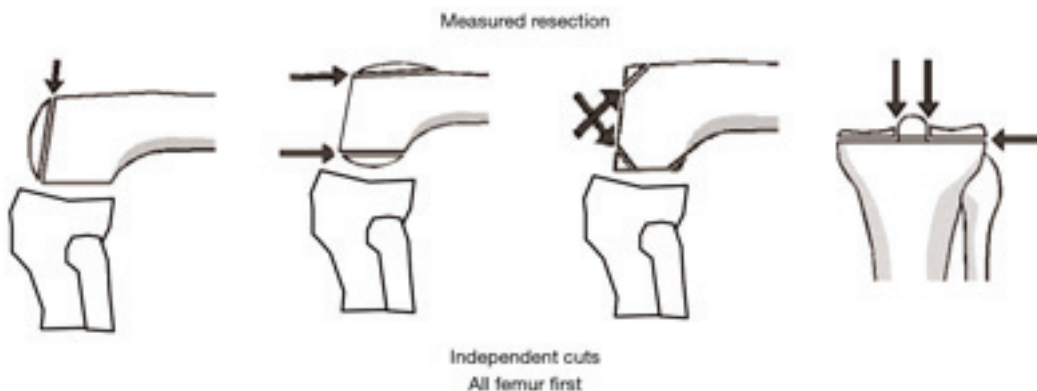


Figure 9 : Coupes osseuses réalisées lors d'une prothèse totale de genou

Le principe des coupes osseuses est de créer un espace correspondant à l'épaisseur de l'implant afin de maintenir le même interligne. L'épaisseur de ces coupes est variable en fonction des implants, de la déformation du membre du patient (en varus pour une usure médiale ou en valgus pour une usure latérale), de ses amplitudes articulaires et de ses éventuels antécédents chirurgicaux sur le genou (déformation post traumatique, chirurgie de réaxation du membre inférieur).

La phase d'équilibrage ligamentaire est essentielle puisqu'elle va conditionner le bon fonctionnement de la prothèse (toute anomalie importante de tension ligamentaire risque de se traduire par une usure accrue du polyéthylène et une instabilité prothétique). Une grande partie de l'équilibrage ligamentaire est donnée par les coupes osseuses. En effet, l'espace créé par les coupes se doit d'être le même en flexion et en extension comme nous l'avons précisé (*Figure 8*). Certains ajustements peuvent être réalisés par un geste de libération des parties molles soit au niveau du compartiment interne par un pie crust du ligament collatéral médial (LCM) voire décollement total du LCM, soit au niveau du compartiment externe par un pie crust du fascia lata. Ces libérations sont assez souvent prédictibles en cas de bonne analyse pré opératoire des radiographies. Elles dépendent de l'importance de la déformation et de son type (varus/valgus). On libère au niveau de la concavité de la déformation, au niveau des rétractations ligamentaires.

2.2.2. Alignement mécanique « gold standard »

L'alignement mécanique, lors de la réalisation de PTG, a été décrit et popularisé en tant que technique de référence « gold standard » par John Insall (10–12). La technique d'AM consiste en une implantation systématisée avec des implants alignés de façon similaire chez tous les patients. L'objectif n'est pas de respecter la physiologie du genou par le biais d'une restauration de son anatomie, mais plutôt de créer un genou artificiel avec un membre rectiligne, ce qui pourrait être avantageux d'un point de vue biomécanique (11,12). Cette technique comporte des coupes osseuses frontales perpendiculaires à l'axe mécanique des deux os longs, une rotation du composant fémoral parallèle à l'axe trans-épicondylien, une pente tibiale postérieure fixe, et d'éventuels gestes de détente ligamentaire pour équilibrer les espaces ainsi créés en extension et en flexion (10). Cela permet d'obtenir un angle Hip-Knee-Ankle (HKA) du membre de 180° considéré comme neutre dans des conditions statiques de mise en charge. Il s'agit d'un principe fondamental de la PTG, qui vise à obtenir une distribution symétrique équilibrée de la charge entre les compartiments médial et latéral afin de minimiser l'usure et le

descellement potentiel des implants (13–17). Cette technique systématique permettait d’obtenir une meilleure reproductibilité.

2.2.3. Résultats PTG avec un alignement mécanique

Malgré une excellente durée de vie des implants (1,18), des résultats cliniques acceptables et une majorité de patients satisfaits de leur PTG (4,19), nul ne doute qu’il persiste une importante marge d’amélioration des performances fonctionnelles des PTG AM. En effet, 15 à 20% des patients ne sont pas satisfaits de leur PTG (4,19) et 50% des patients rapportent des symptômes résiduels (4). Ces limitations deviennent évidentes lorsqu’on les compare aux performances fonctionnelles du remplacement prothétique de la hanche (19). Au cours des dernières décennies, la communauté chirurgicale et l’industrie orthopédique ont conjointement cherché à remédier à ce problème : d’une part par la commercialisation d’implants au dessin permettant de rendre la cinématique prothétique plus physiologique et selon le sexe (20–29), et par la mise au point d’outils technologiques de planification et d’assistance à la mise en place de prothèses (navigation, robotique, instrumentation personnalisée) sensés améliorer l’exécution de l’acte (3). Néanmoins, les avancées technologiques n’ont pas permis d’améliorer significativement les résultats cliniques (30–33).

La figure 10 illustre un cas de PTG bilatérale avec alignement mécanique.

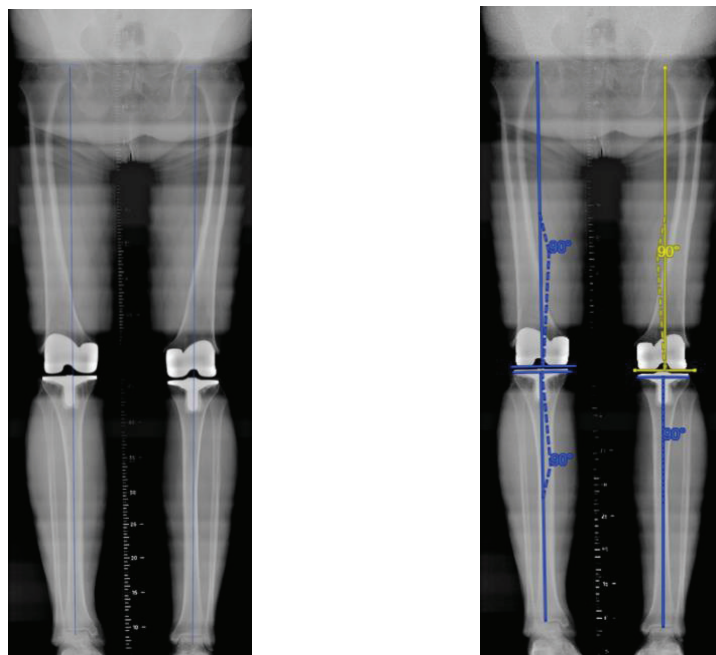


Figure 10 : Cas de PTG bilatérale avec alignement mécanique, implants positionnés à 90°

2.3 Les nouveautés technologiques et idéologiques en arthroplastie du genou

Afin de tenter d'améliorer les résultats des prothèses de genou, différentes technologies récentes ont été développées permettant d'améliorer la précision et la reproductibilité lors de la pose de prothèses de genou. Ces technologies comprennent entre autres la navigation, les guides de coupes sur mesure, les implants sur mesures, les ortho sensors et la chirurgie assistée par robot.

2.3.1 Article 1 – Les nouvelles technologies en arthroplastie du genou

Ce travail a abouti à une publication dans le *Journal of Clinical Medicine (JCM)*.



Review

New Technologies in Knee Arthroplasty: Current Concepts

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Résumé en français

La prothèse totale du genou (PTG) est un traitement efficace de l'arthrose sévère. Malgré de bons taux de survie, jusqu'à 20 % des patients ayant subi une PTG restent insatisfaits. Récemment, de nouvelles technologies prometteuses ont été développées pour l'arthroplastie du genou et pourraient améliorer les résultats fonctionnels. L'objectif de cet article est de présenter quelques nouvelles technologies dans la PTG, leurs concepts actuels, leurs avantages et leurs limites. Les instruments spécifiques au patient peuvent permettre d'améliorer le positionnement de l'implant et l'alignement du membre, mais aucune différence n'est constatée au niveau des résultats fonctionnels. Les implants personnalisés sont conçus pour reproduire l'anatomie native du genou et pour reproduire sa biomécanique. Les capteurs doivent viser à fournir des données objectives sur l'équilibrage des ligaments pendant la PTG. Peu d'études sont publiées sur les résultats à moyen terme de ces deux dispositifs actuellement. Les accéléromètres sont des outils intelligents développés pour améliorer l'alignement des PTG. Leurs avantages restent encore controversés. L'assistance robotique permet une préparation osseuse précise et reproductible grâce à l'interface robotique, avec une planification chirurgicale en 3D, basée sur une imagerie 3D préopératoire ou non. Ce système prometteur conserve néanmoins certaines limites. Les nouvelles technologies dans la PTG sont très attrayantes et ont constamment évolué. Néanmoins, certaines limites persistent, et pourraient être améliorées par l'intelligence artificielle et la modélisation prédictive.

Abstract

Total knee arthroplasty (TKA) is an effective treatment for severe osteoarthritis. Despite good survival rates, up to 20% of TKA patients remain dissatisfied. Recently, promising new technologies have been developed in knee arthroplasty, and could improve the functional outcomes. The aim of this paper was to present some new technologies in TKA, their current concepts, their advantages and limitations. The patient-specific instrumentations can allow an improvement of implant positioning and limb alignment, but no difference is found for functional outcomes. The customized implants are conceived to reproduce the native knee anatomy and to reproduce its biomechanics. The sensors have to aim to give objective data on ligaments balancing during TKA. Few studies are published on the results at mid-term of these two devices currently. The accelerometers are smart tools developed to improve the TKA alignment. Their benefits remain yet controversial. The robotic-assisted systems allow an accurate and reproducible bone preparation due to a robotic interface, with a 3D surgical planning, based on preoperative 3D imaging or not. This promising system conserve nevertheless some limits. The new technologies in TKA are very attractive and have constantly evolved. Nevertheless, some limitations persist, and could be improved by artificial intelligence and predictive modelling.

Introduction

Orthopaedic surgery is one of the most dynamic medical specialties, with rapid and innovative advances in treatment and surgery. Recently, promising new technologies have been developed in knee arthroplasty.

Total knee arthroplasty (TKA) is a very effective treatment for severe osteoarthritis. TKA leads to good results in returning to daily activities, good survival rates, and overall functional improvement. Satisfying the functional expectations of patients undergoing TKA remains an important surgical goal. Despite advances in surgical technique and postoperative management over the years, up to 20% of TKA patients remain dissatisfied (34). In a multicentre series of 347 non-selected TKA patients using various implants, only 62% of the patients were totally pain free during gait, 35% were pain free whilst climbing or descending stairs, and 40% complained of pain whilst running (35). Only 48% of the patients declared

being “very satisfied” with the procedure, and 68% considered their operated knee to be “normal for their age”.

Therefore, although TKA is already an effective surgery, the aim is now to further improve patient satisfaction and functional outcomes. Different types of new technologies have been developed to improve surgical accuracy, and as a result, the hope is that there will be improvement in patient satisfaction after TKA. Technologies such as patient specific instrumentation (PSI), navigation, smart tools, computer or robotic-assisted surgery (CAS) aim to individualize the surgery and account for the anatomy and ligament balancing of each patient, to improve the accuracy of the surgical planning in three dimensions (3D), to increase alignment accuracy and reliability, and improve implant positioning. However, new technologies often have limitations and some disadvantages, and so, knowledge of how to appropriately use these new technologies to improve surgical outcomes is critical.

The aim of this paper was to present some new technologies in TKA, their current concepts, their advantages and limitations and open a discussion for future use and development.

Patient Specific Instrumentation

General concepts

Currently, several orthopaedic implant manufacturers offer PSI systems (Smith & Nephew, Wright Medical Technology, DePuy, Biomet, Medacta, and Zimmer). These systems can be used for total knee arthroplasty or for unicompartmental knee arthroplasty. Preoperative 3D imaging (CT scan or MRI) is used to model the knee anatomy and design a personalized surgical plan with respect to bone resection and component positioning and alignment. Once the surgeon approves the plan, cutting blocks or pin guides are rendered and shipped to the hospital, usually in sterile packaging acceptable for the operating room. Pin guides sit on the anterior aspects of the distal femur and proximal tibia to set the placement of pins into the femur and tibia. Whereas custom cutting guides are pinned directly into place and contain cutting slots through which a standard saw is used (Fig. I.1). These personalized cutting guides allow bone resections to be accurately cut according to preoperative 3D planning.

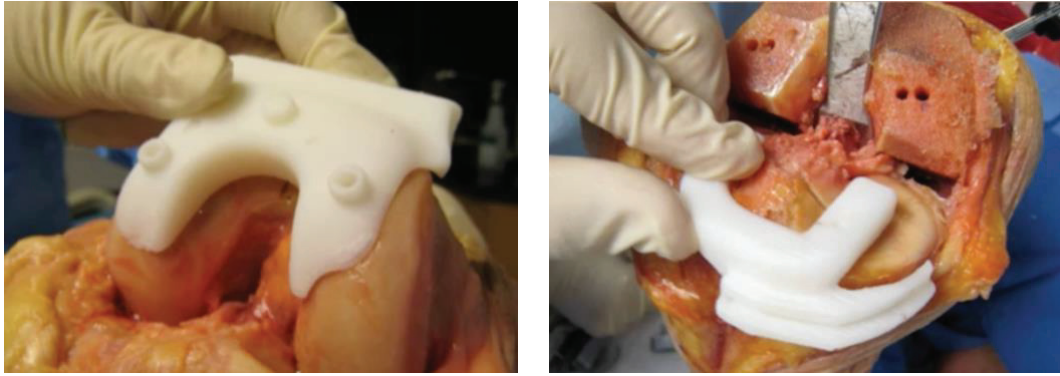


Figure I-1: In the patient-specific instrumentation, the personalized cutting guides can be pinned directly into place in the femur and the tibia and contain cutting slots for a saw.

Results

There are published studies that reported greater accuracy of implant positioning with PSI, however, in different meta-analyses, the benefits of PSI on the radiologic results are not clear (36). Ng et al. reviewed 569 TKAs performed with PSI and 155 with conventional technique using postoperative long-leg radiographs and found significantly less HKA angle outliers ($\pm 3^\circ$) with PSI than with conventional instrumentation, 9% and 22 % respectively (37). Two meta-analyses investigated the accuracy of alignment. Jiang et al. compiled 18 studies with 2417 patients, demonstrating no significant difference in the number of outliers in mechanical axis as well as coronal, sagittal, and axial alignment (38). However, Mannan et al., noted favorable femoral rotational outcomes in a meta-analysis of 6 studies on a total of 444 knees (39). Randelli et al., in a randomized controlled trial on 69 patients reported that PSI did not improve the accuracy of femoral component rotation in TKA in comparison to conventional instrumentation (40). Other studies described even an unacceptable accuracy with patient-specific cutting block for TKA (31,32).

No study has demonstrated any difference on the clinical or functional outcomes according to the technique (PSI or conventional) (41–44). Abdel et al. performed a gait analysis on 40 patients randomized to conventional TKA or PSI and reported no difference in functional or gait parameters after 3 months (41).

Theoretically, the use of PSI should reduce the surgical time, because the operative planning is performed preoperatively, including implant sizing, rotation, femoral and tibial resection. But a recent meta-analysis by Voleti et al. looking at nine studies and 957 patients found a non-statistically significant trend of decreased operative times with a mean of just 5

min per patient (45). It would be interesting and more relevant to compare surgical time between different new technologies, such as PSI versus CAS.

Advantages and Limitations

The goal of PSI is to plan an accurate cutting guide from 3D imaging and thus aim to improve implant positioning. Frye et al. concluded that an MRI-generated template is better than CT-based guides (46). MRI is able to account for residual articular cartilage; therefore, the cutting guide can cover a broad contact area and can be directly placed on bone and residual cartilage of knee joint. CT is unable to account for residual cartilage; the corresponding cutting guide has to rely on multiple bony sites. The use of a preoperative 3D imaging can facilitate the “mini-invasive” surgery, with a limited exposure. And there is no violation of intramedullary canals, with decreased risk of fat embolus and blood loss. PSI can also potentially increase surgical efficiency by reducing operative time and cost compared to robotic-assisted surgery. By contrast, PSI systems do not aid in the performing of gap balancing or soft tissue releases. These steps, which are crucial to surgical success, are performed as usual by the surgeon. Tibial component rotation and implant fixation, as well as patellar preparation, also remain the responsibility of the surgeon.

To complete the benefit of an accurate cutting guide, some authors have associated this technology with another, such as the use of sensors.

Individual knee arthroplasty implant

General concepts

Nowadays, surgeons can choose components from a wide range of sizes, including standard width and narrow and sometimes asymmetrical tibia components. However, anatomic variations are not limited to large or narrow, but also include several other features, such as the trapezoidicity of the distal femur, the condylar radii of curvature, joint-line obliquity and the shape of the trochlea and tibial plateau.

A customized individually made implant device is conceived and designed to reproduce the native (pre-arthritis) anatomy of the knee, using single-use customized instrumentation. Customized implants have been slowly adopted in operating theaters since their introduction

around 2011. The main aims are to optimize bone implant fit and avoid prosthetic overhang or under-coverage, to improve ligament balancing by avoiding resection laxity, to improve mid-flexion stability and kinematics by restoring the native radii of curvature, to improve patellofemoral tracking by restoring the native femoral torsion and customized trochlea, and to facilitate restoration of the native limb alignment.

The design and manufacturing process of the custom TKA takes 6-8 weeks and requires cooperation between the surgeon and engineers. A 3D model, which is made by converting a series of 2D scanned images of the knee joint, is used to fabricate a customized implant and instrumentation by using additive manufacturing/3D printing technologies. Operative planning and the implant design are always validated by the surgeon. The surgery is performed with personalized cutting blocks for the femur and the tibia. All surgical parameters such as implant size and positioning and limb alignment are decided preoperatively.

The customized implants are frequently compared with the “off-the-shelf” implants, which are fabricated in a range of standard sizes. Surgery performed using “off -the-shelf” aims match the most appropriate implants for each patient and to aim for good functional results with lower cost.

Results

Currently, few studies have reported the results of customized implants for TKA. Interesting results have been described on implant positioning and limb alignment (47–50). In a cohort of 258 custom TKAs, Bonnin et al. have reported that 84% of TKA had satisfactory mechanical femoro-tibial axis (HKA), mechanical femoral axis (FMA) and mechanical tibial axis (TMA) (47). Deviation between the planned and postoperative angles were $-0.5^{\circ} \pm 1.8^{\circ}$ for FMA, $-0.5^{\circ} \pm 1.8^{\circ}$ for TMA, and $-1.1^{\circ} \pm 2.1^{\circ}$ for HKA angle. Arbab et al. described, in a case controlled study, that patient-specific TKA demonstrated fewer outliers from neutral coronal leg alignment compared to conventional technique (16% in the patient-specific TKA cohort and 26% in the conventional TKA group) (48).

Very few studies have reported clinical outcomes after custom implants. Reimann et al described that the patient-specific implants might increase patient satisfaction at 2 years (51). Schwarzkopf et al. and White et al., found no significant difference in clinical outcomes, with only a tendency to decreased range of motion (52,53). More studies are needed to assess the functional outcomes after patient-specific implants.

Advantages and Limitations

This technology is based on the theory that many unsatisfactory outcomes or residual pain after TKA can be attributed to a lack of anatomic restoration that can be difficult to identify by clinical examination. Chronic pain, stiffness or laxity can be secondary to incorrect sizing or malrotation of the femoral implant (20,54). A customized implant is thus designed to reproduce the native anatomy. Customization of the bone cuts and implants also allows engineers to minimize, as much as possible, the thickness and weight of the implants and the quantity of bone resection. Ligament balancing also seems to be simpler for the surgeon when using customized implants, particularly at mid-flexion, due to the conservation of the condylar curvature radii.

Nevertheless, the use of customized implants does not take into account ligament balancing, and so ligament balancing remains depend on the surgeon's intraoperative assessment. Bonnin et al. described 46% of tibial bone recuts in 258 custom TKAs (47). Moreover, the preoperative planning is performed using imaging of an arthritic knee to restore a knee to pre-arthritic function. In knees with severe deformity or advanced stage osteoarthritis, the final outcome could still be unsatisfactory with no guarantee of superior results.

Sensors in TKA

General concepts

The current advances in knee arthroplasty result in improved accuracy in implant positioning, limb alignment, implants sizing, and reduced soft tissue damage. However, one of the remaining challenges in achieving a satisfactory TKA is ligament balancing. Ligament balancing is essential during TKA and especially difficult to assess and to manage. Experienced surgeons traditionally obtain soft tissue balance using their own subjective "feeling" rather than a scientific perspective (55–58). The ligament balancing "feeling" is affected by many factors such as patient obesity, gender, generalized laxity, degree of joint contracture, surgical experience and even the surgeon's daily condition (59,60). Poor ligament balancing can cause instability, stiffness, pain and TKA revision or patient dissatisfaction (61). For example, TKA revision for instability has been estimated as greater than 20% each year (62).

New technologies can assess ligament balancing, such as a robotic-assisted system which can register the preoperative laxity and compare this to the planning of the TKA. Navigation also takes into account preoperative laxity and its evolution after the bone resections are made and the implants are positioned. Nevertheless, for each case (robotic or navigation), the laxity assessment at the beginning of the surgery is manual. The surgeon exerts a significant varus and valgus force on the knee. This assessment is dependent on the strength of the surgeon, on the depth of anesthesia, and the BMI or the physical stature of the patient. The ligament balancing utilizing these advanced technologies is not entirely objective and remains challenging and dependent upon the surgeon's experience of with the system. The PSI, the customized implants and the accelerometers are useful tools to determine the bone cut axis and implant positioning, but are completely independent of the ligament balancing.

The purpose of sensors is to give objective data on soft tissue balancing during TKA. These disposable devices deliver wireless data to an intra-operative monitor to facilitate informed decision-making regarding implant position and soft tissue releases to improve balance and stability through a full range of motion. Different manufacturers produce this device, but it is mainly VERASENSE Knee System (OrthoSensor Inc., Dania Beach, FL). This system is a wireless and disposable articular loading quantification device, which is inserted in the tibial component tray during the surgery, after the tibial and femoral cuts are completed (Fig. I.2). The capsule is closed by few stitches. The surgeon holds the leg in a neutral position and monitors the medial and lateral loading forces from full extension to full flexion. Less than differential loading of 15 pounds between the medial and lateral compartments, is considered as adequately "balanced" (63). After initial ligament balance assessment, if the joint shows imbalance, additional soft tissue releases or bony resection can be performed.



Figure I-2: The sensor is an articular loading quantification device, which is inserted in the tibial component tray during the surgery, after the tibial and femoral cuts are completed (Orthosensor, Verasense).

Results

Several studies have described and assessed the results and the consequences of the sensors on ligament balancing of a TKA. Cho et al. have found that an objective quantification using real-time orthosensor improved the soft tissue balance in TKA (for measured resection TKA or modified gap balancing TKA) (64). In a prospective cohort of 50 sensor-assisted TKAs (without severe deformity), Song et al. reported that 74% of knees needed an additional rebalancing procedure with the sensor, after conventional gap balancing with the tensiometer (65). There were coronal and sagittal load imbalances in the evaluation using the sensor, even after the achievement of an appropriate gap balance using the tensiometer. However, few studies have reported an improvement of the functional outcomes after sensor-assisted TKA compared to conventional TKA, and several limits are often present. Chow and Breslauer reported that the clinical scores and range of motion (ROM) were significantly higher after sensor-assisted TKA than after manually balanced TKA, but without preoperative radiographic evaluation (66). Geller et al. reported that the use of the sensor significantly reduced the rate of arthrofibrosis (67). Song et al., in a comparative study of 50 sensor-assisted TKAs, described no clinical and radiological difference between TKA with or without using a sensor system (68). The clinical follow-up remains too short to assess the clinical benefit of this device.

Advantages and Limitations

Apart from the cost, the principal limitation in the assessment of the sensors is that the normal range of joint compartment pressures is not well understood. What are the pressure values in a well-balanced TKA? Several studies have demonstrated that soft tissue imbalance is a major cause of dissatisfaction, and the subjective assessment of surgeons is insufficient to ensure an appropriate soft tissue balancing (69,70). Indeed, some systems can produce an equal and rectangular extension and flexion gaps, such as tensiometers or navigation systems (71,72). However, no study has demonstrated a significant improvement of patient satisfaction after TKA with these devices (73–75). Nagai et al. reported that the medial compartment was always stiffer than the lateral structure at all flexion angles from 0° to 135° (76). Nevertheless, the appropriate loads are defined mainly with arbitrary limits. Meneghini et al. reported that the Knee Society Objective Score remained favorable under high medial compartment loads (> 75 lbs; > 34.0 kg) but decreased significantly under high lateral compartment loads (> 75 lbs; >

34.0 kg) (77). The “normal” values remain extended, and a personalized adaptation is probably required for each patient.

Accelerometer

General concepts of an accelerometer

Accelerometers are smart tools developed to improve the alignment of femoral and tibial components in TKA. Proper component alignment is important to improve the likelihood of functional restoration, patient satisfaction, and TKA survivorship (78,79). Currently, the ideal alignment in TKA remains controversial. New or “modern” concepts about the alignment are a current question in the improvement of the TKA outcomes. Nevertheless, despite the type of alignment (mechanical, kinematic, restricted kinematic), the accuracy of the tibial and femoral cuts remains important. This is especially important for kinematic alignment, because an error of 3° in the component alignment has serious consequences when the targeted alignment is already in varus or valgus. That is why these tools are useful particularly during surgeries with individualized component alignment. In a previous study, the recommended alignment in the coronal plane (within 3° of a neutral mechanical axis) was achieved in only 70-80% of patients undergoing conventional TKA using extra and intramedullary guides (80). Computer assisted surgery or navigation has been developed to improve the component positioning and alignment (81–83).

Accelerometer-based navigation is a portable surgical navigation system that does not use a large computer console for TKA (Fig. I.3). The first validation study about this system was in 2011 (cadaveric study) (84). Accelerometer-based navigation is a handheld, sterile device used within the operative field to determine the hip center of rotation and the femoral mechanical axis, which are used to determine the resection planes of the distal femur and the proximal tibia (85). These systems are wireless and imageless, and they capture data during the procedure, and directly display the data on pods, which are attached to the femoral and tibial resection guides within the surgical field. These systems guide resection angles in the coronal and sagittal planes and confirm alignment accuracy of the femoral and tibial components after resection.



Figure I-3: The accelerometer is a handheld device used within the operative field to determine the resection planes of the proximal tibia. This system guides resection angles in the coronal and sagittal planes (Perseus, Orthokey).

Results of accelerometers

Budhiparama et al. has described the results of the main studies about accelerometers in a systematic review (86). Five of nine studies favored accelerometer-based navigation for the restoration of HKA (87–91), while four of nine studies found no differences between the study groups (92–95). In terms of coronal-axis alignment of the femoral component, seven of nine studies favored accelerometer-based navigation (87–91,95). There was no significant difference in sagittal alignment.

Only two of six studies that evaluated the proportion of patients with outlier alignments supported accelerometer-based navigation (90,91); the other four found no differences in this important endpoint (87,88,93,94). Li et al. have reported similar results in a meta-analysis on 275 total knee arthroplasties performed with the iASSIST navigation system (96). This system provided significantly increased accuracy in the coronal femoral angle ($p < 0.00001$) and the coronal tibial angle ($p < 0.00001$) compared with conventional techniques. There was no

significant difference in functional knee score at short term follow-up in the iASSIST group compared with the conventional group (96). No studies have demonstrated better clinical outcomes with accelerometer-based navigation compared with conventional technique TKA (86).

Most studies did not describe longer surgical times with the accelerometer-based navigation compared with conventional techniques (87,88,90,94,95). No learning curve has been assessed in the literature, likely because this is only a tool and not a complete navigation system. There were no differences concerning the complication rate between these two techniques. No reoperations or revisions have been described following the use of accelerometer-based navigation.

Advantages and Limitations

Budhiparama et al. reported that they “found very inconsistent (and generally small) benefits in favor of accelerometer-based navigation in terms of alignment, but no benefits regarding the functional outcomes or the risk of complications or reoperations. Until or unless more compelling evidence in favor of the new technology emerges, they recommend against its widespread adoption.” (86)

The real benefit of this accelerometer-based navigation is difficult to prove, because the aim is to decrease the alignment outliers. The consequences on the functional outcomes is thus less clear (88). It is used as an adjunct tool during TKA and the clinical follow-up of these studies is very short. The assessment of the long-term revision rate according to the surgical technique is not currently possible, and there are very few high level of evidence studies assessing this accelerometer-based navigation.

This system has limitations. The axis of the bone cut is dependent on the reference points chosen on the patient. Thus, if the knee center is incorrect by some millimeters, the mechanical axis will be incorrect by some degrees. The accuracy of the references is very important and dependent on surgeon precision. Moreover, this system assists only in component alignment, and does not assist with component sizing, component rotation, ligament balancing or even for the target alignment. It can be considered simply as a tool to improve bone cut accuracy compared to extra or intramedullary guide techniques.

Several advantages have been described regarding smart tools in TKA. Conventional CAS systems with large console computers are criticized because they seem to increase

operative time and cost, are associated with a long learning curve (79,97), have sensitive optical instruments (98), and do not report an improvement in component survival. The accelerometer-based navigation appears as a simpler and potentially less expensive alternative. Moreover, it can be used with almost all TKA. Indeed, it is not dependent on particular types of implants.

Currently the accelerometer-based navigation is an interesting system for complex cases with extra articular deformities (post traumatic or developmental). Several studies described difficult cases with severe deformities and the impossibility of using an intramedullary guide (99,100). The accelerometer-based navigation is a simple tool to facilitate a TKA with extra-articular deformity.

Robotic-assisted Knee Arthroplasty

The prevalence of robotic-assisted surgery is a natural evolution from computer-assisted surgery, which has been used for knee arthroplasties for over 20 years. The main benefit offered by robotics is accurate and reproducible bone preparation due to a robotic interface, whatever system is used (101,102). This robotic-assisted system also allows an assessment of the ligament balancing according to the bone cuts and the implant positioning during the surgery. This ligament balancing is usually related to the valgus or varus stress given by the surgeon. The aim of robotic systems is not to replace the surgeon, but to improve their performance.

General principles

Image-guided Versus Image-free surgical planning

Current robotic systems require the creation of a 3D plan based either an intraoperative bone morphology mapping, or a preoperative CT scan. Preoperative CT imaging includes some slices on the ankle and the hip, as well as the knee, to determine the 3D mechanical femorotibial axis. A 3D reconstruction is created to template component size and positioning (103). The surgical planning is completed preoperatively. During surgery, the robotic arm assists in performing very accurate bone cuts according to the surgical plan. The disadvantages include the cost of the preoperative imaging study, the patient inconvenience to obtain the study at certified centers, and the radiation exposure (103–105).

Alternatively, image-free robotic-assisted systems need an intraoperative registration of the anatomical surfaces by a manual bone surface mapping. A 3D virtual model is then created, and the planning is performed during surgery. Preoperative 3D imaging is unnecessary and no specific planning is performed preoperatively. Thus, the intraoperative registration relies on the surgeon's precision of inputting the correct data points, which is subject to human error.

Autonomous, semiautonomous, and passive robotic systems

Three categories of robotic systems for knee arthroplasties exist: passive, semiautonomous and autonomous robotic systems. A passive system provides a 3D virtual model, which allows an accurate preoperative planning. But there is no system to prepare the bone. The autonomous and semiautonomous systems incorporate safeguards against removal of bone beyond the 3D plan (Fig. I.4).

The passive systems are a computer-assisted or navigation system and perform accurate surgical planning and can guide the tools positioning, but the bone removal is performed only by the surgeon.

With the autonomous robotic-assisted system, the surgeon performs the surgical plan (bone resections, implants positioning and sizing), the initial approach and the knee exposure. Then the robotic system has the capability of completing the remaining surgery without surgeon input. Nevertheless, the surgeon can control an emergency switch to stop the procedure or to adjust the plan. CASPAR (Ortho-Maquet/URS, Schwerin, Germany) and ROBODOC (Curexo Technology Corporation, Fremont, CA) are autonomous robotic systems, based on preoperative CT imaging.

The semiautonomous robotic-assisted systems combine the benefits of a navigation system and of an autonomous robotic system. The surgical planning is performed by the surgeon, either based on preoperative 3D imaging or on intraoperative bone surface mapping. Semiautonomous robots are controlled and manipulated by the surgeon. But the surgeon's control is modulated by the robot to limit bone preparation to the surgical plan. Thanks to a feedback loop, the bone removal is controlled (with a saw or a burr), or the cutting guide is positioned. The surgeon cannot deviate from the planned bone resection. This control improves the surgeon accuracy and decreases the risk of errors. These systems include the image-free robotic Navio system (Smith & Nephew, Memphis, TN, USA), the image-based MAKO robotic arm (Stryker, Mahwah, NJ, USA), the ROSA knee system (Zimmer Biomet, Warsaw, USA) and OMNIBOT (OMNIlife Science, Inc.; Raynham, MA).



Figure I-4: The autonomous and semiautonomous robotic systems incorporate safeguards against removal of bone beyond the 3D plan. The first three robotic systems are autonomous (Robodoc, Caspar). The last three robotic systems are semiautonomous (Mako, Navio, Rosa).

Ligament balancing

Ligament balancing during knee arthroplasty is critical to obtain good functional outcomes and maintain normal knee kinematics. These systems can register the ligament balance or imbalance before the intervention, the planned ligament balancing and the balance at the end of the procedure. During all of the steps of the surgery, the surgeon can assess the ligament balancing can make adjustments. Depending on the robotic-assisted system, the ligament balancing can be assessed in extension and knee flexion at 90°, or during all range of motion. Current robotic systems incorporate soft tissue balancing algorithms in their planning and procedures for unicompartmental knee arthroplasty (UKA) and TKA. This system is very helpful, particularly for mid-flexion balancing, which is very difficult to assess during conventional surgery. Nevertheless, the assessment of the ligament balancing is always manual. The robotic system registers only the varus and valgus stress exerted by the surgeon. These values are not entirely objective and again depend on the surgeon and multiple patient and intraoperative factors.

Results

UKA

With image-based and image-free robotic-assisted systems, the results and particularly the positioning of the implants have been significantly improved (81,106–110). Herry et al. have shown that the joint line level was very well controlled with the robotic system (110). Ponzio and Lonner have also reported that aggressive tibial resection is less frequent during robotic-assisted UKA (111). In the literature, the mean implant positioning is not always significantly improved with robotic-assisted UKA. But, the reduction of outliers is significant (81,106) and thus relevant to the reduction of failure. Several meta analyses and systematic reviews reported similar results (102,112). Studies have also suggested that a robotic-assisted system leads to improved ligament balancing (113), decreased post-operative pain (114), faster return to work (115) and to sport (116), and to better functional scores (114).

Studies on robotic-assisted UKA report satisfying short and medium-term survival rates (117,118). Nevertheless, no comparative study has demonstrated a better survival rate for robotic assisted UKA, compared to conventional UKA. Published rates of revision after robotic assisted UKA vary from 3% to 10% at mid-term (119–121).

By contrast, there is less evidence for improvement in functional outcomes after robotic-assisted UKA compared with conventional technique (117). Gilmour et al. reported that more active patients may benefit from image-based robotic-assisted surgery (117).

TKA Results

There are very few studies on robotic-assisted TKA. These studies are essentially preliminary studies without a comparative group or long-term follow up (101).

Only the autonomous robotic-assisted system currently has long follow-up. Using the Robodoc and a minimum follow-up of 10 years, Kim et al. found no differences between robotic-assisted TKA and conventional TKA in terms of functional outcome scores, aseptic loosening, overall survivorship, and complications (122).

Image-based robotic-arm assisted TKA (Mako system) improved accuracy in achieving the planned implant position compared to conventional TKA (123,124). Kayani et al. reported that the image-based robotic system improved the accuracy of femoral sagittal and coronal

alignment, tibial sagittal and coronal alignment, tibial slope and limb alignment, and joint line restoration, compared to a conventional technique (123). The rate of early complications was not significantly different between robotic assisted TKA and conventional TKA (125,126).

Kayani et al. reported that image-based robotic-assisted TKA was associated with reduced bone and periarticular soft tissue injury compared with conventional TKA (127). Several case-controlled studies assessed the short-term functional postoperative scores, with a maximum follow-up of 17 months, between robotic assisted and conventional TKA, with inconclusive results (128–131). More investigations at mid and long-term are necessary for the semiautonomous robotic-assisted system.

Recent developments

Patellofemoral arthroplasty

There are different considerations when performing a patellofemoral arthroplasty. However, it is probably one of the best indications for robotic surgery since the ideal position can only be obtained through accurate mapping of the 3D anatomy of the distal femur. The 3D planning stage is now much easier thanks to the robotic surgical system which produces a 3D model of the trochlea and records landmark points (medial and lateral epicondyle points, Whiteside's Line, femoral mechanical axis and mechanical femoral valgus). It displays a 3D simulation of the trochlear component placement and guarantees a perfect transition area between the femoral component and femoral condyle cartilage prior to the bone cut. The preparation stage is made easier thanks to the controlled bone removal using a robotic handpiece that removes the residual cartilage and subchondral bone in line with the planning, obtaining a more consistent outcome than standard tools.

Very few studies described results of robotic assisted patellofemoral prostheses, and these studies are not comparative. The first series reported satisfying functional scores and good implant positioning (132).

Bicruciate-retaining arthroplasty

There is a long history of bicruciate-retaining total knee replacements with promising long-term results but a reputation as a technically demanding procedure. Robotics have

provided considerable assistance for surgeons undertaking this type of arthroplasty, which requires a meticulous understanding of the difference in joint space between the lateral and medial compartments, as well as highly accurate bone preparation. Protecting the tibial spines is also much easier when using a bur guided by a robotic handpiece.

Combined UKA and anterior cruciate ligament (ACL) reconstruction

ACL reconstruction combined with unicompartmental knee arthroplasty is a tempting solution for anyone keen on unicompartmental procedures. The robotic system ensures accurate implant positioning (with tibial slope and overall alignment control in particular) but also allows the surgeon to visualize any residual gap before and after implant fixation. Both implant position and the polyethylene thickness can be adjusted based on the dynamic data provided by the robotic system.

Bicompartmental arthroplasty

In some cases, if the patient is young and active with bicompartmental osteoarthritis, there may be an indication for two partial knee replacements (usually a medial unicompartmental arthroplasty and a patellofemoral replacement) (Fig. I.5). Despite long-standing support for this surgery, in particular from Philippe Cartier, it is technically challenging. The Navio® system can be used to predict and adjust the relative position of the two implants, making this uncommon procedure more consistent.



Figure I-5: Per operative pictures and radiographs of a medial unicompartmental arthroplasty associated to a patellofemoral replacement in a young and active patient.

Learning curve and specific complications

The new technologies and new systems need an assessment and particularly an evaluation of the learning curve. In fact, learning curves for robotic-assistance in knee replacement surgery have been demonstrated to be quite short (123,133). Kayani et al. showed that robotic-assisted UKA are associated with a learning curve of seven cases for operative time (134). Lonner et al. (135) did a retrospective study of 1064 UKA performed with either the Navio system (Smith and Nephew®) or the MAKO system (Stryker®) and reported no soft tissue or bone injuries or complications related to the use of robotic-assistance. Blyth et al. (136) in study on UKA performed with the assistance of the MAKO system found no complications. Only some minor complications related to the use of navigation pins are described (135,137). Similar results have been described with the Navio system (138).

Sometimes, use of the robotic system was aborted during the procedure. The rate of intra-operative switching from the robotic to a conventional technique varies in the literature (1-22%) (139–141). These occasions all occurred in the learning curve of the robotic-assisted system. A good knowledge of this robotic system by the surgeon and the nurses is critical to avoid errors during this procedure.

Conclusion

The new technologies in TKA are very attractive and have constantly evolved. They expand the possibilities and the surgical indications, improve our knowledge of knee biomechanics, and try to restore native knee function. Nevertheless, all technologies need long-term assessment and critical appraisal. The limitations of new technologies could be improved by artificial intelligence and predictive modelling. Many medical technology and health insurance companies, as well as arthroplasty registries are already collecting data on patient demographics, implant survivorship, causes for revision and patient reported outcome measures. Creating accurate, reproducible and predictive algorithms may one day provide advanced tools for shared decision making regarding surgical indications and predicting expected outcomes in knee arthroplasty.

En résumé, les nouvelles technologies concernant l'arthroplastie de genou sont très attrayantes et n'ont cessé d'évoluer. Elles élargissent les possibilités et les indications chirurgicales, améliorent notre connaissance de la biomécanique du genou et tentent de restaurer la fonction native du genou. Néanmoins, toutes les technologies nécessitent une évaluation à long terme et une appréciation critique. Les limites des nouvelles technologies pourraient être améliorées par l'intelligence artificielle et la modélisation prédictive. La création d'algorithmes précis, reproductibles et prédictifs pourrait un jour fournir des outils avancés pour la prise de décision partagée concernant les indications chirurgicales et la prédiction des résultats attendus pour l'arthroplastie du genou.

2.3.2 Article 2 – Description de l’alignement coronal d’une population arthrosique

Bien que les PTG avec AM offrent une bonne survie à long terme des implants (13,16,17), cette approche systématique peut être trop simpliste et ignorer l'anatomie native de l'articulation (142,143). Cela pourrait être une raison potentielle de l'insatisfaction des patients après une PTG (4,19). Récemment, de nombreux auteurs se sont demandé si l'AM reste le meilleur alignement du genou après une PTG (144,145). Il semble que pour mieux comprendre l'insatisfaction des patients après une PTG, une analyse plus personnalisée et individualisée du phénotype de chaque genou et de la déformation osseuse devrait être effectuée avant la prothèse.

Cependant, la stratégie de réalignement la plus appropriée reste inconnue. Pour déterminer l'alignement souhaité pour la prothèse, Hirschmann et al. (146–148) se sont concentrés sur l'alignement coronal fémoral et tibial natif et ont montré une large distribution de l'alignement coronal du genou dans une population jeune non arthrosique. Il a été suggéré que pour les PTG visant à reproduire l'alignement coronal natif, une approche plus individualisée devrait être adoptée pour obtenir un alignement individualisé, dans le but d'obtenir de meilleurs résultats fonctionnels. Cependant, nous ne savons pas si les populations arthrosiques et non arthrosiques ont une distribution similaire de l'alignement coronal fémoral et tibial, notamment en cas d'arthrose primaire.

Nous avons donc réalisé une étude dont le but est de décrire la distribution de l'alignement coronal fémoral et tibial dans une large population d'arthrose essentielle et de la comparer à une population jeune non arthrosique déjà décrite dans la littérature (147).

Ce travail a abouti à une publication dans le journal *Knee Surgery Sports Traumatology Arthroscopy*.

Knee Surgery, Sports Traumatology, Arthroscopy
<https://doi.org/10.1007/s00167-020-06083-5>

KNEE



Primary osteoarthritic knees have more varus coronal alignment of the femur compared to young non-arthritic knees in a large cohort study

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Received: 29 April 2020 / Accepted: 27 May 2020
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Résumé en français

Objectif

De nombreux chirurgiens réalisent des prothèses totales du genou (PTG) dans le but de reproduire l'alignement coronal anatomique natif. Pourtant, on ne sait toujours pas si les populations atteintes d'arthrose essentielle et non arthrosiques ont un alignement coronal du genou similaire. Cette étude vise à décrire et à comparer la distribution de l'alignement coronal fémoral et tibial dans une grande cohorte atteinte d'arthrose essentielle et une jeune cohorte de patients non-arthrosiques.

Méthodes

Il s'agit d'une analyse rétrospective monocentrique d'un recueil de données collectées de façon prospective, de 1990 à 2019, de 2859 genoux consécutifs atteints d'arthrose primaire chez 2279 patients. Les patients ont réalisé des télémétries des membres inférieurs en appui bipodal. L'angle fémoral mécanique (AFM) et l'angle tibial mécanique (ATM) ont été mesurés numériquement à l'aide d'un logiciel. Les phénotypes fémoraux, tibiaux et du genou ont été analysés, et les données descriptives ont été rapportées. Les données ont été comparées à celles d'une population jeune non arthrosique précédemment décrite.

Résultats

Dans les genoux arthrosiques, l'AFM moyen était de $91^{\circ} \pm 2,9^{\circ}$ (de 86° à 100°) et l'ATM moyen était de $87^{\circ} \pm 3,1^{\circ}$ (de 80° à 94°). Aucune différence significative n'a été observée pour l'AFM et l'ATM entre les sexes. Les phénotypes fémoraux et tibiaux les plus fréquents étaient varus ($38,7\%$) et neutre ($37,1\%$). Le phénotype de genou le plus fréquent était un phénotype fémoral en varus avec un phénotype tibial neutre ($15,5\%$), ce qui est différent de la population non arthrosique.

Conclusion

Cette étude a montré la large distribution des phénotypes du genou dans une grande cohorte de patients atteints d'arthrose essentielle. La distribution en varus de l'alignement coronal fémoral était plus importante que dans la population non arthrosique, ce qui suggère une réflexion et une adaptation potentielle de la stratégie de réaligement du composant fémoral pendant la réalisation de la PTG.

Abstract

Purpose

Many surgeons are performing total knee arthroplasty (TKA) with an aim to reproducing native anatomical coronal alignment. Yet, it remains unclear if primary osteoarthritic and non-osteoarthritic populations have similar knee coronal alignment. This study aims to describe and compare the distribution of femoral and tibial coronal alignment in a large primary osteoarthritic cohort and a young non-osteoarthritic cohort.

Methods

This is a retrospective analysis of a monocentric prospectively gathered data, from 1990 to 2019, of 2859 consecutive primary osteoarthritic knees in 2279 patients. Patients underwent standardized long-leg radiographs. Femoral mechanical angle (FMA) and tibial mechanical angle (TMA) were digitally measured using software. Femoral, tibial and knee phenotypes were analyzed, and descriptive data were reported. Data were compared to a young non-osteoarthritic population previously described.

Results

In osteoarthritic knees, the mean FMA was $91^{\circ} \pm 2.9^{\circ}$ (range 86° to 100°) and the mean TMA was $87^{\circ} \pm 3.1^{\circ}$ (range 80° to 94°). No significant difference was observed for FMA and TMA between genders. The most common femoral and tibial phenotypes were varus (38.7%) and neutral (37.1%). The most frequent knee phenotype was a varus femoral phenotype with a neutral tibial phenotype (15.5%), which is different to the non-osteoarthritic population.

Conclusion

This study showed the wide distribution of knee phenotypes in a large osteoarthritic cohort. There was more varus distribution of the femoral coronal alignment compared to a non-osteoarthritic population, suggesting consideration and potential adaptation of the realignment strategy of the femoral component during TKA.

Level of evidence III

Keywords Knee, alignment, femoral mechanical angle, tibial mechanical angle, osteoarthritis, phenotype

Introduction

Historically, one of the principles of a successful Total Knee Arthroplasty (TKA) was the restoration of a neutral knee alignment with a Hip-Knee-Ankle (HKA) angle of 180° (16,17). This is obtained by reproducing a neutral mechanical alignment (MA), in which both of the femoral and tibial components are implanted perpendicular to the mechanical axis of the limb (13,149). Although MA TKA offers good long-term implant survival (13,16,17), this systematic approach may be too simplistic, and ignore the native joint anatomy (142,143). This could be a potential reason for various studies showing up to 20% patient dissatisfaction after TKA (4,19). Recently, many authors have questioned if MA remains the best knee alignment after TKA (145,150). Thus, many alternative knee alignments have been proposed to attempt improvement in functional results after TKA, with more soft tissue friendly TKA implantation (5,151). But, some of these new knee alignments remain systematic approaches. It appears that for better understanding of patient dissatisfaction after TKA, a more personalized and individualized analysis of each knee phenotype and bone deformity should be performed prior to TKA.

However, the most appropriate realignment strategy remains unknown. To determine the possible desired alignment for TKA, Hirschmann et al. (146–148) focused on native femoral and tibial coronal alignment and showed a wide distribution of knee coronal alignment in a young non-osteoarthritic population. It was suggested that for TKA aiming to reproduce native coronal alignment, a more individualized approach should be taken to achieve an individualized alignment, with the goal of achieving better functional results. However, it remains unclear if osteoarthritic and non-osteoarthritic populations have similar femoral and tibial coronal alignment distribution, especially considering primary osteoarthritis. Thus, this may change the realignment strategy for TKA procedures.

The purpose of this study is to describe the distribution of femoral and tibial coronal alignment in a large primary osteoarthritic population and to compare it to a young non-osteoarthritic population already described in the literature (147). The hypothesis is that there is a different distribution of femoral and tibial alignment in the primary osteoarthritic population.

Material and methods

A total of 5656 osteoarthritic knees were retrospectively included in this monocentric study of prospectively collected data from 1990 to 2019. This series was compound by all consecutive primary total knee arthroplasties. From this cohort, all patients with previous knee or limb surgery were excluded. It is reported that flexion contracture may decrease the accuracy of measuring coronal knee alignment (152,153). Thus, to avoid inaccurate measurements of radiologic parameters, all patients with knee flexion contractures more than 5° and severe bone deformity with bone loss (Ahlbäck classification > 3) were excluded. A total of 2859 primary osteoarthritic knees in 2279 patients were included for final analysis. The flow chart is illustrated in Figure 1.

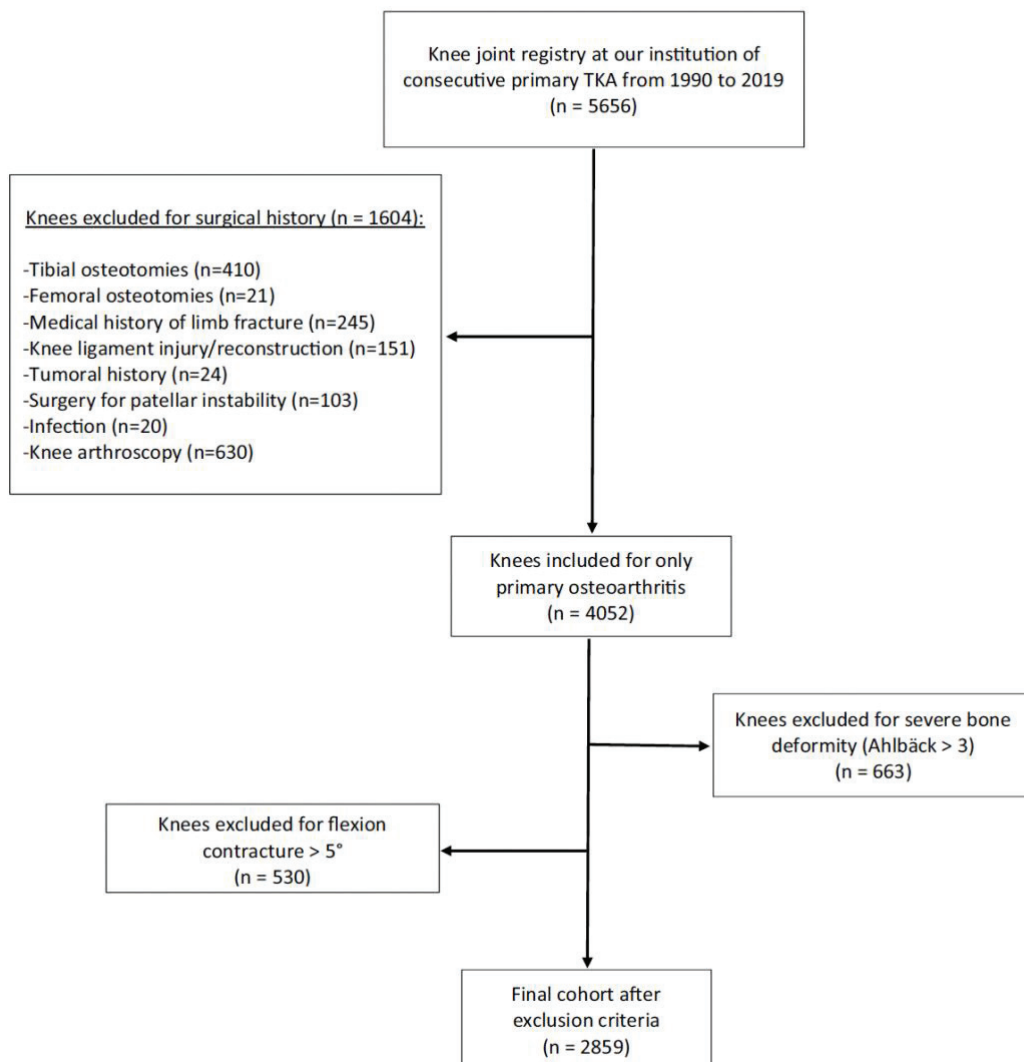


Figure II-1: Flowchart of the population

All patients underwent full weight-bearing long-leg standing radiographs according to a standardized protocol to avoid bias. Each patient was barefoot and placed their feet together with the patellae oriented forward to avoid rotational variation (154). The X-ray beam was centered on the knee with the radiography tube at a distance of 150cm. The radiographs were performed whilst the patients held their breath. Three cassettes from superiorly to inferiorly were placed immediately behind the subject and the Leonardo, Syngo Workplace (Siemens, United States) was used for digital stitching. Standard values such as 500 mA and 70kV were used, and individually adapted when necessary. Radiographs ranged from the whole pelvis to the feet.

For measurements of the joint centers and axes, the center of the femoral head was determined using a digital circle template. The center of the knee was determined as the midpoint of the line between the midpoint of the distal femur and the tibial spines. The center of the ankle was determined as the midpoint of the talar dome. The mechanical femoral axis was defined as the line from the center of the femoral head to the center of the knee. The mechanical tibial axis was defined as the line from the center of the knee to the center of the ankle. In this study, being full weight-bearing radiographs, measurement of Hip-Knee-Ankle angle could be incorrect because of soft tissue laxity. Thus, the authors decided to focus only on bony landmarks and to measure the joint line orientation of the femur and tibia in relation to their mechanical axes.

Two classifications defining knee coronal alignment were found for young non-osteoarthritic populations. Bellemans et al. (155) described the first knee classification of the coronal alignment based on the HKA angle. Knees were considered as having constitutional varus if the HKA angle was -3° or less, as normal if the HKA angle was between -3° and $+3^\circ$, and as having constitutional valgus if the HKA angle was 3° or more. Hirschmann et al., (146–148) in a more recent study, defined a more accurate classification of the knee coronal alignment. They considered not only the HKA angle, but also the Femoral Mechanical Angle (FMA) and the Tibial Mechanical Angle (TMA). The authors of this study decided to use Hirschmann's classification to assess the coronal alignment of the osteoarthritic population. The FMA and TMA were measured as follows (Figure 2): the FMA was measured as the medial angle between the femoral mechanical axis and a tangent to the distal femoral condyles. The TMA was defined as the medial angle between the tibial axis and a tangent to the proximal tibial joint surface. The authors agree with Hirschmann et al. (147) and consider it more coherent to measure both angles medially. Neutral TMA was defined as 87° and was noted

$NEU_{TMA}0^\circ$, all values under 87° were described as VAR_{TMA} and all values above 87° were considered as VAL_{TMA} . Neutral FMA was defined as 93° and was noted $NEU_{FMA}0^\circ$, all values under 93° were considered as VAR_{FMA} and all values above 93° were considered as VAL_{FMA} . The combination of the tibial and femoral phenotypes defined the knee phenotype. This specific classification was previously described in detail by Hirschmann et al. (147). The distribution of knee phenotypes was evaluated in our large primary osteoarthritic population.

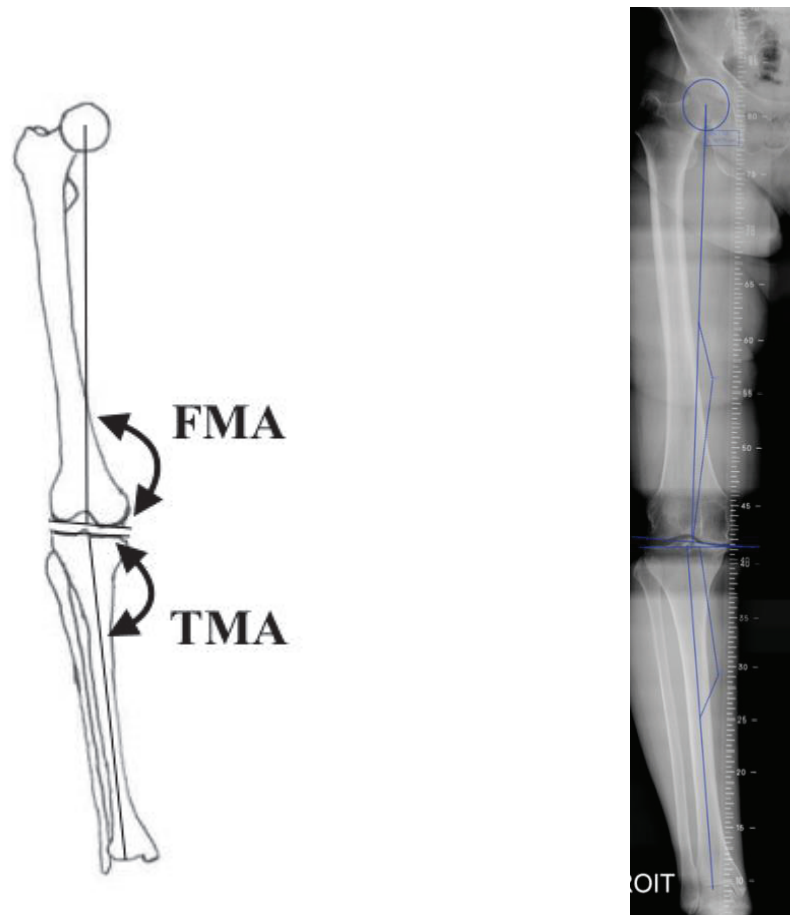


Figure II-2: Measurements of the femoral mechanical angle (FMA) and the tibial mechanical angle (TMA)

All osteoarthritic cohort demographic characteristics are presented in Table 1. There were no significant differences in FMA and TMA between genders. First, femoral and tibial phenotypes were described followed by knee phenotypes in this osteoarthritic population. Recently, Hirschmann et al. (147) described a young non-osteoarthritic population with this specific phenotype classification. It was decided to compare the phenotypes of this young non-osteoarthritic population with the osteoarthritic cohort from the present study.

Table II-1: Demographic characteristics and measurements of FMA and TMA according to gender in the osteoarthritic population

	Entire population (n= 2859)	Male (n= 1804)	Female (n= 1055)	p value
Mean age \pm SD (range)	71.5 \pm 8.5 (26–97)	71.6 \pm 8.6 (26–97)	71.2 \pm 8.2 (37–93)	0.14
Mean BMI \pm SD (range)	29.9 \pm 5.5 (16–55)	29.9 \pm 5.7 (16–54)	29.8 \pm 5.3 (16–55)	0.87
Mean FMA \pm SD (range)	91.4 \pm 2.9 (86–100)	91.5 \pm 2.8 (86–100)	91.4 \pm 2.9 (86–100)	0.53
Mean TMA \pm SD (range)	86.8 \pm 3.1 (80–94)	87.0 \pm 3.1 (80–94)	86.6 \pm 3.1 (80–94)	0.06

Two surgeons performed fifty measurements of the two different angles twice in order to assess intra and inter-observer reliability with a period of one month between measurements. Intra-observer reliability was found to be good, with a Pearson correlation coefficient, of $\rho=0.84$ (95% CI [0.74 ; 0.91]; $p<0.001$) for FMA and $\rho=0.87$ (95% CI [0.78 ; 0.92]; $p<0.001$) for TMA. Inter-observer reliability was also found to be good, with a Pearson correlation coefficient of $\rho=0.88$ (95% CI [0.80 ; 0.93]; $p<0.001$) for FMA and $\rho=0.78$ (95% CI [0.64 ; 0.87]; $p<0.0001$) for TMA.

The French advisory committee on health research data processing (*Comité Consultatif sur le Traitement de l'Information en matière de Recherche dans le domaine de la Santé* [CCTIRS]) approved this study on the 24th January 2012 and then 9 March 2015 (approval #11-681).

Statistical analysis

Statistical analysis was performed using XLSTAT software. Descriptive data analysis such as means, standard deviations and ranges were performed. T test for independent samples were performed to compare group differences. No significant difference was observed for femoral and tibial angles between male and female limbs, thus overall results did not need to be gender weighted. Significance was set at $p < 0.05$.

Results

Femoral and tibial phenotypes

Absolute and relative values of femoral and tibial angles among the osteoarthritic cohort are presented in Table 2.

More than eighty percent of the knees (82.3%) had the femur within the three phenotypes: VAR_{FMA3°}, NEU_{FMA0°}, VAL_{FMA3°}. A comparable distribution was observed for the tibiae. Most of the tibia (84.8%) were distributed within the three phenotypes: VAR_{TMA3°}, NEU_{TMA0°}, VAL_{TMA3°}.

Overall, the most frequent femoral and tibial phenotypes were VAR_{FMA3°} and NEU_{TMA0°}, 38.7% and 37.1% respectively.

Table II-2: Overall absolute and relative phenotypes among the entire population

		FMA					Total
		87°±1.5 VAR _{FMA6°}	90°±1.5 VAR _{FMA3°}	93°±1.5 NEU _{FMA0°}	96°±1.5 VAL _{FMA3°}	99°±1.5 VAL _{FMA6°}	
TMA							
81°±1.5	VAR _{TMA6°}	52	124	70	12	3	261
84°±1.5	VAR _{TMA3°}	136	315	182	58	11	702
87°±1.5	NEU _{TMA0°}	146	443	349	103	19	1060
90°±1.5	VAL _{TMA3°}	75	198	243	120	26	662
93°±1.5	VAL _{TMA6°}	20	27	56	55	16	174
Total		429	1107	900	348	75	2859

		FMA					Total
		87°±1.5 VAR _{FMA6°}	90°±1.5 VAR _{FMA3°}	93°±1.5 NEU _{FMA0°}	96°±1.5 VAL _{FMA3°}	99°±1.5 VAL _{FMA6°}	
TMA							
81°±1.5	VAR _{TMA6°}	1.8%	4.3%	2.4%	0.4%	0.1%	9.0%
84°±1.5	VAR _{TMA3°}	4.8%	11.0%	6.4%	2.0%	0.4%	24.6%
87°±1.5	NEU _{TMA0°}	5.1%	15.5%	12.2%	3.6%	0.7%	37.1%
90°±1.5	VAL _{TMA3°}	2.6%	6.9%	8.5%	4.2%	0.9%	23.1%
93°±1.5	VAL _{TMA6°}	0.7%	1.0%	2.0%	1.9%	0.6%	6.2%
Total		15.0%	38.7%	31.5%	12.1%	2.7%	100.0%

Absolute and relative values of FMA and TMA according to gender are shown in Table 3 (males) and Table 4 (females). The same distribution for FMA and TMA was found as in the entire population. The most frequent phenotypes for males were VAR_{FMA3}^o and NEU_{TMA0}^o, 39.7% and 36.6% respectively. For females, the most frequent phenotypes were VAR_{FMA3}^o and NEU_{TMA0}^o, 37.0% and 38.0% respectively.

Table II-3: Overall absolute and relative phenotypes for males

TMA		FMA					Total
		87°±1.5 VAR _{FMA6} ^o	90°±1.5 VAR _{FMA3} ^o	93°±1.5 NEU _{FMA0} ^o	96°±1.5 VAL _{FMA3} ^o	99°±1.5 VAL _{FMA6} ^o	
81°±1.5	VAR _{TMA6} ^o	31	72	40	6	3	152
84°±1.5	VAR _{TMA3} ^o	92	191	106	27	7	423
87°±1.5	NEU _{TMA0} ^o	81	293	214	58	14	660
90°±1.5	VAL _{TMA3} ^o	47	144	170	82	15	458
93°±1.5	VAL _{TMA6} ^o	8	16	34	40	13	111
Total		259	716	564	213	52	1804

TMA		FMA					Total
		87°±1.5 VAR _{FMA6} ^o	90°±1.5 VAR _{FMA3} ^o	93°±1.5 NEU _{FMA0} ^o	96°±1.5 VAL _{FMA3} ^o	99°±1.5 VAL _{FMA6} ^o	
81°±1.5	VAR _{TMA6} ^o	1.7%	4.0%	2.2%	0.3%	0.2%	8.4%
84°±1.5	VAR _{TMA3} ^o	5.1%	10.6%	5.9%	1.5%	0.4%	23.5%
87°±1.5	NEU _{TMA0} ^o	4.5%	16.2%	11.9%	3.2%	0.8%	36.6%
90°±1.5	VAL _{TMA3} ^o	2.6%	8.0%	9.4%	4.6%	0.8%	25.4%
93°±1.5	VAL _{TMA6} ^o	0.4%	0.9%	1.9%	2.2%	0.7%	6.1%
Total		14.3%	39.7%	31.3%	11.8%	2.9%	100.0%

Table II-4: Overall absolute and relative phenotypes for females

TMA		FMA					Total
		87°±1.5 VAR _{FMA6} ^o	90°±1.5 VAR _{FMA3} ^o	93°±1.5 NEU _{FMA0} ^o	96°±1.5 VAL _{FMA3} ^o	99°±1.5 VAL _{FMA6} ^o	
81°±1.5	VAR _{TMA6} ^o	21	52	30	6	0	109
84°±1.5	VAR _{TMA3} ^o	44	124	76	31	4	279
87°±1.5	NEU _{TMA0} ^o	65	150	135	45	5	400
90°±1.5	VAL _{TMA3} ^o	28	54	73	38	11	204
93°±1.5	VAL _{TMA6} ^o	12	11	22	15	3	63
Total		170	391	336	135	23	1055

TMA		FMA					Total
		87°±1.5 VAR _{FMA6} ^o	90°±1.5 VAR _{FMA3} ^o	93°±1.5 NEU _{FMA0} ^o	96°±1.5 VAL _{FMA3} ^o	99°±1.5 VAL _{FMA6} ^o	
81°±1.5	VAR _{TMA6} ^o	2.0%	4.9%	2.8%	0.6%	0.0%	10.3%
84°±1.5	VAR _{TMA3} ^o	4.2%	11.8%	7.2%	2.9%	0.4%	26.5%
87°±1.5	NEU _{TMA0} ^o	6.2%	14.2%	12.8%	4.3%	0.5%	38.0%
90°±1.5	VAL _{TMA3} ^o	2.7%	5.1%	6.9%	3.6%	1.0%	19.3%
93°±1.5	VAL _{TMA6} ^o	1.1%	1.0%	2.1%	1.4%	0.3%	5.9%
Total		16.2%	37.0%	31.8%	12.8%	2.2%	100.0%

Knee phenotypes

In this osteoarthritic population, all of the 25 potential phenotypes were observed. The three most observed knee phenotypes were $\text{VAR}_{\text{FMA}3^\circ} + \text{NEU}_{\text{TMA}0^\circ}$ (15.5%), $\text{NEU}_{\text{FMA}0^\circ} + \text{NEU}_{\text{TMA}0^\circ}$ (12.2%) and $\text{VAR}_{\text{FMA}3^\circ} + \text{VAR}_{\text{TMA}0^\circ}$ (11.0%). The same knee phenotype distribution was found in both genders. The three most frequent knee phenotypes in males and females were $\text{VAR}_{\text{FMA}3^\circ} + \text{NEU}_{\text{TMA}0^\circ}$ (16.2%), $\text{NEU}_{\text{FMA}0^\circ} + \text{NEU}_{\text{TMA}0^\circ}$ (11.9%), $\text{VAR}_{\text{FMA}3^\circ} + \text{VAR}_{\text{TMA}0^\circ}$ (10.6%) and $\text{VAR}_{\text{FMA}3^\circ} + \text{NEU}_{\text{TMA}0^\circ}$ (14.2%), $\text{NEU}_{\text{FMA}0^\circ} + \text{NEU}_{\text{TMA}0^\circ}$ (12.8%), $\text{VAR}_{\text{FMA}3^\circ} + \text{VAR}_{\text{TMA}0^\circ}$ (11.8%), respectively.

Comparison with a young non-osteoarthritic population

Comparison of FMA and TMA between the two cohorts are illustrated in Figure 3. A similar distribution was observed for the tibiae in both populations. By contrast, a more varus distribution of FMA was noticed for the osteoarthritic cohort compared to the non-osteoarthritic cohort.

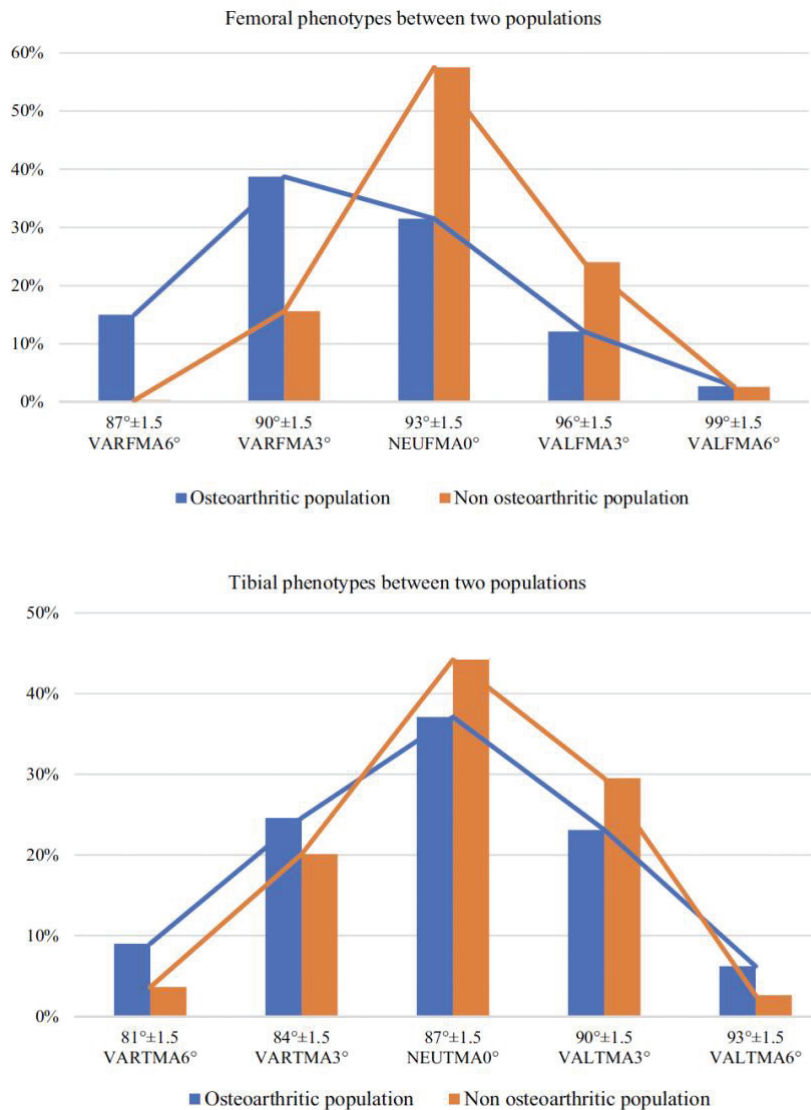


Figure II-3: Femoral and tibial coronal alignment distribution between osteoarthritic and non-osteoarthritic cohorts

Discussion

The most important finding of this study was that, although the tibial coronal alignment was similar between osteoarthritic and non-arthritic populations, there was a wider and more varus distribution of the femoral coronal alignment in the osteoarthritic population compared to the non-osteoarthritic population. This is the first study describing the wide distribution of knee phenotypes in a large cohort of osteoarthritic knees.

In fact, in this study, a wide range of TMA and FMA was observed, highlighting the broad variability among osteoarthritic knees, as is already observed in the non-osteoarthritic population. The overall mean TMA was $87^{\circ}\pm 3.1^{\circ}$, which is in line with previous studies (156), and is similar to mean TMA values observed in young non-osteoarthritic populations (147,155). However, the overall mean FMA was $91^{\circ}\pm 2.9^{\circ}$, which is slightly more varus than in other studies (157), especially in the young non-osteoarthritic population (147,155,158). Hirschmann et al. (147) considered that they found a wider distribution of TMA and FMA than other previous studies thanks to more accurate measurements on 3D-CT compared to 2D (159). However, in the present study, the authors found an even wider distribution of TMA and FMA with 2D images compared to Hirschmann et al. Thus, even if 2D images have a lower accuracy level than measurements in 3D, it seemed adequate to detect wide distribution of TMA and FMA. Also, the wider distribution observed in the present study might be due to the great measurement variability in 2D.

In this study, there were no significant differences in the distribution of TMA and FMA in males and females. The current literature is not unanimous regarding the coronal alignment distribution according to gender. Indeed, some studies found a more valgus overall limb alignment in females, especially in non-osteoarthritic knees (157,160). On the other hand, Bellemans et al. (155) observed similar findings to our study, with no gender differences in distribution of knee coronal alignment.

In a systematic review, Hess et al. (156) reported, amongst other findings, femoral alignment in osteoarthritic knees. Mean values of FMA ranged from 88.6° to 92.7° . This is in agreement with the present study, where the mean FMA in osteoarthritic patients was more varus than in the non-osteoarthritic population. Therefore, one could hypothesize that distal femoral varus plays a role in the pathogenesis of primary knee osteoarthritis.

This study presented the coronal alignment distribution results on the largest cohort ever published on primary knee osteoarthritis. The wide distribution of knee phenotypes found in this study confirmed Hirschmann's suggestion that there is a need for a more personalized realignment strategy. Still, it remains unclear which realignment strategy should be considered. It could be hypothesized that we should aim for the coronal alignment of a native non-arthritis population. However, this study emphasized the fact that non-arthritis and primary osteoarthritic populations have the same TMA distribution, but a different FMA distribution. Thus, in cases of TKA procedures with individualized alignment, aiming for an anatomical native coronal alignment could result in imperfect outcomes because of mismatch in the femoral

coronal alignment. Rather, the authors suggest that careful consideration should be given to preoperative coronal femoral alignment and to particularly adapt the femoral component alignment when needed. In line with this suggestion, a previous study showed good results after TKA for varus osteoarthritis while maintaining a postoperative varus alignment of the femoral component (161).

This study has several limitations. Alignment measurements on full weight-bearing long leg radiographs could be criticized for being less accurate compared to measurements using other imaging modalities such as CT or MRI (159). Still, multiple authors (162–165) observed good agreement between supine CT scanograms and full-length radiographs. Also, in this study, the authors considered only FMA and TMA, which are measured by bony landmarks which are amenable to accurate determination with long-leg radiographs. Not analyzing HKA allowed this study to avoid the confounding factor of knee laxity under weight-bearing. Moreover, to avoid any measurement inaccuracies in radiological parameters, very strict inclusion criteria were adhered to, and only knees without any medical or surgical history were considered for final analysis. Radiographs were all performed to a standardized protocol to avoid rotational variance, which could alter coronal alignment measurements. Finally, patient ethnic origin was not recorded and gender groups were unequal, however no significant difference was observed between genders.

Conclusion

This study showed the wide distribution of knee phenotypes in a large osteoarthritic cohort. There are more knee phenotypes specific to an osteoarthritic population with more varus distribution of the femoral coronal alignment compared to a non-osteoarthritic population. This difference may be significant in the pathogenesis of primary knee osteoarthritis, and this may have clinical importance when performing a TKA with a more personalized alignment approach, especially regarding femoral component positioning.

En résumé, cette étude a permis de montrer une grande variation interindividuelle de l'alignement coronal fémoral et tibial au sein d'une population atteinte d'arthrose essentielle. Aussi, les patients atteints d'arthrose présenteraient une déformation fémorale légèrement plus en varus par rapport à une population jeune non arthrosique. Ainsi, l'alignement personnalisé de la PTG pourrait être envisagé en adaptant la position du composant fémoral.

2.3.3. Article 3 – Revue systématique des alignements personnalisés en arthroplastie du genou

L'article 2 a permis de mieux comprendre le phénotype du genou arthrosique et que ce dernier ne présenterait pas exactement la même distribution d'alignement coronal fémoral et tibial par rapport aux genoux non-arthrosiques. Lors de la réalisation d'une PTG, plusieurs auteurs proposent différentes stratégies de réaligement du genou avec pour objectif de rétablir l'alignement du genou pré-arthrose. Nous avons donc réalisé une revue systématique des différents alignements personnalisés dans le cadre des prothèses totales de genou.

Ce travail a abouti à une publication dans le journal *SICOT J*.

SICOT-J 2021, 7, 19
© The Authors, published by EDP Sciences, 2021
<https://doi.org/10.1051/sicotj/2021021>



Available online at:
www.sicot-j.org

REVIEW ARTICLE

OPEN ACCESS

Personalized alignment in total knee arthroplasty: current concepts

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Received 17 February 2021, Accepted 3 March 2021, Published online 26 March 2021

Résumé en français

Traditionnellement, dans la prothèse totale du genou (PTG), un alignement neutre postopératoire était le « gold standard ». Ce principe a été contesté car les résultats fonctionnels se sont avérés insatisfaisants. L'analyse de l'alignement des membres dans la population non arthrosique révèle des variations par rapport à l'alignement neutre et la prise en compte d'un alignement personnalisé ou individualisé dans la PTG remet en question les concepts précédents. L'objectif de cette revue était de clarifier les variations des alignements personnalisés actuels et de rapporter leurs résultats. Les différentes propositions d'alignements personnalisés actuels sont : cinématique, cinématique inverse, cinématique restreint et fonctionnel. Le principe de « l'alignement cinématique » est le resurfaçage du genou avec restitution de l'anatomie pré-arthrose. L'objectif est de resurfacer le fémur en conservant l'obliquité native de l'axe articulaire fémoral. Les écarts de flexion et d'extension sont équilibrés par la résection tibiale. Le principe de « l'alignement cinématique inverse » consiste à resurfacer le tibia avec des résections osseuses médianes et latérales symétriques afin de conserver l'obliquité native de l'axe articulaire tibial. L'équilibrage des écarts est réalisé en ajustant les résections fémorales. Pour éviter de reproduire des alignements anatomiques extrêmes, il existe un « alignement cinématique restreint » qui est un compromis entre l'alignement mécanique et l'alignement cinématique réel avec une zone d'alignement sûre définie. Enfin, il existe le concept « d'alignement fonctionnel », qui est une évolution de l'alignement cinématique au fur et à mesure des progrès de la technologie. On l'obtient en manipulant l'alignement, les résections osseuses, la libération des tissus mous et/ou le positionnement de l'implant avec un système robotisé afin d'optimiser la fonction de la prothèse en fonction de l'alignement, de la morphologie osseuse et de l'enveloppe ligamentaire spécifiques au patient. L'objectif de la personnalisation de l'alignement est de restaurer la cinématique native du genou et d'améliorer les résultats fonctionnels après PTG. Un suivi à long terme reste crucial pour évaluer à la fois les résultats et la survie des implants de ces concepts actuels.

Abstract

Traditionally in total knee arthroplasty (TKA), a post-operative neutral alignment was the gold standard. This principle has been contested as functional outcomes were found to be inconsistent. Analysis of limb alignment in the non-osteoarthritic population reveals variations from neutral alignment and consideration of a personalized or patient-specific alignment in TKA is challenging previous concepts. The aim of this review was to clarify the variations of current personalized alignments and to report their results. Current personalized approaches of alignment reported are: kinematic, inverse kinematic, restricted kinematic, and functional. The principle of “kinematic alignment” is knee resurfacing with restitution of pre-arthritis anatomy. The aim is to resurface the femur maintaining the native femoral joint line obliquity. The flexion and extension gaps are balanced with the tibial resection. The principle of the “inverse kinematic alignment” is to resurface the tibia with similar medial and lateral bone resections in order to keep the native tibial joint line obliquity. Gap balancing is performed by adjusting the femoral resections. To avoid reproducing extreme anatomical alignments there is “restricted kinematic alignment” which is a compromise between mechanical alignment and true kinematic alignment with a defined safe zone of alignment. Finally, there is the concept of “functional alignment” which is an evolution of kinematic alignment as enabling technology has progressed. This is obtained by manipulating alignment, bone resections, soft tissue releases, and/or implant positioning with a robotic-assisted system to optimize TKA function for a patient’s specific alignment, bone morphology, and soft tissue envelope. The aim of personalizing alignment is to restore native knee kinematics and improve functional outcomes after TKA. A long-term follow-up remains crucial to assess both outcomes and implant survivorship of these current concepts.

Key words: Total knee arthroplasty, Personalized alignment, Kinematic alignment, Restricted alignment, Functional alignment, Implant survivorship.

Introduction

Traditionally in total knee arthroplasty (TKA), a postoperative neutral alignment was a standard principle (5,16,142). To obtain a mechanical alignment the femoral and tibial components are positioned at 90° to the tibial and femoral mechanical axis. This alignment philosophy for knee arthroplasty was driven by equalizing load on the implant to decrease wear and loosening rather than restoring normal knee kinematics and function. Mechanical Alignment (MA) in TKA has demonstrated good long-term implant survival (13,16,17). However, functional outcomes of the TKA are inconsistent. Bonnin et al. found 75%–89% of patients with TKA reported significant discomfort (166). Discomfort during activities of daily living is a significant cause of patient's dissatisfaction after TKA (166–168).

Several recent studies have described limb alignment in non-osteoarthritic and osteoarthritic populations. A systematic review by Moser et al. reported that the mean hip knee ankle angle (HKA) ranged from 176.7 to 180.7° in a native non-osteoarthritic knee (169). The majority of studies in the review (146,147,155,156) did not report a neutral native limb alignment of 180°, apart from Hovinga and Lerner (170) or Khattak et al. (171). The coronal alignment variability in non-osteoarthritic knees raises the question of a limb alignment of 180° is “normal”. This alignment could be not the target in TKA for all patients. Hess et al. in a second paper reviewed femorotibial alignment in osteoarthritic knees and concluded there were a large variation in overall coronal limb alignment as well as isolated tibial and femoral coronal alignments (156). This observation continues to fuel the discussion and classification of limb alignment. In an asymptomatic cohort of 250 adults, Bellemans et al. described a neutral alignment as $180^\circ \pm 3^\circ$, constitutional varus inferior to 177°, and constitutional valgus superior to 183° (155). Hirschmann et al. in more recent studies further classified the HKA alignment to include the femoral and the tibial mechanical angles (FMA and TMA, respectively) (146–148). This classification is more useful and is an explanation of how current concepts of alignment variations in both femoral and tibial cuts will affect the final alignment.

As the concept of MA was questioned in the 1980s anatomical alignment was described by Krackow and Hungerford with the aim to improve functionality by closer reproducing the native knee alignment (5,172), but the alignment was similar for all and not personalized. This led to the development of several concepts of personalized alignment: kinematic, inverse kinematic, restricted kinematic, and functional. The distinction between these different concepts of alignment is sometimes difficult to interpret and reporting inconsistent in the literature.

The goal of this current concepts paper is to clarify the different types of current personalized alignments, summarize their main principles and report their results.

Kinematic alignment

Principles

Kinematic alignment (KA), described by Howell et al. in 2006, is an “individualized” or patient-specific technique (173). The aim of KA is knee resurfacing with restitution of the pre-arthritis anatomy and preservation of the soft-tissue envelope. In this technique the knee is represented in three kinematic axes with respect to the joint lines of the posterior and distal femur (Figure 1): one transverse axis in the femur about which the tibia extends and flexes, one about which the patella extends and flexes and one longitudinal axis about which the tibia externally and internally rotates on the femur. All three axes are either parallel or perpendicular to the joint lines (174). By resurfacing the femorotibial joint, the KA technique aims to co-align the axes and joint lines of implants with the three “kinematic” axes and joint lines of the native joint. The surgeon resurfaces the femur maintaining the pre-arthritis femoral joint line obliquity, and adjusts the extension and flexion gaps with the resection of the proximal tibia. Sometimes, KA involves complex algorithms to balance the extension and flexion gaps (143). The tibial compensation can result in more oblique tibial varus resections with an increased medial tibial cut compared to MA.

Tibial and femoral resection thicknesses are validated with caliper measures and must match the thickness of the implants after compensating for saw cut and wear. It restores pre-arthritis ligament lengthening, does not create gap imbalance, minimizes the need for release (175–178). Howell does not place restrictions on the patient’s anatomy or final correction. For this reason, KA requires an accurate surgical technique and can be performed by multiple methods: conventional instrumentation, computer navigation, personalized instruments, or robotic-assisted.

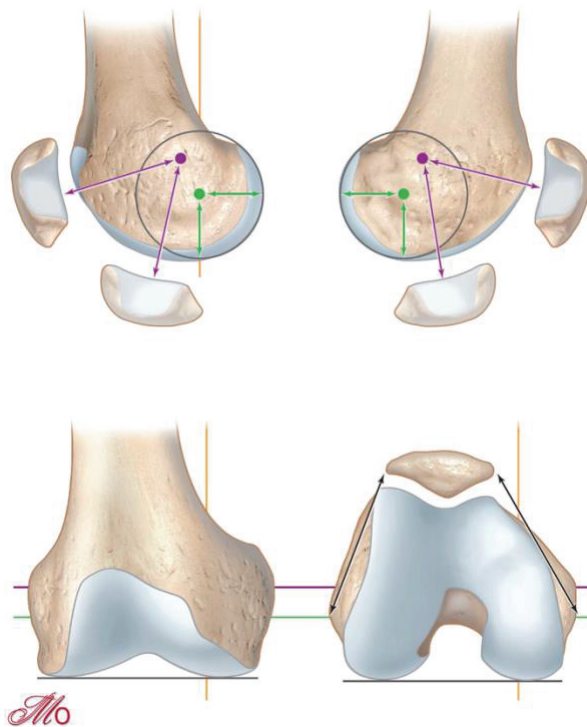


Figure III-1:

The femoral transverse axis about which the tibia extends and flexes is the most distal and posterior (Green line).

The femoral transverse axis about which the patella extends and flexes is more proximal and anterior (Violet line).

The longitudinal axis about which the tibia externally and internally rotates on the femur passes through the medial femorotibial compartment (Yellow line).

All three axes are either perpendicular or parallel to the joint lines (Blackline).

Surgical technique

KA implantation is usually a measured resection technique with the femur first (Figure 2b). Initially, the surgeon must estimate the individual physiological knee laxity throughout the range of motion of the knee and the amount of bone loss. The first cut is the distal femoral cut which is parallel to the joint line after correcting for the estimated bone loss. The posterior femoral cut is then performed parallel to the posterior condylar plane (usually no wear posteriorly). Resection of bone (corrected for wear) from the posterior and distal femur is equal in thickness to the femoral implant condyle which kinematically aligns the femoral implant. The surgeon then cuts the tibia parallel to the joint line. The tibial resected bone (corrected for wear) is equal in thickness to the tibial component will kinematically align the tibial component (174).

The surgeon must always measure each bone resection with a caliper. The thickness of the bone cut is calculated by deducting 1 mm from the component thickness for the saw cut thickness and by estimating the amount of articular surface wear. The cartilage thickness is frequently almost 2 mm on the distal and posterior parts of the femoral condyles.

During the trials, if there is a femorotibial soft-tissue imbalance (tightness, excessive laxity) and the soft-tissue envelope remains intact (no release/deficiency), the proximal tibia should be recut to compensate. Kinematic femoral component implantation is relatively straightforward and highly reproducible compared to a kinematic tibial cut and component insertion. A common technique for this method is to use personalized (patient-specific) cutting guides that enable additional degrees of slope/valgus/varus. In summary, the ligament balancing is performed by the bone cuts and adjusted as required by the tibial cut. This results in two important limitations that can occur with KA and have led to the development of restricted KA and inverse KA which is discussed later.

Results

Sappey-Marinier et al. performed a systematic review of the clinical and radiological outcomes after TKA with KA versus with MA at 2 years of follow-up (7). They reported that four of five prospective randomized controlled trial studies did not find any difference between the two groups (MA or KA) for all scores (179–182). One study reported that kinematically aligned TKA had significantly better scores for a range of motion, function, pain than those who underwent mechanically aligned TKA (183). Young et al. (179) found no difference between kinematic alignment (n=49) and mechanical alignment (n=50) in Oxford Knee Score (OKS) (42 ± 6 and 41 ± 6 , respectively) at 2-years follow-up. A randomized controlled trial by Dossett et al. (183) revealed a significant difference ($p=0.005$) with KA outcomes (n=44) greater than MA (n=44) in OKS (40 ± 10.2 and 33 ± 11.1 , resp.) at 2-years follow up. Of note, 90% of knees in the latter study were preoperatively in varus alignment and at 24 months there was no differences concerning the complication and revision rates, postoperative gait analysis, and tibial component migration.

Shelton et al. have assessed the functional outcomes and satisfaction rate of patients treated with a kinematically aligned TKA that had a contralateral MA TKA (184). 83% of patients were satisfied with the mechanically aligned TKA when they were treated with the kinematically aligned TKA and 92% were satisfied with the KA TKA at the last follow-up. The median forgotten joint score (FJS) for KA TKA was higher than MA TKA by a significant difference of 15 points ($p=0.006$). 56% favored the KA TKA, 8% favored the mechanically aligned TKA, and 36% rated both knees the same ($p<0.001$). 74% of patients favored the recovery of the kinematically aligned TKA, 6% favored the recovery of the mechanically aligned TKA.

A concern with kinematic alignment is the risk of developing aseptic loosening due to the increased varus alignment. Howell et al. reported implant survival of 220 (unrestricted) KA TKA at 10 years of follow-up of 97.5% for revision for any reason and 98.4% for aseptic failure (177). Tibial implant loosening occurred in 1 patient, with a reverse tibial slope. Using MA criteria, the percentage postoperatively aligned in the varus (valgus) outlier range ($>3^\circ$) was 78% (0%) for the tibial implant, 31% (5%) for the femoral implant knee, and 7% (21%) for the HKA (unknown mean varus).

Inverse kinematic alignment

Principles

A limitation of correcting ligament balancing with a tibial recut is that the “resurfacing” of the femur is at the expense of adjustment with the tibial cut. Two difficulties can occur if a tibial recut is necessary for ligament rebalance. Firstly, a more oblique and deeper recut will sacrifice medial tibial bone stock. Sappey-Marinier has demonstrated that an increased tibial resection depth is associated with significantly greater laxity in valgus between 30 and 90° of flexion, particularly with a tibial resection ≥ 14 mm (185). Increasing the tibial resection could jeopardize the medial collateral ligament and could complicate TKA revision if required. The risk of early loosening with tibial secondary displacement is increased with a severe varus tibial alignment (186). The second difficulty concerns gap balancing where an increased tibial recut impacts the flexion and the extension gaps. In the majority of “standard” cases the difference between gaps is small. But in complex cases where the recut may be asymmetrical, it could lead to laxity.

The principle of the “inverse kinematic alignment” is to “resurface” the tibia with similar medial and lateral resections after correcting for wear, maintaining the pre-articular tibial joint line obliquity. The gap balancing is then performed by adjusting the femoral posterior and distal resections (Figure 2c). This technique could avoid tibial over resection and tibia-related complications postoperatively. This technique has the advantage to manage independently the flexion and extension gaps. However, to perform an inverse KA accurately with conventional instrumentation or patient-specific guides is challenging and complex while a robotic-assisted system enables intraoperative planning of bone resections and gap balancing before the cuts.

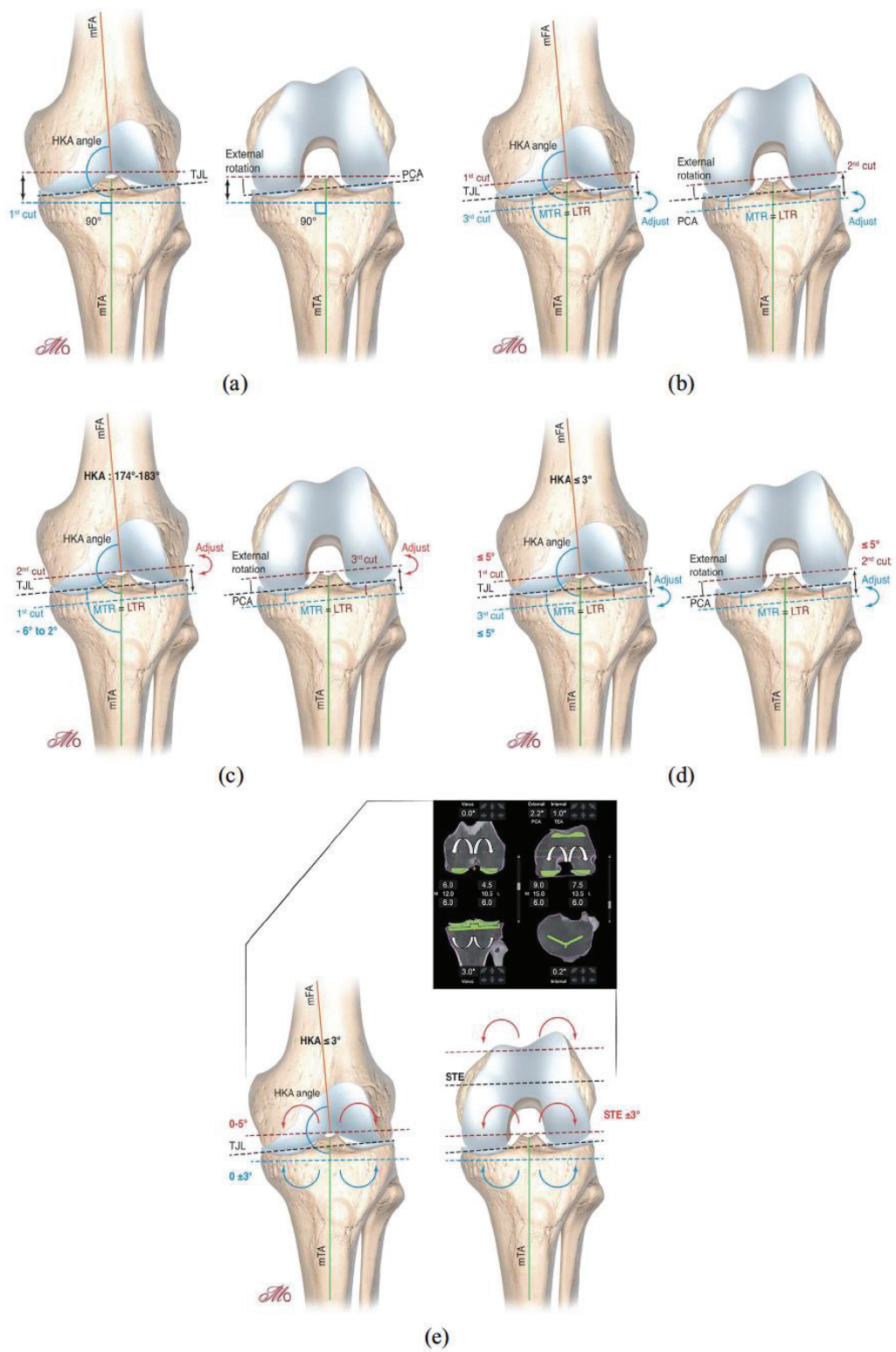


Figure III-2 : (a) Mechanical alignment, (b) kinematic alignment, (c) inverse kinematic alignment, (d) restricted kinematic alignment, (e) functional alignment.

Surgical technique

Winnock de Grave et al. described this new concept and technique with a robotic-assisted system (187). The tibial implant is positioned first with resection of equal amounts of bone lateral and medial on the tibia, after correcting for bone wear. The goal is to restore the native medial proximal tibial angle, within a safe zone of 84–92°. The tibial slope is determined by the pre-arthritic medial tibial slope. On the femoral side, the femoral implant is positioned to restore the medial joint line height both in flexion and extension. The extension and flexion gaps are balanced by adjusting the posterior and distal femoral resection levels. For the flexion gap, the goal is to achieve with the robotic-assisted system residual laxity of 1–3 mm in the lateral compartment and 1–2 mm in the medial compartment. For the extension gap, the goal is to achieve with the robotic-assisted system residual laxity of 1–2 mm in the two compartments. The target for the HKA angle remains in a safe zone between 174° and 183°. Readjustment of the femoral cuts a second time after the first cuts after trialing is difficult with a conventional resection guide. The robotic-assisted system estimates gap balancing prior to the cuts but also to potentially estimate and perform an adjustment and recuts after initial resections and trial.

Results

Only Winnock de Grave et al. have reported the outcomes of the inverse KA. They found no significant difference in clinical results at 12 months between inverse KA and adjusted MA (187). They reported a higher rate of satisfaction and significant improvement in postoperative OKS for restricted inverse KA, compared to adjusted MA. Of note, knees with preoperative varus deformity had an apparent improved functional score and satisfaction for restricted inverse KA compared to adjusted MA. No complication or revision was reported in both groups in the short term. However, these early results require further studies with increased patients and longer follow-up.

Restricted kinematic alignment

Principles

KA without restriction remains controversial due to the increased stress on the implants as the knee deformity increases and alignment deviates from MA increasing the risk of aseptic loosening. Nakamura et al. with finite element analysis assessed the tibiofemoral contact force in relation to the limb alignment (188). In the varus knees, KA increases the contact stress on the tibial insert, medial tibial cortex, and bone resection surface. For moderate (10°) and severe

(15°) varus knees, the maximum stress in kinematically aligned TKA increased by 24.8 and 32.2%, compared with to mechanically aligned TKA.

To account for the increasing stress, Vendittoli recommended “safe zones” for TKA alignment. He purposed a restricted KA protocol (189). Advanced osteoarthritic knee anatomy is very variable and to avoid reproducing extreme anatomy, the restricted KA is a hybrid option between MA and KA. The algorithm involves modifications of bone cuts within a “safe range” defined by some criteria: independent femoral and tibial cuts must be within $\pm 5^\circ$ of the mechanical axis and the HKA angle must fall within $\pm 3^\circ$ of neutral. But the restricted KA technique follows the main technical principle of the KA technique, which is to respect as much as possible the KA of the femoral implant, and adjustment of the coronal limb alignment and joint line obliquity is first performed by adjusting the tibial implant cut.

Surgical technique

The surgical planning is well described by Vendittoli (Figure 3). There are two situations: either the tibial and femoral mechanical axis are inferior or equal to 5° , or superior to 5° .

In the first case with femoral and tibial axis inferior to 5° , if the femorotibial axis (HKA angle) is equal or inferior to 3° , the surgeon can perform the TKA with a KA technique. If the femorotibial axis is superior to 3° of varus, the tibial varus will be reduced until the HKA is equal to 3° of varus. If the femorotibial axis is superior to 3° of valgus, the tibial varus will be reduced until the HKA is equal to 3° of valgus.

In cases where the femoral and tibial axis is superior to 5° , the surgeon will correct the tibial and/or the femoral bone cuts to stay within the 5° limit. This will correct the overall HKA to within $\pm 3^\circ$ of neutral. If the patient maintains an HKA superior to 3° , the surgeon will further adjust the tibial cut as in the first situation.

We prefer to modify the tibia to preserve as much as possible the native femoral anatomy and the flexion axis, as in the KA technique. Releases of the ligaments are not needed in cases with anatomic modifications inferior to 3° . In larger corrections, minimal releases can be added (to a much lesser degree compared to MA).

As with the unrestricted KA technique, it is important to measure the bone resections after each cut. Computer navigation and robotic-assisted systems facilitate intraoperative operative adjustment in complex cases.

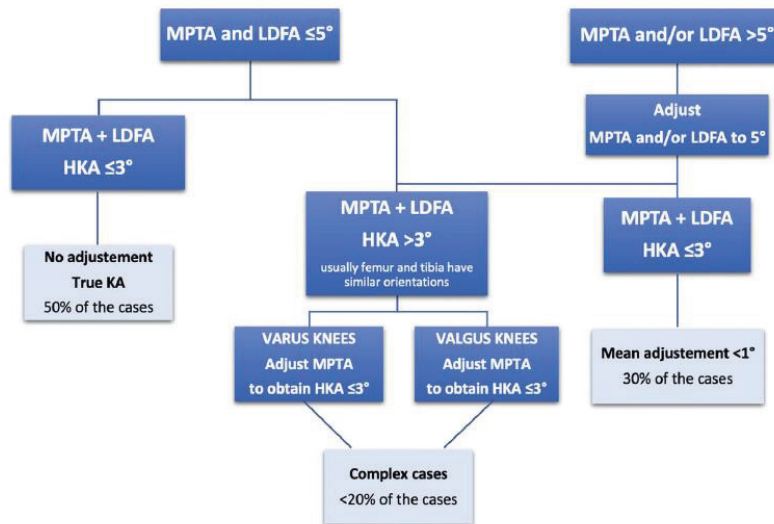


Figure III-3: Restricted kinematic alignment protocol

Results

Of 2475 TKA cases Almaawi et al. reported 49% required restricted KA TKA and 51% unrestricted KA TKA (189). Blakeney et al. simulated the extension and flexion gaps on 1000 lower limb CT scan according to the restricted KA or MA protocols. An “imbalance” was defined as a difference between lateral and medial gaps. In extension, there were significantly fewer cases having an imbalance ≥ 3 mm with restricted KA (8.3%) versus MA (33%), and ≥ 5 mm with restricted KA (1.5%) versus MA (11%). With restricted KA, the percentage of knees with space imbalances inferior to 3 mm in both flexion and extension was 92% versus 63% with MA with posterior condylar reference and 49% with MA with trans epicondylar reference (190).

MacDessi et al. have reported encouraging results after TKA with restricted kinematic alignment in a randomized controlled trial (191). They found that the mean intraoperative intercompartmental pressure difference at 10° of flexion in the kinematic group was significantly lower than in the mechanical group, using an interoperative pressure sensor. Overall, participants in the kinematic group were more likely to obtain optimal knee balance (80% vs. 35%).

Currently, no study has assessed the mid- or long-term clinical outcomes after restricted KA TKA.

Functional alignment

Principles

Functional alignment has similar aims and was developed for similar reasons as KA (192,193). It constitutes an evolution and increased precision of the KA concept. Patient-specific implants and 3D printed cutting blocks were used preoperatively to achieve KA in total knee arthroplasty. Functional alignment is obtained by manipulating alignment, bone resections, fine-tuning component positioning, and/or soft tissue releases at the surgeon's discretion intraoperatively with robotic-assisted systems to achieve balanced extension-flexion gaps and soft tissue tension while maintaining the patient's native alignment. These new and constantly improving technologies enable quantifiable measurement and precision adjustment of femoral and tibial cuts, implant positioning, or tissue release in three planes, of one or two degrees, to obtain optimal functional alignment. The precision offered by robotic assistance may make achieving non-neutral alignment targets more reproducible (134), reducing the risk of missing the target and producing significant outliers of the limb alignment. Theoretically, functional TKA reduces the need for periarticular soft-tissue releases if not desired by the surgeon while restoring the patient's native knee kinematics

Surgical technique

Robotic-assisted systems are constantly evolving both in hardware and software platforms and algorithms. Planning may initially begin preoperatively on a 3D and be completed during the surgery prior to bone cuts. Once the bone cuts have been made and the trial is in place the robotic system, soft tissue sensor or surgeon may discover a soft tissue imbalance. Adjustments can then be assessed with software 3D manipulation virtually and then recut guidance or releases performed with the robotic-assisted system if indicated.

In the coronal plane, femoral component positioning is modified from a starting point of 0° to the mechanical axis to balance the extension gap. In the sagittal plane, the femoral component is positioned to optimize the component sizing and to avoid femoral notch by flexing up to 5°. In the axial plane, the femoral implant is aligned to the transepicondylar axis with 3° of freedom to balance the flexion gap. The size of the femoral component is selected using posterior referencing with the smallest size that does not overhang the femur, notch the anterior femur, or overhang mediolateral bone edges, and avoids overstuffing the patellofemoral joint. The femoral component is positioned at the center of the mediolateral cortical bone edges, with a small lateral position if necessary. In the coronal plane, the tibial

component position is aligned to the tibial mechanical axis and modified to balance extension and flexion gaps by up to 3° of varus. Valgus tibial position should be avoided. In the sagittal plane, the tibial component position is set to match the patient's pre-arthritis posterior tibial slope, modified to balance the flexion gap if necessary. In the axial plane, the tibial component is positioned using the line of Akagi.

The aim of functional alignment is to position the implants in the position that least compromises the knee ligaments envelope in 3D and hence to restore the obliquity and plane of the joint to that which the ligaments dictate. If the deformities are fixed, the soft-tissues release is required to balance the gaps, although the extent and frequency of such releases are smaller when compared with the MA technique.

Results

Several studies assessed the accuracy and the reproducibility of robotic-assisted surgery (123,124,194–196). Sires and Wilson performed CT scans postoperatively to assess the precision of the image-based robotic-assisted TKA and found that 93% of the surgical measurements were $\leq 3^\circ$ of the CT measures postoperatively (196). The use of preoperative CT scanning and the planning accuracy of robotic-assisted TKA resulted in well-balanced knees (197). Nevertheless, no study has assessed the functional and clinical outcomes of this alignment technique, nor the implant survivorship.

Table III-1: Surgical parameters for each kind of alignment

		Mechanical alignment	Kinematic alignment	Inverse kinematic alignment	Restricted alignment	Functional alignment
Femoral component	Flexion	Follows distal femoral bowing Target: 0 to 5° of flexion	Follows distal femoral bowing Target: 2 ± 3°	Follows distal femoral bowing Target: 2 ± 3°	Follows distal femoral bowing Target: 2 ± 3°	Follows distal femoral bowing Target: 0 to 5° of flexion
	Distal cut	Systematic and perpendicular to the femoral mechanical axis Target: 0°	Parallel to the distal femoral joint line (considering wear)	Parallel to the distal femoral joint line (considering wear)	Correct to < 5°, then Parallel to the distal femoral joint line (considering wear) Target: < 5°	Parallel to the distal femoral joint line (considering wear)
	Posterior cut	External or neutral rotation relative to posterior condylar line. Measured resection or gap-balancing techniques. Posterior or anterior referencing techniques	Parallel to the posterior condylar line	Parallel to the posterior condylar line	Parallel to the posterior condylar line	Surgical trans epicondylar axis; ± 3°
	Mediolateral	Slightly lateralized	Centered on the notch	Centered on the notch	Centered on the notch	Centered on the distal femur
Tibial component	Coronal cut	Systematic and perpendicular to the tibial mechanical axis Target: 0°	Parallel to proximal tibial joint line (considering wear)	Parallel to proximal tibial joint line (considering wear) within safe zone of 84° to 92°	Correct to < 5°, then Parallel to proximal tibial joint line (considering wear) Target: < 5°	Perpendicular to the tibial mechanical axis Target: 0 ± 3°
	Slope	Systematic. Between 2° and 7° relative to sagittal tibial mechanical axis	Target: -6° to 9° Parallel to the medial plateau slope	Target: -6° to 2° Parallel to the medial plateau slope	Parallel to the medial plateau slope	Parallel to the medial plateau slope; Target: 0° to 3°
	Rotation	Towards the medial third of the tibial tuberosity	Parallel to lateral plateau long-axis	Parallel to lateral plateau long-axis	Parallel to lateral plateau long-axis	0 to 5° of external rotation to Akagi's line
Knee balancing	Soft tissues	Tibial cut	Femoral cut (distal and/or posterior)	Tibial cut + Soft tissues	Femoral and tibial positioning + Soft tissues	
Soft tissue Release	Femorotibial joint	Frequent	None	None	Sometimes	Sometimes
	Lateral retinaculum	Sometimes	Rarely	Rarely	Rarely	Rarely
Technologies		All	All	Robotic-assisted	All	Robotic-assisted

Conclusion

Several concepts and evolving surgical techniques continue to develop personalized alignment in TKA. Personalized alignment aims to restore native knee alignment and improve functional outcomes after TKA. New technologies have increased the ability to restore native knee kinematics with TKA. A long-term follow-up is crucial to determine clinical outcomes and implant survivorship of these current alignment concepts.

En résumé, cette revue systématique a permis de détailler les différentes techniques d'alignement personnalisé. Toutes ces techniques essayent d'obtenir l'alignement du genou natif préopératoire. Deux principaux alignements se démarquent avec des techniques différentes :

- **Alignement cinématique**
 - Objectif restituer la situation du genou natif
 - Repères osseux
 - Préservation enveloppe ligamentaire
 - Pas de restriction dans le positionnement des implants
 - Fémur distal en premier puis coupe postérieure et adaptation tibia
- **Alignement fonctionnel**
 - Résection osseuse symétrique et adaptation selon équilibrage ligamentaire
 - Équilibrage ligamentaire 3D en peropératoire à l'aide d'un outil robotique
 - Fémur en premier puis adaptation tibia

2.3.4 Article 4 – Revue systématique comparant alignement cinématique et mécanique à un recul minimum de 2 ans

Après avoir présenté une revue systématique des différents alignements personnalisés existants, nous avons réalisé une revue systématique comparant alignement cinématique et alignement mécanique avec un recul minimum de 2 ans. Nous souhaitons savoir si l'alignement cinématique pouvait être considéré comme une technique d'alignement alternative et fiable à l'alignement mécanique.

Ce travail a abouti à une publication dans le journal *SICOT J*.

SICOT-J 2020, 6, 18
© The Authors, published by EDP Sciences, 2020
<https://doi.org/10.1051/sicotj/2020014>



Available online at:
www.sicot-j.org

REVIEW ARTICLE

OPEN ACCESS

Kinematic versus mechanical alignment for primary total knee arthroplasty with minimum 2 years follow-up: a systematic review

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Received 23 April 2020, Accepted 24 April 2020, Published online 17 June 2020

Résumé en français

Objectif

L'objectif de cette étude était de réaliser une revue systématique de la littérature afin de déterminer s'il existe des différences sur les résultats cliniques ou radiologiques entre une prothèse totale de genou (PTG) réalisée avec un alignement mécanique et une PTG avec un alignement cinématique.

Méthodes

Cette étude comprenait des études de cohorte rétrospectives, des essais contrôlés randomisés prospectifs (ECRP) et des études de cohorte prospectives comparant les résultats cliniques et radiologiques et les complications des PTG avec alignement cinématique (AC) et alignement mécanique (AM). Toutes les études avaient un suivi minimum de 2 ans.

Résultats

Cinq ECRP publiés entre 2014 et 2020 ont été inclus. Ces études présentaient un faible risque de biais et étaient de très bonne qualité. Nous n'avons pas trouvé de supériorité de la technique d'alignement cinématique par rapport à la technique d'alignement mécanique pour les résultats cliniques et radiologiques, sauf dans une étude qui a montré une différence significative en faveur de l'alignement cinématique entre les deux groupes pour tous les scores cliniques.

Conclusion

Nous avons constaté que la technique d'alignement cinématique dans la PTG permettait d'obtenir des résultats cliniques et radiologiques similaires à ceux de la technique d'alignement mécanique. Le taux de complication n'était pas augmenté pour les PTG avec alignement cinématique. Des études avec un suivi plus long et des cohortes plus importantes sont nécessaires pour prouver tout avantage de la technique cinématique par rapport à la technique mécanique.

Abstract

Purpose

The aim of this study is to perform a systematic review of the literature to determine whether there are any clinical or radiological differences in mechanically aligned Total Knee Arthroplasty (TKA) compared with kinematically aligned TKA.

Methods

This study included retrospective cohort studies, prospective randomized controlled trials (PRCTs) and prospective cohort studies comparing clinical and radiological outcomes, and complications in TKA with kinematic alignment (KA) and mechanical alignment (MA). All studies had a minimum follow-up of 2 years.

Results

Five PRCTs published between 2014 and 2020 were included. These studies showed a low risk of bias and were of very high quality. We did not find a superiority of KA compared to MA technique for clinical and radiological outcomes, except in one study which showed a significant difference favoring KA between the two groups for all clinical scores.

Conclusion

We found that KA in TKA achieved clinical and radiological results similar to those of MA. The complication rate was not increased for KA TKAs. Studies with longer follow-up and larger cohorts are required to prove any benefit of KA technique over MA technique.

Level of evidence Systematic review, Level IV

Keywords Total knee arthroplasty, total knee replacement, mechanical alignment, kinematic alignment, systematic review

Introduction

Total knee arthroplasty (TKA) is an effective method for the treatment of severe osteoarthritis of the knee (18). One of the foundations of a successful TKA is the restoration of neutral knee alignment (198). Mechanical alignment (MA) in TKA aims to position both femoral and tibial components perpendicular to the mechanical axis of each bone. This allows to obtain a hip-knee-ankle (HKA) angle of the limb of 180° considered as neutral under static weightbearing conditions (11). This is a fundamental principle of TKA, willing to obtain a symmetric balanced load distribution between the medial and lateral compartments in order to minimize wear and potential component loosening (13,16,17,199,200).

However, this situation differs from the native knee. Indeed, the tibial coronal alignment averages 3° varus and the mean femoral coronal alignment is of 3° valgus relative to the mechanical axis. Moreover, there is a wide individual variation in limb alignment. Bellemans et al. showed that more than 30% of male non-arthritic patients had a constitutional varus angle of $> 3^\circ$ (155). Also, Hirschmann et al. (147) showed a wide distribution of femoral and tibial coronal alignment in young non-osteoarthritic knees. If such patients undergo TKA according to MA principles, medial or lateral soft tissue adjustments may be required (155,174,199), which could explain the results of various studies (200,201) showing that up to 20% of patients are dissatisfied after TKA.

Therefore, kinematic alignment, (KA) for TKA, in the wider sense, has been proposed as an alternative approach to neutral mechanical alignment (202). This alternative alignment approach is more patient-specific and is defined by four alignment strategies: anatomic alignment, adjusted mechanical alignment, kinematic alignment, and restricted alignment techniques (5). In different studies assessing this alternative alignment, there still persists some ambiguities on which of the four techniques was analyzed, whilst all authors name it kinematic alignment in the wider sense. KA aims to position TKA implants to match the native anatomy of each patient. It produces anatomic rather than systematic component positions, more physiological joint line obliquity and more physiological knee kinematics (203). Defenders of KA suggest that this will improve clinical results in terms of pain and function compared to MA technique by reducing the need for ligament releases and improve soft tissue balancing (183,204,205). However, there are concerns on implant survival with implants positioned in a different way from traditional targets (14,186,206,207). Several systematic reviews were performed comparing KA and MA techniques at an early follow-up (178,198,208–212). No review has been performed comparing KA and MA with a minimum follow-up of 2 years. Thus,

the aim of this study is to perform a systematic review of the literature to determine whether there are any clinical or radiological differences in mechanically aligned TKA compared with kinematically aligned TKA. Our outcome variables included clinical rating scores, radiological outcomes, survivorship, complications or gait analysis at a minimum follow-up of 2 years.

Methods

Literature search strategy

For this study, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed (213). A first electronic search was performed using PubMed, Ovid Medline and Cochrane library from their dates of inception to the 2nd March 2020. To maximize sensitivity of the search strategy the authors combined the terms “knee”, “arthroplasty”, “replacement”, “kinematic”, “kinematically”, “mechanical”, “mechanically” and “alignment” when searching in the title, abstract, keywords and MeSH fields. A secondary search was performed examining the references cited in the articles found in the primary search. All articles were reviewed by two authors independently following this systematic approach. Each reviewer was blinded with regard to the determination of the other reviewer. Ethical approval was not necessary in this study as it only analyzed current studies and did not collect individual patient data. No external funding was received for this project.

Selection criteria

This study included retrospective cohort studies, prospective randomized controlled trials (PRCTs) and prospective cohort studies comparing clinical and radiological outcomes with KA and MA in TKA. For inclusion, studies contained a KA group and a MA group with a minimum of 10 TKAs in each group and a minimum follow-up of 2 years. Final analysis involved studies reporting clinical outcome scores, survivorship, complications or postoperative radiographic alignment between kinematic and mechanical alignment prostheses. When several studies reported the results of the same patient series with different follow-ups, only the last study with the longest follow-up was analyzed. All publications included were limited to those written in English language, involving human subjects and full-text availability for the articles. Case reports, duplicate studies, letters, noncomparative studies, conference presentations, expert opinions and reviews were excluded.

Data extraction

All the relevant data was extracted from article text, figures and tables. Two investigators independently reviewed and extracted data from the retrieved articles. Discrepancies at the full-text stage were resolved by consensus between the two reviewers. If a consensus could not be reached, a third, more senior reviewer helped to resolve the discrepancy. The two reviewers collected information regarding the authors, publication origin, publication date, patient demographics (age, gender, sample size, and body mass index (BMI)), surgical methods, prosthetic designs, and outcome measurements.

The primary outcomes were the clinical and radiological results. The clinical results included the Knee Society score (KSS) (214), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) (215), Oxford Knee score (OKS) (216), range of motion (ROM), Hospital for special surgery (HSS) score, Forgotten Joint Score (FJS) (8), Knee Injury and Osteoarthritis Outcome Score (KOOS JR) (217), a visual analogue score for satisfaction and the University of California, Los Angeles Activity Score (UCLA) (218).

Quality assessment

A risk-of-bias evaluation was performed using the Cochrane Collaboration tool (219). Seven domain-based evaluations related to risk of bias were performed, including evaluation for random sequence generation (selection bias), allocation concealment (selection bias), blinding of the participants and personnel (performance bias), blinding of the assessors (defection bias), incomplete outcome data (attrition bias), and selective reporting (reporting bias) and other biases. The overall quality of each study was evaluated as a “low risk of bias”, a “high risk of bias”, or an “unclear risk of bias”.

A modified Jadad score was used for the quality evaluation of PRCTS including data analysis, blinding, randomization, withdrawal, adverse reactions and inclusion criteria. Low-quality studies scored from 0 to 3 and high-quality studies scored from 4 to 8.

Statistical analysis

Descriptive statistics, such as means, ranges, and measures of variance (standard deviations, 95% confidence intervals (CI)), are presented where applicable. No meta-analysis was performed.

Results

The selection procedure is shown in Figure 1. A total of 1156 studies were identified by using our primary and secondary search strategy. After exclusion of duplicate studies, a total of 820 studies remained for further screening. Examination of title/abstracts excluded 780 records, and a further 35 were excluded. Thus, 5 PRCTs were included (179–183) and were published between 2014 and 2020. Characteristics of the studies included are reported in Table 1.

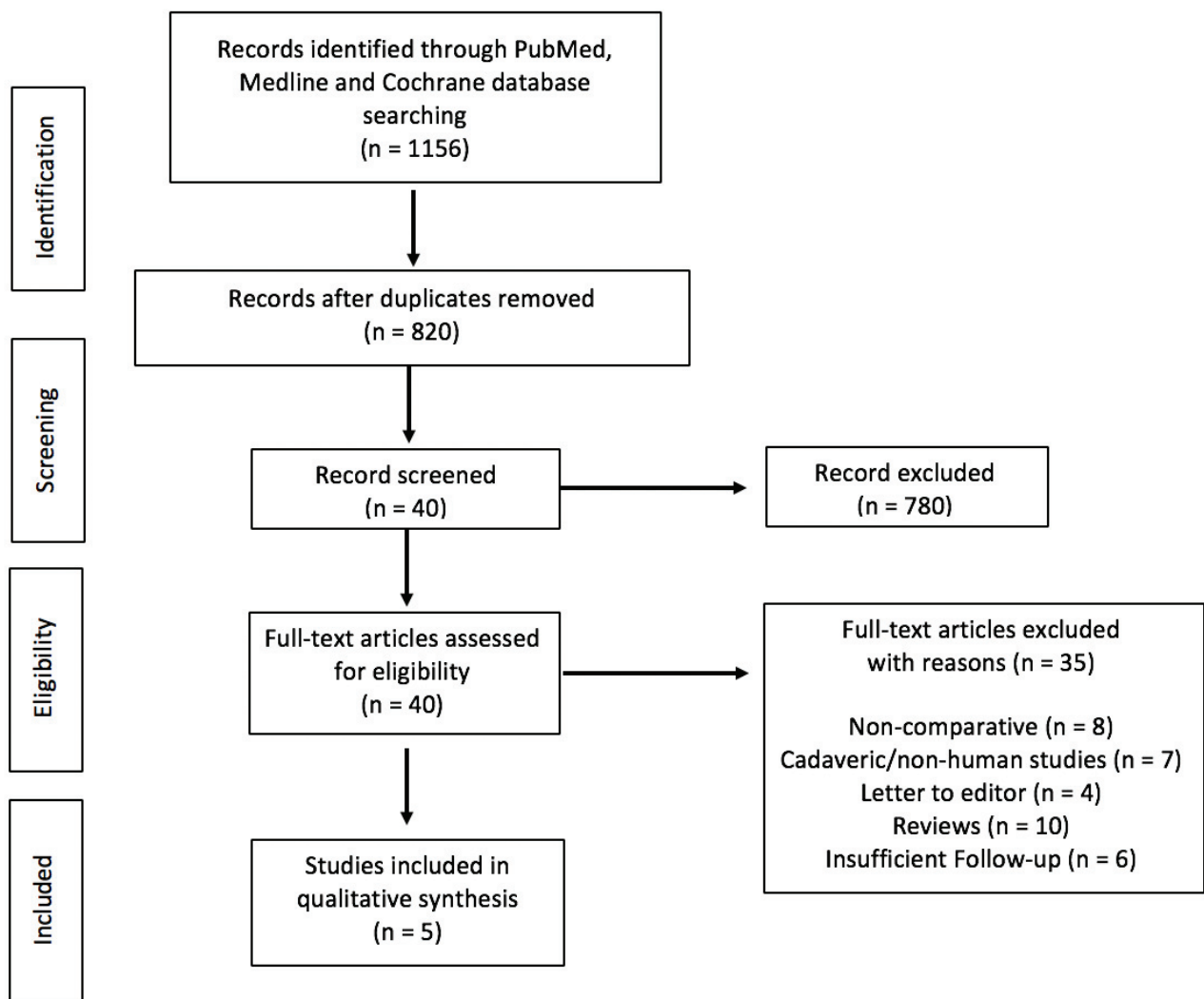


Figure IV-1: Flow chart

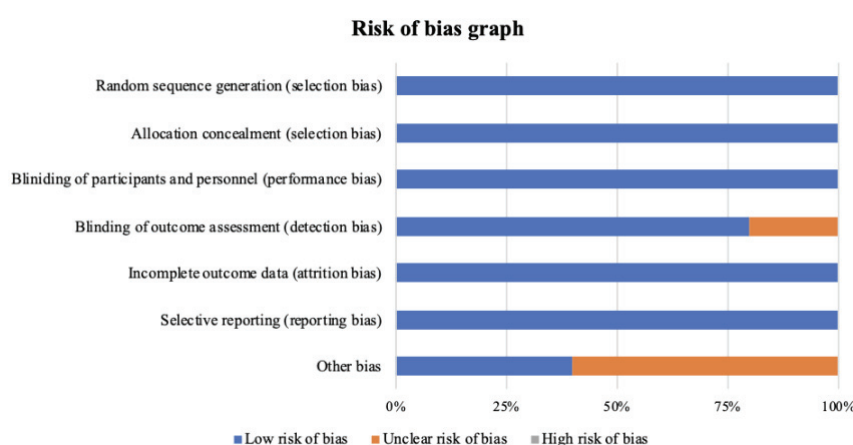
Table IV-1: characteristic of the studies

Studies	Location	Study design	Minimum follow-up (m)	Sample size			Me an age			Female			BMI (mean)			Prosthesis design	Operative method	Clinic al measurements	Radiological measurements	Other measurements
				KA	MA	MA	KA	MA	KA	MA	KA	MA	KA	MA	KA					
Dossett et al. [18]	United States	PRCT	24	44	44	44	66	66	66	41	38	29	32	KA: Vanguard, CR, FB, SR, cemented, all PR MA: Vanguard, CR, FB, SR, cemented, all PR	KA: PSI MA: Conventional	OXS, WOMAC, KSS, ROM	HKA, AKA, JLOA, FMA, TMA	Complications		
Yeo et al. [39]	South Korea	PRCT	96	30	30	72	74	27	25	27	26	26	26	KA: NextGen, CR, FB, MR, cemented, partial PR MA: NextGen, CR, FB, MR, cemented, partial PR	KA: ROBDOC system, robotic aassisted MA: Robotic aassisted	HSS, WOMAC, KSS, ROM	HKA, FMA, TMA, TS	Gait analysis		
Laende et al. [40]	Canada	PRCT	24	24	23	64	63	16	17	36	34	36	34	KA: Triathlon, CR, FB, SR, cemented, all PR MA: Triathlon, CR, FB, SR, cemented, all PR	KA: PSI MA: Computer navigation	OXS, satisfaction, UCLA	HKA, MPTA	Tibial migration		
McEwen et al. [41]	Australia	PRCT	24	41	41	65	NA	NA	NA	NA	31	31	31	MA: Triathlon, CR, FB, SR, cemented, all PR KA: Triathlon, CR, FB, SR, cementless femur, cemented tibia, partial PR MA: Triathlon, CR, FB, SR, cementless femur, cemented tibia, partial PR	KA: computer navigation MA: computer navigation	OXS, FJS, KOOS, JR, ROM	HKA, FMA, TMA, TS, JLOA, JLCA, PTA	Intraoperative gap laxity, soft tissue release, 4 specific clinical questions, complications		
Young et al. [38]	New Zealand	PRCT	60	47	48	72	70	25	26	30	31.5	30	31.5	KA: Triathlon, CR, FB, SR, cemented, partial PR MA: Triathlon, CR, FB, SR, cemented, partial PR	KA: PSI MA: Computer navigation	OXS, WOMAC, FJS, KSS, VAS	HKA, FMA, TMA, TS	Intraoperative gap laxity, soft tissue release, complications		

NA: Not Applicable, PRCT: Prospective Randomized Controlled Trial, KA: Kinematic Alignment, MA: Mechanical Alignment, CR: Cruciate-Retaining, FB: Fixed-Bearing, SR: Single Radius, MR: Multi-Radius, PR: Patella Resurfacing, PSI: Patient-Specific Instrument, OXS: Oxford Knee Score, WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index, KSS: Knee Society Score, ROM: Range of Motion, FJS: Forgotten Joint Score, VAS: Visual Analogue Scale, HSS: Hospital for Special Surgery knee score, UCLA: University of California at Los Angeles Loneliness score, KOOS JR: Knee Injury and Osteoarthritis Outcome Score Junior, HKA: Hip-Knee-Ankle angle, AKA: Anatomic Knee Angle, JLOA: Joint Line Orientation Angle, FMA: Femoral component relative to Mechanical Axis, TMA: Tibial component relative to Mechanical Axis, TS: Tibial Slope, MPTA: Medial Proximal Tibial Angle, JLCA: Joint Line Convergence Angle, PTA: Patellar Tilt Angle.

Risk of bias and quality of evidence

Risk-of-bias assessment results of the studies are reported in Figure 2. There was an unclear risk of bias in one study in blinding the outcome assessment (detection bias). There was an unclear risk of bias for the category “other bias” in three studies. We did not find other bias in the included studies. The quality evaluation scores of the studies are shown in Table 2. The studies included in this systematic review were given scores of 8. Thus, after examination, the five included studies had a low risk of bias and were of very high quality.



	Dossett 2014	Yeo 2018	Laende 2019	McEwen 2020	Young 2020
Random sequence generation (selection bias)	+	+	+	+	+
Allocation concealment (selection bias)	+	+	+	+	+
Blinding of participants and personnel (performance bias)	+	+	+	+	+
Blinding of outcome assessment (detection bias)	?	+	+	+	+
Incomplete outcome data (attrition bias)	+	+	+	+	+
Selective reporting (reporting bias)	+	+	+	+	+
Other bias	?	?	+	?	+

Figure IV-2: Risk of bias graph; “+ or plus” indicates a low risk of bias; “- or minus” indicates a high risk of bias; and “? or question mark” indicates unclear of unknown risk of bias

Table IV-2: Modified-Jadad score

	Dossett 2014	Yeo 2018	Laende 2019	McEwen 2020	Young 2020
Was the study described as randomized?	Yes	Yes	Yes	Yes	Yes
Was the method of randomization appropriate?	Yes	Yes	Yes	Yes	Yes
Was the study described as blinded?	Yes	Yes	Yes	Yes	Yes
Was the method of blinding appropriate?	Yes	Yes	Yes	Yes	Yes
Was there a description of withdrawals or dropouts?	Yes	Yes	Yes	Yes	Yes
Was there a clear description of the inclusion/exclusion criteria?	Yes	Yes	Yes	Yes	Yes
Was the method used to assess adverse effects described?	Yes	Yes	Yes	Yes	Yes
Was the method of statistical analysis described?	Yes	Yes	Yes	Yes	Yes
Total score	8	8	8	8	8

Clinical results

Four studies did not find any significant difference between the two groups (mechanical or kinematic alignment) for all the scores (179–182). One study found a significant difference between the two groups for all the scores (183). In this study, patients who underwent kinematically aligned TKA had significantly better scores for pain, function and ROM than those who underwent mechanically aligned TKR. Patients in KA group had less pain according to the OKS and WOMAC scores. The mean flexion was increased by 8.5° in the KA group compared to the MA group. All clinical results are reported in Table 3.

Table IV-3: Clinical results at the last follow up

Studies	Clinical assessment	Kinematic alignment Mean (SD) (range)	Mechanical alignment Mean (SD) (range)	<i>p</i> -value
Dossett et al. 2014 (183)	OKS	40 (10.2) (15-48)	33 (11.1) (13-48)	0.005
	WOMAC	81 (20.3) (33-100)	70 (22.6) (23-100)	0.005
	KSS	160 (31.9) (93-200)	137 (37.9) (64-200)	0.005
	Flexion	121 (10.4) (100-150)	113 (12.5) (80-130)	0.002
Yeo et al. 2018 (180)	HSS	94.8 (5.5)	79.6 93.2 (8.0)	> 0.05
	WOMAC	(1.8)	140.2 80.7 (1.9)	> 0.05
	KSS	(16.6)	129 137.6 (16.1)	> 0.05
	Flexion	(11.5)	125 (11.5)	> 0.05
Laende et al. 2019 (181)	OKS	31 (7.8)	94 30 (8.6)	0.61
	Satisfaction	(12.9)	6.1 91 (19.0)	0.49
	UCLA	(1.9)	5.9 (2.0)	0.60
McEwen et al. 2020 (182)	OKS	44.4 (4.3) (30-48)	44.1 (4.1) (32-48)	0.58
	KOOS JR	89.6 (12.9) (55-100)	88.5 (13.7) (45-100)	0.69
	FJS	79.9 (23.5) (0-100)	79.6 (19.4) (19-100)	0.54
	Flexion	127 (10) (101-154)	127 (11) (105-150)	0.98
Young et al. 2020 (179)	OKS	41.4 (7.2)	86.1 41.7 (6.3)	0.99
	WOMAC	(15.5)	68 (28.8) 89.1 (15.3)	0.65
	FJS	155.6 (30.6)	78.2 74.4 (23.6)	0.29
	KSS	(16.5)	160.9 (25.8)	0.65
	VAS		78.4 (17.1)	0.99

(SD=Standard deviation)

OKS Oxford Knee Score, WOMAC Western Ontario and McMaster Universities Osteoarthritis Index, KSS Knee Society Score, ROM Range of Motion, FJS Forgotten Joint Score, VAS Visual Analogue Scale, HSS Hospital for Special Surgery knee score, UCLA University of California at Los Angeles Activity score, KOOS JR Knee Injury and Osteoarthritis Outcome Score Junior

Radiological results

For all studies, postoperative HKA was not significantly different between both groups. However, in each study, the tibial component was placed significantly more in varus (from 2° to 3.5°) in the KA group compared to the MA group. Also, four studies reported the femoral component positioning and it was significantly more in valgus (from 1.3° to 1.8°) in the KA group compared to the MA group. All radiographic results are reported in Table 4.

Table IV-4: Radiological results at the last follow up

Studies	Radiological assessment	Kinematic alignment	Mechanical alignment	p-value
		Mean (SD) (range)	Mean (SD) (range)	
Dossett et al. 2014 (183)	HKA	-0.1 (2.8) (-8.5 to 7.7)	0.1 (2.5) (-4.9 to 8.9)	0.818
	AKA	3.5 (2.3) (0.1 to 9.5)	2.9 (2.3) (-1.2 to 8.0)	0.233
	JLOA	2.0 (2.0) (-3.1 to 6.6)	0.1 (2.7) (-4.1 to 8.4)	<0.001
	FMA	1.3 (2.0) (-2.4 to 6.5)	-0.8 (2.7) (-5.8 to 6.3)	<0.001
	TMA	-2.2 (2.6) (-8.7 to 4.4)	0.0 (2.1) (-6.4 to 3.8)	<0.001
Yeo et al. 2018 (180)	HKA	0.1 (2.0)	-0.3 (1.7)	n.s
	FMA	1.7 (1.9)	-0.5 (0.4)	0.04
	TMA	-2.5 (1.7)	0.1 (0.4)	0.03
	TS	-7.5 (2.8)	-6.4 (1.0)	n.s
Laende et al. 2019 (181)	HKA	-2.3 (2.6)	-2.1 (2.1)	0.75
	MPTA	-3.3 (2.0)	-0.8 (1.7)	<0.001
McEwen et al. 2020 (182)	HKA	-1.0 (2.4) (-6.0 to 3.9)	-0.2 (2.1) (-4.5 to 5)	0.097
	FMA	1.8 (2.0) (-2.5 to 5.5)	-0.1 (0.6) (-1.5 to 1)	<0.001
	TMA	-2.5 (1.3) (-5.5 to 0.5)	-0.3 (0.4) (-1 to 0.5)	<0.001
	TS	3.1 (1.8) (-0.5 to 7.5)	3.2 (1.8) (-0.5 to 7.5)	0.713
	JLOA	-0.9 (2.6) (-6.4 to 4.9)	0.8 (2.1) (-5.2 to 5.2)	0.002
	JLCA	0.7 (0.7) (0.0 to 3.3)	0.9 (0.6) (0 to 2.2)	0.141
	PTA	5.7 (5.8) (-2.9 to 20.1)	4.4 (4.9) (-6 to 14.8)	0.278
Young et al. 2020 (179)	HKA	-0.4 (3) (-11 to 6)	-0.7 (2) (-5 to 4)	0.6
	FMA	2 (2.5) (-4 to 6)	0.5 (1.6) (-3 to 4)	0.002
	TMA	-3 (3) (-10 to 4)	-0.7 (1.8) (-6 to 2)	<0.001
	TS	-4 (2.5) (-10 to 2)	-1.3 (2) (-7 to 3)	<0.001

(SD=Standard deviation)

HKA Hip-Knee-Ankle angle, AKA Anatomic Knee Angle, JLOA Joint Line Orientation Angle, FMA Femoral component relative to Mechanical Axis, TMA Tibial component relative to Mechanical Axis, TS Tibial Slope, MPTA Medial Proximal Tibial Angle, JLCA Joint Line Convergence Angle, PTA Patellar Tilt Angle

Other measurements

Among studies, three reported postoperative complication rate between MA and KA groups at the last follow-up and no significant difference was found (179,182,183). One study compared gait analysis, and no significant difference was found between the KA and MA groups (180). Laende et al. (181) compared the tibial component migration at two years which was not significantly different between both groups. McEwen et al. (182) in their study found that significantly more patients preferred their KA joint and patients were visually insensitive to HKA angle asymmetry.

Two studies (179,182) reported intraoperative gap laxity values and soft tissue releases. Both studies showed the same results with no significant difference being found for the gap laxity values between KA and MA groups. However, a significant increase in the number of releases was necessary to produce the target laxity values in the MA group compared to the KA group in both studies.

Discussion

This review is the first to isolate all comparative studies between KA and MA groups with a minimum follow-up of 2 years. All studies included were level I and therefore of very high quality. The most important findings of this review were to show comparable or superior clinical outcomes of KA TKA to those of MA TKA. The limb and knee alignment in KA TKA were similar to those of MA TKA, still the femoral component was placed slightly more in valgus and the tibial component was implanted in mild varus in KA TKA. The JLOA of the KA TKA was quite parallel to the floor and closer to the native knee than the JLOA of the MA TKA. Moreover, the complication rate was not increased for KA TKA.

More individualized alignment strategies in TKA, such as kinematic alignment, appears to be one of the “hot” topics in TKA procedures (220). This is particularly interesting to surgeons convinced by the fundamental principles of mechanically aligned TKA, and yet willing to improve clinical results after TKA. Indeed, according to previous studies (204,221), good performance of knee functional recovery is directly associated with patient satisfaction and implant survival. KA has gained extensive interest according to high encouraging patient-reported results (203,204). McEwen et al. (182) showed that significantly more patients preferred their KA joint compared to their MA joint. The satisfactory results reached with KA TKA could be attributable to the attempt to replicate the alignment of the pre-osteoarthritic knee

(222). A study of 214 cases with a mean follow-up of 38 months showed that no patients required revision of either component for loosening, wear or instability, which helps support the efficiency of KA in TKA (176). However, this study only analyzed a cohort of TKA aligned kinematically and did not compare with a control group.

There has been, and there still is a concern, that varus alignment of the tibial component might compromise clinical results and place implants at a higher risk for loosening (186,223–225). KA, which increases the varus angle of the tibial implant, could result in different complications. However, focusing on implant survivorship, in contrast to the original concerns, KA TKA did not appear to lead to an increased early may not lead to increased early rate of loosening (174,205,226,227) considering short and mid-term follow-up. One explanation is that KA TKA restores the JLOA of the native knee, which is parallel to the floor when standing, thereby mitigating overload of the medial and lateral tibial compartment (226,228). Moreover, Howell et al. reported no significant difference in complication rate for TKA with KA compared to TKA with MA even at long term follow-up (177). Laende et al. (181) showed a similar tibial component migration in the KA group compared to the MA group, even with a tibial component placed in varus. However, precautions must be taken when placing component in a kinematical alignment. Nedopil et al. highlighted a strategy for lowering the risk of tibial component loosening when performing KA which is to set the tibial component parallel to the flexion-extension plane (slope) and varus-valgus plane of the native joint line (229).

In KA TKA, the aim is to implant components in a personal position recreating the anatomy of the pre-arthritis articular surface of each patient is chosen. KA allowing a closely match with the native patient anatomy and the soft tissue envelope of the knee potentially, it will potentially improve ligament balancing and minimize the need for soft tissue releases and decreases the bone resection (179,182,230,231). Moreover, Blakeney et al. showed that the knee kinematics of patients with kinematically aligned TKAs more closely resembled that of normal healthy controls than that of patients with mechanically aligned TKAs (232). Thus, a return to normal gait parameters after TKA will potentially lead to improved clinical outcomes with greater patient satisfaction. Consequently, KA may be considered as a safe procedure based on our review and the literature.

Several limitations should be discussed. Firstly, we only found five relevant studies that compared KA with MA in TKA with a minimum follow-up of 2 years. Secondly, despite a minimum follow-up of 2 years, the follow-up periods were generally too short to determine long-term longevity and survival. Thirdly, the operative method and instrumentation used to

achieve kinematic alignment was not identical in all the studies, ranging from the use of patient-specific instruments with custom cutting guides to computer navigation or robotic assisted instrumentation. Furthermore, the target alignment in KA groups was not well defined for each study. However, radiological alignment results in KA groups appeared to be comparable for all studies. And lastly, the sample size in each group was relatively small.

Conclusion

In conclusion, we found that KA in TKA achieved clinical and radiological results similar to those of MA. The complication rate was not increased for KA TKAs. The present review suggests that KA is an acceptable and alternative alignment to MA. Studies with longer follow-up and larger cohorts are required to prove any benefit of the KA technique over MA technique.

En résumé, cette revue systématique a permis de montrer que l'alignement cinématique après PTG permettait d'obtenir des résultats cliniques similaires voire meilleurs par rapport à l'alignement mécanique à un recul minimum de 2 ans. Il est important de noter que les études inclus dans cette revue comparent des PTG à conservation du ligament croisé postérieur.

2.3.5 Article 5 – L’alignement cinématique correspond à l’alignement fonctionnel sur l’espace en extension: analyse consécutive de 749 genoux en varus à l’aide de radiographie en stress

Cette revue de la littérature a permis de montrer que l’alignement cinématique est une alternative envisageable à l’alignement mécanique. Une nouvelle classification radiologique, à partir de repères osseux, (CPAK-Coronal Plane Alignment of the Knee) (233) de l’alignement coronal du genou a été décrite pour mieux comprendre les différents phénotypes du genou en considérant l’alignement constitutionnel (Arithmetic HKA) et l’obliquité de l’interligne (Joint Line Obliquity-JLO) (Figure 11).

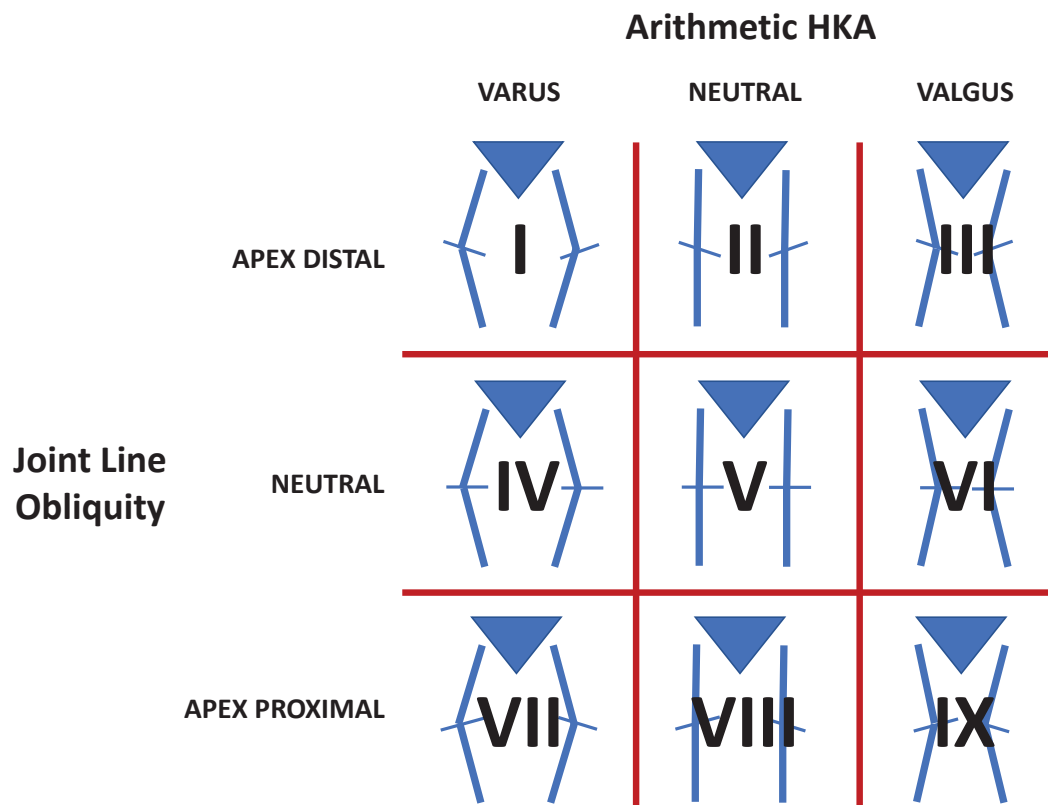


Figure 11: Classification CPAK (Coronal Plane Alignment of the Knee) avec 9 phénotypes différents.

Il a été montré que l’arithmetic HKA, sur un genou atteint d’arthrose, prédisait l’alignement constitutionnel du membre inférieur avant le développement de l’arthrose (234). Cependant, cette classification étant basée sur des repères osseux, nous nous sommes demandé si l’alignement constitutionnel évalué par l’arithmetic HKA prenait en compte la laxité

ligamentaire. Nous avons donc mesuré l'angle médial « valgus corrected HKA » (vcHKA), sur nos radiographies préopératoires dynamiques en valgus. Cet angle vcHKA compense l'usure cartilagineuse et la laxité ligamentaire médiale en cas d'arthrose en varus. Si les résultats sont similaires entre l'alignement constitutionnel mesuré par l'arithmetic HKA et le vcHKA, cela signifierait que la classification CPAK permettrait d'anticiper l'alignement fonctionnel sur l'espace en extension du genou.


Ce travail a abouti à une publication dans le journal *Knee Surgery Sports Traumatology Arthroscopy*.

Knee Surgery, Sports Traumatology, Arthroscopy
<https://doi.org/10.1007/s00167-021-06832-0>

KNEE



Kinematic alignment matches functional alignment for the extension gap: a consecutive analysis of 749 primary varus osteoarthritic knees with stress radiographs

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Received: 17 August 2021 / Accepted: 30 November 2021

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Résumé en français

Introduction

Récemment, plusieurs auteurs ont souligné la nécessité d'une stratégie de réaligement plus personnalisée et plus individuelle lors de la réalisation d'une prothèse totale de genou. Deux principales stratégies persistent : l'alignement cinématique et fonctionnelle. Une nouvelle classification « Coronal Plane Alignment of the Knee » a été décrite considérant l'obliquité de l'interligne et l'angle HipKneeAnkle (HKA) arithmétique (aHKA). Il a été montré que l'aHKA permettrait de prédire l'alignement constitutionnel du genou arthrosique par rapport au genou controlatéral sain. Il pourrait donc être proposé comme objectif d'alignement postopératoire en cas d'alignement cinématique obtenu à partir de repères osseux. Les radiographies en stress en valgus compensent l'usure cartilagineuse et l'équilibrage ligamentaire en cas d'arthrose en varus. Le but de cette étude est de comparer l'angle mesuré en médial sur les clichés en stress en valgus (vcHKA) et l'aHKA afin d'évaluer l'usure cartilagineuse et l'équilibrage ligamentaire.

Matériels et méthodes

Une étude rétrospective monocentrique a été menée à partir de données colligées en prospectif entre 2015 et 2019, incluant 749 arthroses médiales essentielles consécutives chez 672 patients. Une pangonométrie et des radiographies en stress en valgus étaient réalisées. L'angle tibial mécanique (ATM), l'angle fémoral mécanique (AFM), l'angle aHKA (ATM+AFM) et le vcHKA étaient mesurés. L'aHKA et le vcHKA ont été comparés.

Résultats

L'AFM moyen était $91,3^\circ \pm 2,3$ ($82^\circ - 97^\circ$), l'ATM était $85,7^\circ \pm 2,5$ ($75^\circ - 98^\circ$), l'aHKA moyen était $177,1^\circ \pm 3,3$ ($164^\circ - 185^\circ$) et le vcHKA moyen était $176,9^\circ \pm 3,2$ ($165^\circ - 192^\circ$). Aucune différence significative n'a été retrouvée entre l'aHKA et le vcHKA ($p=0,06$). Une corrélation significative a été identifiée entre vcHKA et l'ATM ($\rho=0,3$; $p<0,001$) et entre le vcHKA et l'AFM ($\rho=0,41$; $p<0,001$).

Conclusion

Cette étude a montré que le vcHKA était identique à l'aHKA confirmant que l'aHKA prédit l'alignement pré-arthritique du genou. De plus, cela souligne le fait que l'alignement cinématique, obtenu à partir de repères osseux, est efficace pour reproduire l'alignement du genou natif ainsi que l'équilibrage ligamentaire natif.

Abstract

Purpose

The alignment goal in total knee arthroplasty (TKA) remains debated. Two major strategies have emerged based on recreating the native knee: kinematic and functional alignment (KA and FA). Recently a new Coronal Plane Alignment of the Knee (CPAK) classification for KA, based on bony landmarks, was described considering joint line obliquity and the arithmetic HipKneeAnkle angle (aHKA). Valgus corrected HKA medial angle (vcHKA) was measured on distractive valgus preoperative radiographs compensating for cartilage wear and ligament balance in varus osteoarthritis. The purpose of this study was to determine if aHKA accounts for differences in medial laxity for the extension gap by comparing vcHKA to aHKA. The hypothesis was that no significant difference would be observed between the two measurements.

Methods

This is a retrospective analysis of 749 knees in consecutive patients presenting to a single-centre with primary medial osteoarthritis. Patients underwent standardized weight bearing long-leg and valgus stress radiographs. Tibial mechanical angle (TMA), femoral mechanical angle (FMA) and vcHKA were measured using digital software. aHKA and vcHKA were compared to determine differences due to soft tissue balancing.

Results

The mean FMA was $91.3 \pm 2.2^\circ$ (range $82^\circ - 97^\circ$), the mean TMA was $85.7 \pm 2.5^\circ$ (range $75^\circ - 98^\circ$), the mean aHKA was $177.0 \pm 3.0^\circ$ (range $164^\circ - 185^\circ$) and the mean vcHKA was $176.6 \pm 3.1^\circ$ (range $165^\circ - 192^\circ$). No significant difference was observed between aHKA and vcHKA ($p=0.06$). A significant correlation was found between vcHKA and TMA ($\rho=0.3$; $p<0.001$) and between vcHKA and FMA ($\rho=0.41$; $p<0.001$).

Conclusion

This study showed that vcHKA was similar to aHKA confirming that aHKA accounts for ligamentous medial laxity. Therefore, kinematic alignment based on the CPAK classification matches the pre-arthritis coronal alignment of the knee for the extension gap.

Level of evidence: IV.

Keywords constitutional alignment; distractive valgus knee radiographs; Total Knee Arthroplasty; functional alignment; kinematic alignment; extension gap

Introduction

Insall et al. described mechanical alignment (MA) for TKA procedures (12) offering good long-term implant survival. However, 20% of the patients remain dissatisfied following TKA (200). MA has recently been criticized for its systematic approach that does not accommodate and consider variations in native anatomy (155,203).

Alternative alignment philosophies have been proposed in an attempt to improve clinical outcomes and reduce patient dissatisfaction (5,6). Recently studies suggest performing a more personalized realignment strategy with the aim of reproducing native knee alignment may result in joint behavior that more closely resembles normal kinematics (187,189,220,233). Several studies showed wide variation for knee coronal alignment in native population (147), in osteoarthritic population (235) and found comparable joint line orientation between native and osteoarthritic populations (236). These observations support a rationale for an alignment philosophy that adjusts for variations in patient anatomy, however the appropriate strategy remains elusive. Kinematic and functional alignment techniques are two such strategies that aim to restore the knee to its pre-arthritis state (151). Kinematic alignment is based on bony landmarks. Concerns regarding variation in ligament laxity profile of patients has given rise to the concept of a functional alignment (6). Functional alignment considers cartilage wear, but adjusts the planned cuts based on predicted gaps using ligament balancing (193). Defining KA requires the patient's constitutional alignment to be known, however determining this once arthritic wear has occurred can be difficult. Recently, MacDessi et al. (233) described a new classification for knee alignment using an arithmetic HKA (aHKA) method and validated its use in KA by demonstrating it accurately predicts the constitutional alignment of the arthritic knee. This method however is based on bony landmarks and therefore may not reflect ligament balancing. Furthermore, it has previously been suggested that distractive stress radiographs provide a more accurate indication of the ligamentous laxity compared to weight-bearing films in the knee (237).

The purpose of this study was to measure and compare valgus corrected HKA (obtained from distractive valgus x-rays) to aHKA. The hypothesis was that no significant difference would be observed between the two measurements indicating that the aHKA method predicts constitutional knee alignment and accounts for ligamentous laxity in this patient group for the extension gap.

Material and methods

Ethical approval

The Advisory Committee on Research Information Processing in the Field of Health (CCTIRS) approved this study on June 4, 2015 under the number 135-5265. All procedures performed were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

A monocentric study of prospectively collected data from 2015 and 2019 included a total of 1095 consecutive osteoarthritic knees presenting for primary TKA. Patients with any previous history of surgery on the ipsilateral limb, including the knee, were excluded. Measurement of the Hip-Knee-Ankle (HKA) angle can be modified by a flexion contracture (152,153). Thus, to avoid any inaccurate measurements of radiologic parameters, all patients with knee flexion contracture of more than 5° and severe bone deformity (Ahlbäck classification > 3) were excluded. A total of 749 knees in 672 patients were included for final analysis. The flowchart is illustrated in Figure 1. All data related to the cohort is presented in Table 1.

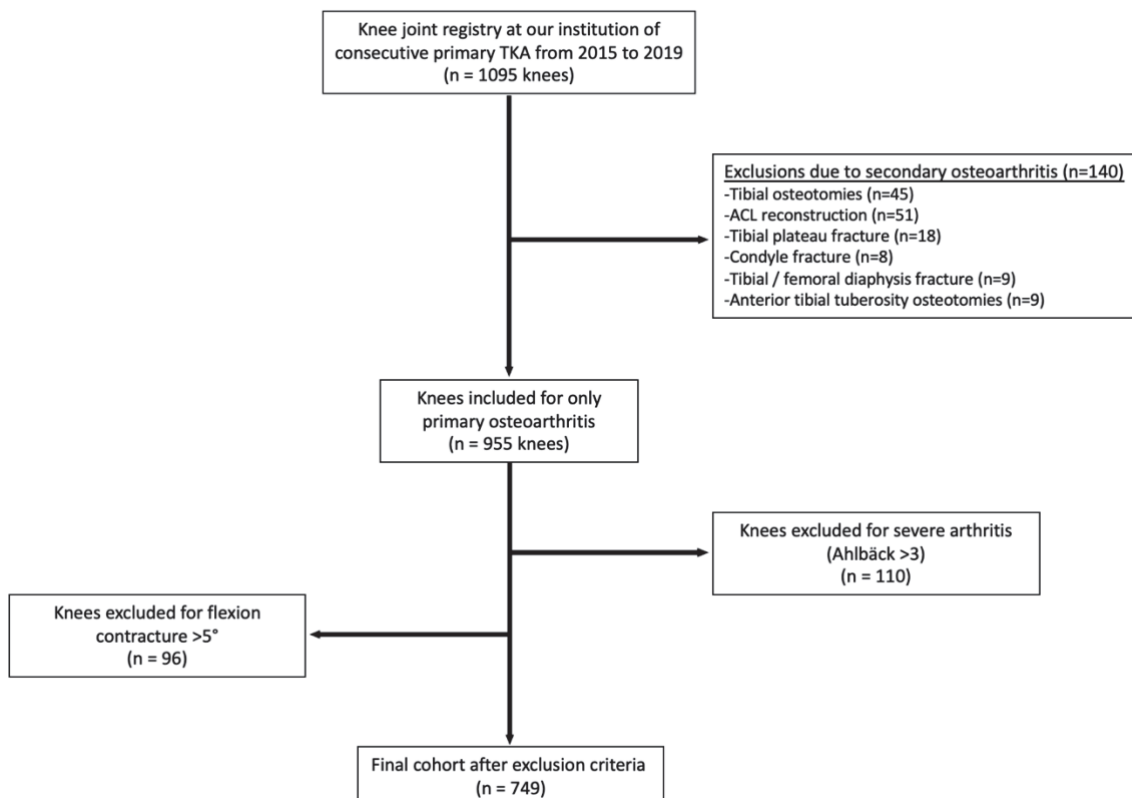


Figure V-1: Consort diagram of the population of the study.

Table V-1: Patient Demographics

	n= 672
Mean age at surgery (years)	70.4 ± 8.2 (43-97)
Gender	
Female	390 (52.1%)
Male	359 (47.9%)
Side	
Right	282
Left	313
Bilateral	77
Mean BMI	30.7 ± 6.5 (18.4-55.0)
Ahlbäck Classification	n=749
Grade 0	-
Grade 1	23 (0.3%)
Grade 2	228 (30.3%)
Grade 3	498 (66.4%)
> Grade 3	Excluded

Imaging Protocol

All patients underwent radiographic assessment according to a standardized protocol (235). Briefly, full weight-bearing long-leg standing radiographs were performed barefoot with feet placed together and the patella oriented forward to avoid rotational variation (154). Distractive valgus radiographs were performed using a standardized protocol that applies a valgus force of 12kg (127 Newton) with a Telos device (Telos, Weiterstadt, Germany).

Radiographic Measurement

All measurements were made using PACS digital radiographic software (Centricity™, GE healthcare, Chicago, USA) and measured by the same evaluator (P.M.). All measurements were rounded to the first decimal place. The HKA angle, the Tibial Mechanical Angle (TMA) and the Femoral Mechanical Angle (FMA) were measured according to previously described technique (154,235). These angles are illustrated in figure 2. The constitutional HKA (cHKA), considered as the constitutional limb alignment, was calculated by adding FMA and TMA as previously described by Macdessi et al. Absolute values between the cHKA and aHKA are different but have corresponding meanings. For example, varus cHKA will have a value inferior to 180°, ie 176° whereas varus aHKA will have a negative value (<0°), ie -4°.

The Hip-Knee-Shaft (HKS) angle corresponded to the angle between the anatomical axis (diaphysis center) and the mechanical axis of the femur. The Lateral Stress Valgus angle (LSV) corresponded to the lateral angle between the mechanical axis of the femur and the mechanical axis of the tibia measured on distractive valgus radiographs. These two angles are illustrated in figure 3. The valgus corrected HKA angle (vcHKA) was determined by subtracting (HKS + LSV) angle from 360° . The vcHKA reflects the alignment of the lower limb compensating the medial cartilage wear and the medial ligament balance.

The vcHKA and aHKA were compared. A subgroup analysis was performed to compare aHKA and vcHKA according to the pre-operative HKA defined as three subgroups (group 1: $HKA > 175^\circ$; group 2: $170^\circ < HKA < 175^\circ$; group 3: $HKA < 170^\circ$). Correlation analyses were performed between the vcHKA and TMA or FMA.

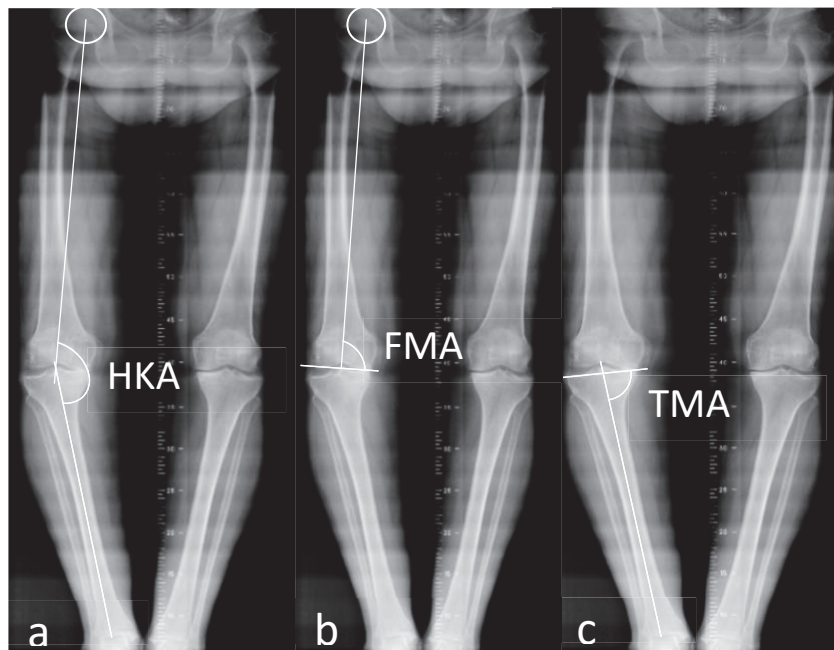


Figure V-2: Measurement Methodology
a. HKA: Hip-Knee-Ankle angle.
b. FMA: Femoral Mechanical Angle.
c. TMA: Tibial Mechanical Angle.

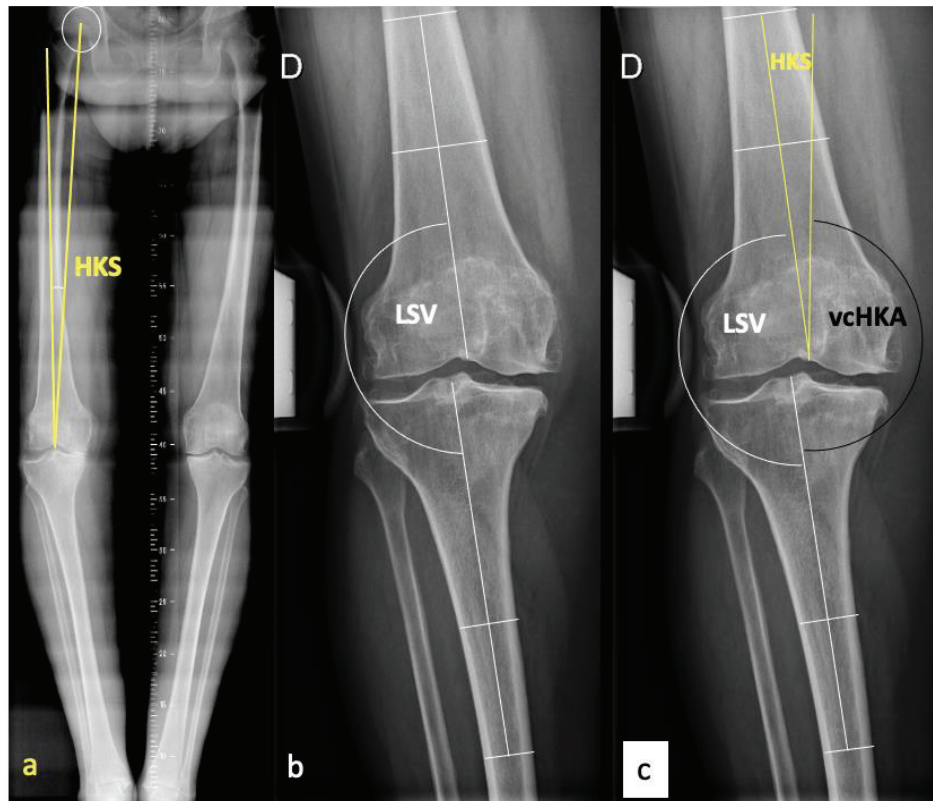


Figure V-3: Measurement Methodology

a. HKS: Hip-Knee-Shaft angle (yellow)

b. LSV: Lateral Stress Valgus angle (white)

Valgus stress radiograph were used to calculate LSV angles, which are measured by taking the angle created by two lines. The first line passes through the midpoints of the distal femoral shaft, 12.5cm and 7.5 cm from the distal femoral articular surface. The second line passes through the midpoints of the proximal tibia, 12.5cm and 7.5 cm from the proximal tibial articular surface.

c. vcHKA: valgus corrected HKA angle (vcHKA) was determined by subtracting (HKS + LSV) angle from 360° (dark)

Statistical analysis

Statistical analysis was performed using XLSTAT software (copyright Addinsoft 2021). Descriptive data analysis such as means, standard deviations and ranges were performed. T tests for independent samples were performed to compare group differences. Pearson correlation Significance was set at $p < 0.05$.

A post hoc analysis was performed with a mean difference of 0.4 degrees between both groups, with common standard deviation of 3 points, a power at 0.8 and an alpha risk at 0.05. A minimum sample size of 696 cases in each group was necessary for this study.

Results

Descriptive demographics and radiological outcomes

All radiological parameters measured and differences between genders are reported in Table 2. Significant differences for all radiological parameters were found, except the HKS, between males and females.

Table V-2: Radiographic outcomes

	n= 749	n=461 Female gender	n=288 Male gender	p-value
Mean HKA angle (°)	172.0 ± 4.0 (159-179)	172.4 ± 4.0 (159-180)	171.3 ± 3.9 (159-179)	< 0.001
Mean FMA angle (°)	91.3 ± 2.2 (82-97)	91.5 ± 2.3 (82-96)	91.0 ± 2.2 (84-97)	0.003
Mean TMA angle (°)	85.7 ± 2.5 (75-98)	86.0 ± 2.4 (78-98)	85.1 ± 2.5 (75-91)	< 0.001
Mean HKS angle (°)	6.5 ± 1.0 (4-12)	6.5 ± 1.0 (4-12)	6.6 ± 1.0 (4-10)	0.78
Mean cHKA angle (°)	177.0 ± 3.0 (164-185)	177.5 ± 3.0 (167-185)	176.2 ± 3.1 (164-184)	< 0.001
Mean vcHKA angle (°)	176.6 ± 3.1 (165-192)	177.3 ± 3.2 (167-191)	176.2 ± 3.1 (165-192)	< 0.001

Comparisons analyses

No significant difference was observed between aHKA and vcHKA (177.0 ± 3.0 [range $164^\circ - 185^\circ$] vs 176.6 ± 3.1 [range $165^\circ - 192^\circ$]; $p=0.06$). All comparisons results are reported in Table 3. No significant differences were found for the subgroup analysis for the groups 1 and 3. A significant difference was found for the group 2, although this was not clinically significant as the mean difference was only 0.5° .

A significant correlation was found between vcHKA and TMA ($\rho=0.3$; $p<0.001$) and between vcHKA and FMA ($\rho=0.41$; $p<0.001$). The more the tibia or the femur was in varus, the lower was the vcHKA.

Table V-3: Comparison of radiographic results

	cHKA(°)	vcHKA(°)	p Value
Overall population (n=749)	177.0 ± 3.0 (164-185)	176.6 ± 3.1 (165-192)	0.06
Preop HKA > 175° (n=224)	179.6 ± 2.2 (171-185)	179.8 ± 2.7 (173-192)	0.81
$170^\circ <$ Preop HKA $< 175^\circ$ (n=340)	177.1 ± 2.2 (170-184)	176.6 ± 2.3 (170-184)	0.003
Preop HKA < 170° (n=185)	173.8 ± 3.3 (164-181)	174.3 ± 2.7 (165-184)	0.16

Intra- and inter- observer reliability

Two surgeons performed fifty measurements of the three different angles twice in order to assess intra and inter-observer reliability with a period of one month between measurements. Intra-observer reliability was found to be good, with a Pearson correlation coefficient, of $\rho=0.82$ (95% CI [0.75 ; 0.89]; $p<0.001$) for FMA, $\rho=0.85$ (95% CI [0.77 ; 0.93]; $p<0.001$) for TMA and $\rho=0.88$ (95% CI [0.81 ; 0.94]; $p<0.001$) for vcHKA. Inter-observer reliability was also found to be good, with a Pearson correlation coefficient of $\rho=0.87$ (95% CI [0.81 ; 0.92]; $p<0.001$) for FMA, $\rho=0.76$ (95% CI [0.66 ; 0.86]; $p<0.0001$) for TMA and $\rho=0.81$ (95% CI [0.76 ; 0.90]; $p<0.001$) for vcHKA.

Discussion

The most important finding of this study was that vcHKA was not significantly different from cHKA confirming that the arithmetic algorithm accounts for variations in ligamentous laxity in varus knee OA up to severity Alback grade 3. These findings are significant as they further validate the aHKA method and demonstrate that this algorithm can be used as a tool for surgeons planning KA TKA considering the extension gap.

Several studies showed less soft tissue releases when performing KA compared to MA (182,191,238). Also, a better ligament balance and a more natural gait was found by some authors when performing KA (190,232,239). As no significant difference was found between aHKA and vcHKA in the present study, these results confirm that KA using the aHKA predicts constitutional alignment in extension by accounting for ligament balance for varus knees.

Significant correlations were found between vcHKA and TMA and between vcHKA and FMA. The more the tibia or the femur was in varus, the lower the reducibility of the deformity was observed. This suggests that when bony morphology is the main contributor to varus deformity (varus FMA or TMA), residual varus alignment of the lower limb will be observed when medial soft tissue releases are avoided, especially with kinematic or functional philosophies.

The findings of the current study indicate that in a varus population when surgeons perform a TKA using a KA philosophy they will obtain a well-balanced knee in extension when the aHKA and the vcHKA are identical. In the case of vcHKA and aHKA being the same, balancing the knee from bony landmarks is achieved by the composite-cartilage thickness to matching the implant and restores the pre-arthritis knee alignment. This is supported by the findings of Waldtsein et al. (240) who found stress radiographs accurately measured reflect bone and cartilage loss in the lateral compartment. However, when aHKA is higher or lower than the vcHKA, this suggests medial collateral ligament has changed length either through attenuation or fibrosis. These findings are supported by Lee et al. (241) who recently demonstrated that valgus stress x-rays can predict the need for soft tissue release in varus deformity during TKA (242,243). In these scenarios a functional alignment that accounts for the change in laxity would be required to obtain a well-balanced knee. Moreover, Graichen et al. (244) showed a large inter-individual variability regarding gap widths and gap differences in varus knees. As varus knees are not all alike, especially considering the flexion gap, the individual gap sizes need to be analyzed and addressed accordingly with an individualized

balancing technique such as functional alignment. Therefore, arithmetic HKA would not be sufficient to anticipate the constitutional knee alignment.

In the present study, significant differences were found between genders. Female patients appeared to have more laxity compared to male patients. This is in line with previous studies (245). However, it should be interpreted with caution as differences even though statistically significant were so small as to not be considered as clinically relevant. Indeed, the mean differences observed of one degree could be due to the accuracy of the measurements (246).

This study has several limitations. Alignment measurements on full weight-bearing long leg radiographs could be criticized for being less accurate compared to measurements using other imaging modalities such as CT or MRI. Still, multiple authors observed good agreement between supine CT scanograms and full-length radiographs (162,163,165). Also, in this study, the authors considered only FMA and TMA, which are measured by bony landmarks which are amenable to accurate determination with long-leg radiographs. Not analyzing HKA allowed this study to avoid the confounding factor of knee laxity under weight-bearing. Moreover, to avoid any measurement inaccuracies in radiological parameters, very strict inclusion criteria were adhered to, and only knees without any medical or surgical history were considered for final analysis. Radiographs were all performed to a standardized protocol to avoid rotational variance, which could alter coronal alignment measurements (164). Finally, it is important to emphasize that like previous methods described (233), valgus stress x-rays provide information regarding balancing in extension, and its ability to predict ligament behavior in flexion has not been studied in the present study. Further research is required to determine if stress radiographs provide similar information regarding flexion space balancing or if functional sagittal and horizontal positioning of TKA requires additional tools accounting for ligament tension during surgery such as robotics or sensors.

This study is clinically relevant highlighting that constitutional knee alignment determined by kinematic alignment using the arithmetic HKA matches functional coronal alignment of the knee after TKA. It allows to restore the constitutional knee alignment and constitutional knee balance for varus knees considering the extension gap.

Conclusion

This study showed that vcHKA was similar to aHKA confirming that aHKA accounts for ligamentous medial laxity. Therefore, kinematic alignment based on the CPAK classification matches the pre-arthritic coronal alignment of the knee for the extension gap.

Funding No specific grants were received from public, private for-profit and non-profit organizations for this study.

En résumé, cette étude a permis de montrer que l'alignement cinématique évalué par la nouvelle classification CPAK correspondait à l'alignement fonctionnel du genou avant arthrose pour l'espace en extension.

2.4 La marche humaine

2.4.1. Définition de la marche

La marche peut être définie comme une répétition de séquences de mouvements des segments du corps permettant la propulsion et l'avancement du corps tout en maintenant l'équilibre (247). A un rythme libre, c'est une activité quasi-périodique avec des phases droites et gauches. De ce fait, pour pouvoir être analysée, la marche est découpée en termes d'événements clés et de phases principales qui se produisent pendant le cycle de marche.

2.4.2 Le cycle de marche

Un cycle de marche pour un membre est défini comme la durée qui va de la survenue d'un événement particulier, habituellement le contact du pied au sol, jusqu'à la prochaine apparition du même événement sur le même membre (par exemple, du contact du pied droit au prochain contact du même pied). Il est souvent représenté en pourcentage, tel que le contact du talon correspond à 0% du cycle de marche, le prochain contact du même talon correspondra à 100% du cycle de marche. Le cycle de marche peut être réduit pour chaque membre en deux phases principales, la phase d'appui (60% du cycle) et la phase oscillante (40% du cycle), qui alterne pour chaque membre pendant la marche (Figure 12). On parle d'appui bipodal (ou double appui) lorsque les deux jambes sont en contact avec le sol et on parle d'appui unipodal (ou simple appui) lorsqu'une seule jambe est en contact avec le sol.

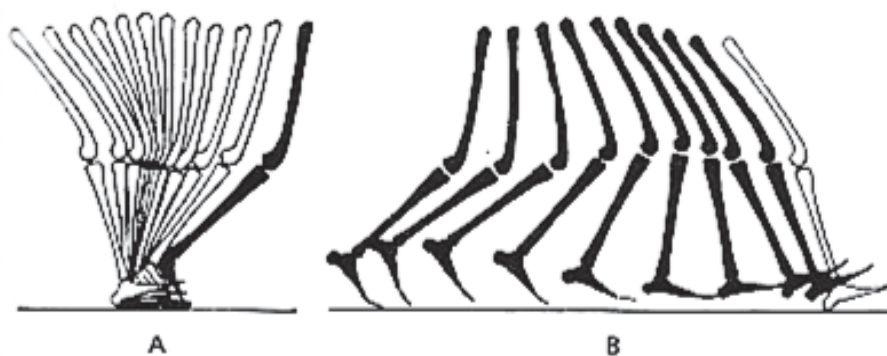


Figure 12: Positions de la jambe pendant la phase d'appui (A) et la phase oscillante (B), d'après Drillis (1958).

D'autres auteurs ont proposé différents modèles pour affiner le découpage du cycle de marche. On considèrera quatre phases dans chaque cycle de marche (Figure 13) :

❖ **La phase de mise en charge** (0 à 10% du cycle de marche).

Elle débute lorsque le pied entre en contact avec le sol (0 à 2%) alors que le membre inférieur controlatéral touche encore le sol et correspond donc au premier appui bipodal. Son rôle est de transférer le poids vers la jambe en phase d'appui, d'absorber les chocs et de conserver la vitesse de marche tout en maintenant l'équilibre.

❖ **La phase d'appui** (10 à 50% du cycle de marche).

C'est la phase de l'appui unipodal. Elle permet au corps d'avancer au-dessus du pied en appui, jusqu'à ce que le centre de masse passe en avant de l'appui. La phase se termine au contact du pied opposé avec le sol. Durant toute cette phase le pied controlatéral est en phase oscillante.

❖ **La phase de poussée** (50 à 60% du cycle de marche).

Cette phase correspond au deuxième appui bipodal. Son rôle est la propulsion du corps vers l'avant avec le transfert de poids vers la jambe en phase d'appui.

❖ **La phase oscillante** (60 à 100% du cycle de marche).

Elle correspond à la phase sans appui du pied étudié. Le rôle de cette phase est de permettre l'avancée du membre oscillant sans qu'il ait de contact avec le sol. Elle se termine lorsque le pied étudié entre à nouveau en contact avec le sol.

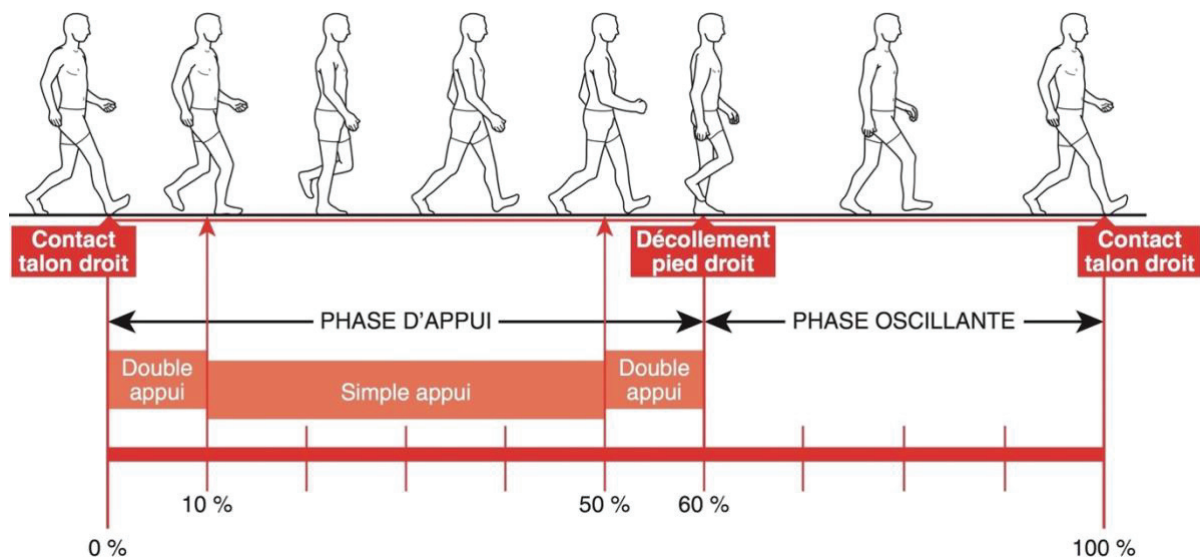


Figure 13: Différentes phases du cycle de marche comprenant deux phases d'appui bipodal, une phase de simple appui et une phase oscillante (Source : Cofemer – item 107).

Lors de l'analyse du genou au cours de la marche, il est important de distinguer ces différentes phases d'appui (unipodal, bipodal) et la phase oscillante. Pour une marche normale chez un patient sans pathologie du genou, l'axe fémoro-tibial dans le plan frontal varie peu

selon ces différentes phases. En revanche, pour un patient présentant une arthrose évoluée du genou, il peut présenter une usure fémoro-tibiale importante et donc une laxité d'usure. Selon si le patient est en charge complète ou non sur ce membre inférieur, l'axe fémoro-tibial dans le plan frontal pourrait varier selon la sévérité de l'usure fémoro-tibiale et de sa laxité d'usure.

2.5 L'analyse de la marche

2.5.1 Principe et déroulement de l'examen d'analyse de la marche

Le système KneeKG est un dispositif de traçage tibiofémoral dynamique (Figure 14). Il a pour objectif d'enregistrer et d'analyser l'alignement fémorotibial dans les trois plans de l'espace (frontal, sagittal et axial) au cours de la marche. Il mesure et analyse la position et les mouvements en 3D de capteurs insérés dans un harnais, lequel est placé sur le genou des patients dont la fonction de mouvement doit être évaluée. Le système permet de mesurer la position et l'orientation relatives en 3D du tibia par rapport au fémur. De plus, un modèle 3D de reconstruction de l'os est affiché à l'écran pendant l'évaluation afin de faciliter l'analyse et la visualisation du mouvement de l'articulation (fémur-tibia).

Il comprend un harnais pratique et facile à installer, qui permet de fixer de manière quasi rigide et non invasive des références de position optiques sur les os du genou, permettant au système de saisir les mouvements du genou en temps réel. Les données sont enregistrées dans un ordinateur hôte (à l'aide du logiciel Knee3D assessment). Le logiciel Knee3D analysis affiche les données sur des graphiques, les analyse et produit des rapports.

Le système KneeKG enregistre les données suivantes : l'alignement du membre inférieur (varus/valgus), la flexion/extension et la rotation interne/externe du tibia par rapport au fémur, ainsi que la translation antéropostérieure du tibia par rapport au fémur (Figure 15). Ces données seront disponibles à chaque étape de la marche notamment lorsque le pied entre en contact avec le sol et en appui simple monopodal.

La reproductibilité des mesures du système KneeKG a été validée par plusieurs études (248,249). La fiabilité inter et intra observateur s'est révélée satisfaisante (entre 0,88 et 0,94) (250).

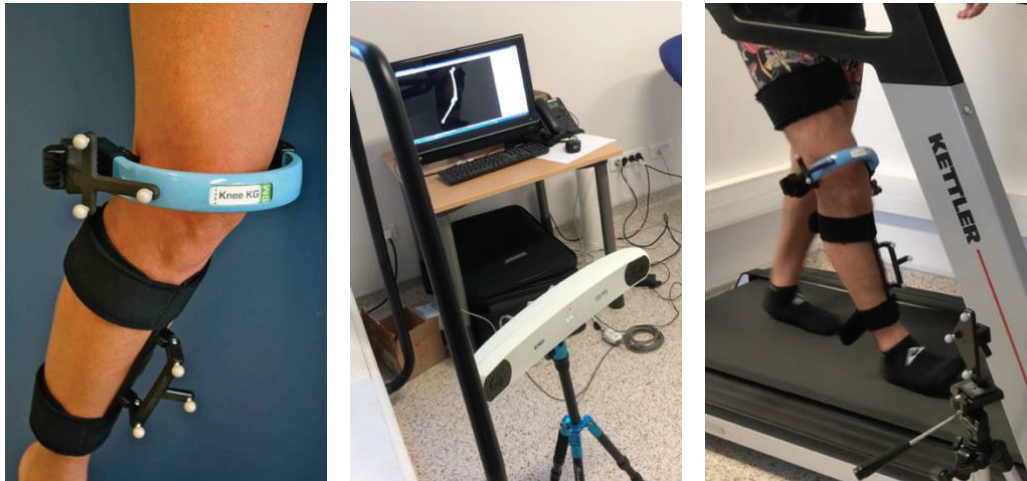


Figure 14: Système KneeKG comprenant l'ordinateur hôte avec le logiciel d'enregistrement et d'analyse, les harnais avec les capteurs pour le membre inférieur et la caméra infrarouge.

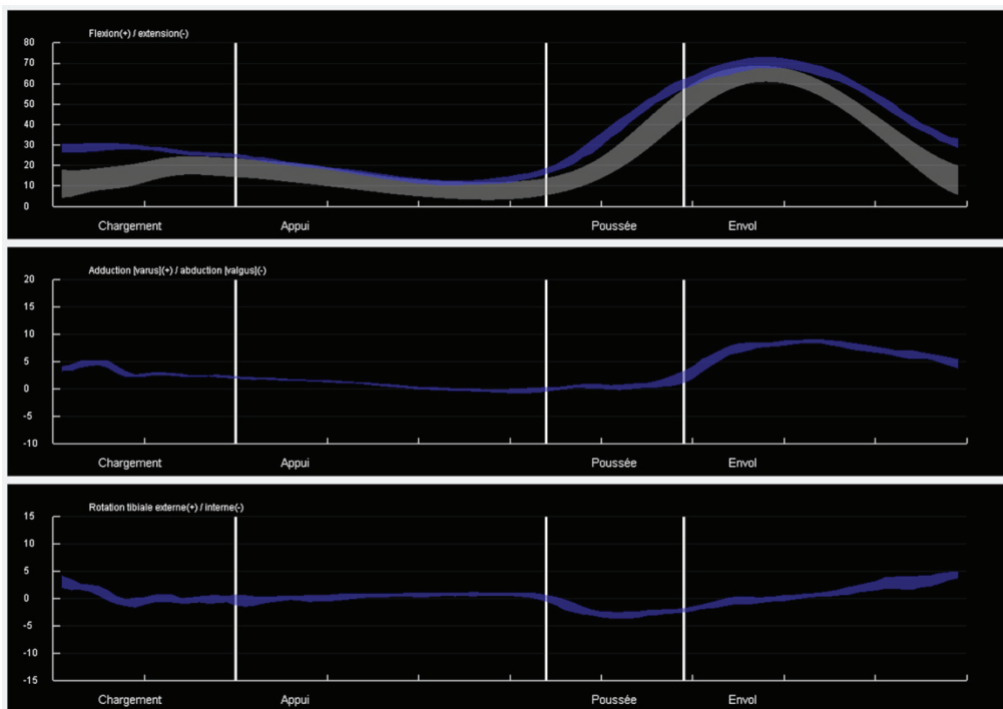


Figure 15: Graphiques obtenus avec le système KneeKG montrant la flexion/extension, l'adduction/abduction, et la rotation tibiale interne et externe en moyenne durant le cycle de marche.

Dans un premier temps, on réalise une adaptation à la marche : le patient marche 10 minutes sur le tapis de marche afin de s'habituer à marcher sur un tapis et pour déterminer sa vitesse de marche confortable la plus rapide possible. Les harnais avec les capteurs infra rouges sont ensuite positionnés par l'évaluateur (Figure 16). La plaque tibiale est positionnée légèrement en dessous de la tubérosité tibiale antérieure, et longe en interne la crête tibiale. Pour les capteurs fémoraux, l'opérateur positionne deux orthoplasts des deux côtés du genou, l'un au-dessus de la région des condyles au niveau de l'espace latéral situé entre la bandelette

iliotibiale et le tendon du muscle biceps fémoral, et le second au niveau de l'espace médial situé entre le muscle vaste médial et le tendon du muscle sartorius et du tendon des muscles semi-membraneux et tendineux (Figure 17). Les derniers capteurs (ceinture sacro-iliaque) sont installés en regard du sacrum. L'opérateur s'assure que la ceinture est positionnée sous les épines iliaques antéro-supérieures et les épines postéro-supérieures. Les extrémités supérieures du coussinet sacral sont positionnées sous les épines iliaques postéro-supérieures.



Figure 16 : Photographie d'un membre inférieur gauche montrant le bon positionnement des capteurs tibiaux et fémoraux, ainsi que le positionnement du capteur sacro-iliaque (251).

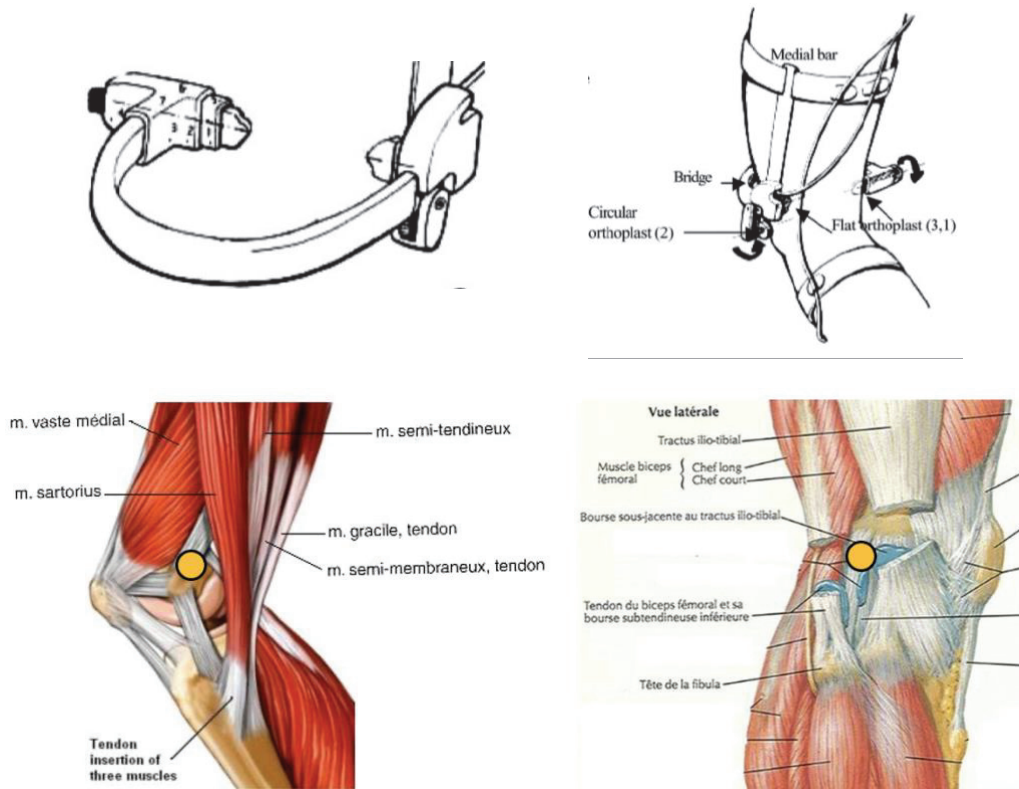


Figure 17: Schémas du harnais fémoral avec les deux orthoplasts à positionner de part d'autre du genou au-dessus des deux condyles (248).

L'étape suivante consiste à réaliser un calibrage fonctionnel postural. Cette procédure de calibrage détermine la position et l'orientation d'un premier système d'axes sur le fémur et d'un deuxième sur le tibia. La définition de ces deux systèmes d'axes aide à générer les données servant à décrire des mouvements 3D complexes du genou, mouvements de flexion-extension, d'abduction-adduction et de rotation interne-externe tibiale. Durant cette procédure, plusieurs sites anatomiques sont repérés (malléoles interne et externe, condyles interne et externe), le centre de hanche est localisé par des mouvements de circumduction du fémur, le centre du genou est également affiné à l'aide de mouvements de flexion/extension. Une fois ce calibrage effectué et les axes pour le fémur et le tibia définis, le test de marche peut être réalisé.

Le patient doit alors marcher sur le tapis de marche avec la démarche la plus naturelle possible et à la vitesse définie au début de l'examen. L'enregistrement dure 45 secondes.

Une fois l'enregistrement terminé, l'évaluateur peut accéder aux données, évaluer leur cohérence et si besoin refaire un enregistrement de la marche. Avant de les analyser, on effectue un retrait des valeurs aberrantes (Figure 18). Il est recommandé d'avoir au minimum 15 cycles de marche pour calculer la moyenne.

Le logiciel Knee3D analysis interpole les valeurs d'angles afin d'obtenir 100 valeurs pour chaque cycle de marche : il fait la moyenne de tous les cycles gardés sur 100 répétitions afin d'obtenir un cycle de marche moyen et un écart pour chaque angle. Ces valeurs sont utilisées pour produire des graphiques. Bien que le cycle de marche ait sa propre durée et que cette durée puisse être un paramètre important en soi, le cycle de marche était normalisé de sorte que le contact initial du pied représente 0% (début du cycle) et que le contact suivant du même pied représente 100% (fin du cycle). Ce procédé de normalisation rend la comparaison de cycles entre les deux membres ou à travers des personnes différentes beaucoup plus facile.

Les données obtenues correspondent à l'abduction/adduction du membre inférieur, à la flexion/extension, à la rotation tibiale par rapport au fémur et à la translation antéropostérieure lors des cycles de marche. Ces données sont réparties en quatre phases correspondant aux phases de la marche décrites dans l'introduction. Cette répartition est effectuée en fonction du pourcentage du cycle de marche.

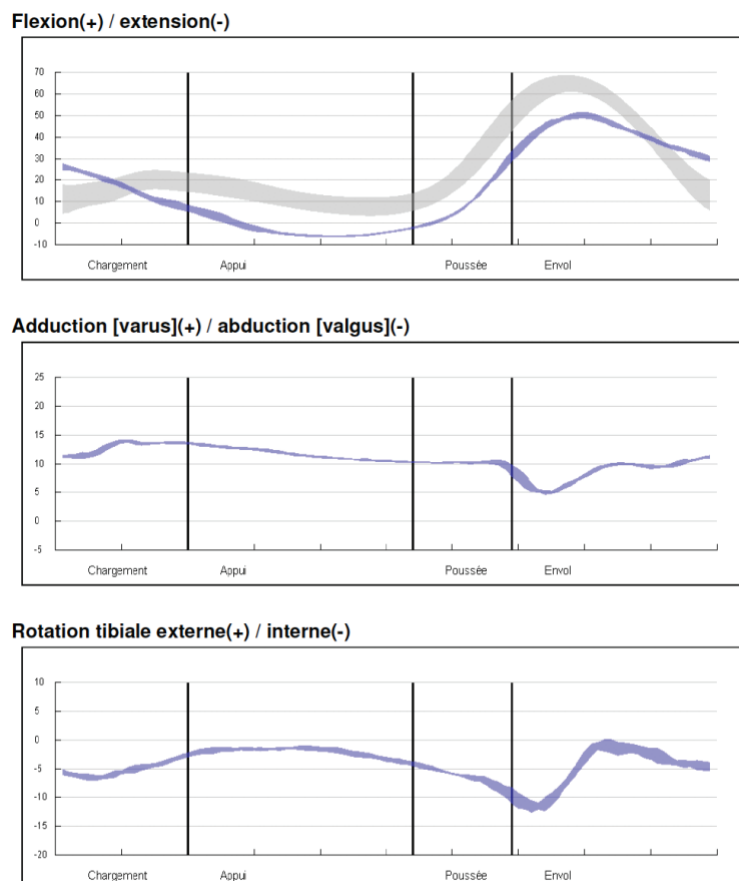


Figure 18 : Exemple de rapport obtenu à la fin du test de marche, après retrait des valeurs aberrantes. Ces graphiques représentant les mouvements en flexion/extension, varus/valgus et rotation tibiale interne/externe durant le cycle de marche, permettaient de déceler une incohérence dans les mesures obtenues et un aperçu global de la marche. Les mesures précises étaient étudiées secondairement.

2.5.2 Analyse de la marche chez un patient présentant une gonarthrose

Depuis plus de 20 ans, de nombreuses études scientifiques ont tentées d'évaluer les effets de l'arthrose fémoro-tibiale sur la cinématique du genou, notamment lors de la marche. Hamai et al. ont évalué 12 patients présentant une arthrose fémoro-tibiale médiale (252). Leur genou a été modélisé en 3D à partir d'un scanner et les patients étaient également évalués par radiographies dynamiques lors des mouvements de mise à genoux, de squat et de montée d'escaliers. Les images radiologiques étaient ensuite couplées au modélisation 3D issues du scanner. Les auteurs retrouvaient plusieurs différences entre le genou arthrosique et le genou sain. Premièrement, les genoux avec une arthrose fémoro-tibiale médiale (stade 4 de la classification de Kellgren et Lawrence) présentaient un défaut de rotation fémorale interne de 8° en moyenne (rotation fémorale latérale de 4° à 20° de flexion et 15° à 100° de flexion du genou dans le groupe arthrosique versus 12° et 24° respectivement dans le groupe sain). Deuxièmement, les genoux arthrosiques ne présentaient pas de phénomènes de « screw-home mechanism ». Mais ceci était peut-être lié aux types de mouvements réalisés lors de cette étude (mise à genoux, squat, escaliers), qui ne nécessitaient pas d'extension complète du genou. Et enfin la translation antéropostérieure des condyles fémoraux n'étaient pas reproduites entre 30 et 80° de flexion dans les genoux arthrosiques.

Dans une étude radio stéréométrique, Saari et al. retrouvaient que les patients présentant une arthrose fémoro-tibiale médiale (essentiellement des stades inférieurs ou égaux à 3 de la classification d'Ahlbäck) avaient une diminution de la rotation interne tibiale entre 50° et 20° de flexion par rapport à un genou sain, et donc une translation postérieure fémorale moins importante (253). Des conclusions similaires étaient rapportées par Matsui et al. sur une étude d'imagerie sur scanner (254).

Kaufman et al. ont évalué l'analyse de la marche sur une large cohorte de 139 patients présentant une arthrose fémoro-tibiale médiale débutante (stade 2 de la classification d'Ahlbäck), comparé à un groupe de 20 patients sains (255). Les patients présentant une gonarthrose avaient une réduction des amplitudes articulaires avec en moyenne 6° de flexion en moins et une période plus courte d'extension du genou, probablement secondaire à une position antalgique du genou. La vitesse de marche était également inférieure dans le groupe arthrosique.

Briem et Snyder-Mackler évaluait 32 patients ayant un genou sans arthrose et avec une arthrose fémoro-tibiale médiale modérée (256). Ils ont démontré que les genoux

arthrosiques avaient une flexion moins importante, ainsi qu'un mouvement d'adduction plus important lors de la mise en charge du pied, par rapport aux genoux non arthrosiques. Mündermann et al. (257) puis Nagano et al. (258) retrouvaient des résultats similaires avec une extension plus importante lors du contact du pied au sol chez les patients ayant une arthrose fémoro-tibiale médiale. Cette dernière étude évaluait 45 patients présentant une arthrose fémoro-tibiale plus ou moins sévère, comparé à 13 sujets sains. Les patients avec une arthrose fémoro-tibiale médiale sévère présentaient une déformation en varus lors de la mise en charge significativement plus importante que les sujets sains ou avec une arthrose modérée. Ce mouvement d'abduction lors de la mise en charge traduit la laxité dans le plan frontal, liée à l'usure importante fémoro-tibiale. La rotation tibiale était en revanche diminuée dans le groupe avec une arthrose sévère. Plusieurs études rapportent des résultats similaires sur la diminution des mobilités et l'adduction du genou en cas d'arthrose fémoro-tibiale (259–263).

En résumé, le genou ayant une arthrose fémoro-tibiale médiale sévère présente une réduction de ses mobilités, avec une perte de flexion lors du contact du pied avec le sol et une augmentation du mouvement d'adduction lors de la mise en charge. La translation antéropostérieure du fémur sur le tibia et la rotation tibiale semblent diminuées mais restent encore mal comprises.

3. Partie 2 – Etudes de recherche clinique

3.1 Article 6 – Résultats cliniques après PTG selon la restauration de l'alignement coronal et de l'obliquité de l'interligne

La nouvelle classification radiologique CPAK (233) semble intéressante notamment pour l'application de la technique d'alignement cinématique permettant de restituer l'alignement constitutionnel. Aucune étude clinique après PTG analyse ses résultats cliniques selon la restauration des différentes catégories de cette classification. Nous avons donc réalisé une étude rétrospective en comparant les résultats cliniques après PTG selon la restauration de la catégorie CPAK préopératoire sachant qu'un alignement mécanique était l'objectif initial.


Ce travail a abouti à une publication dans le journal *Knee Surgery Sports Traumatology Arthroscopy*.

Knee Surgery, Sports Traumatology, Arthroscopy
<https://doi.org/10.1007/s00167-021-06674-w>

KNEE



Mechanical alignment for primary TKA may change both knee phenotype and joint line obliquity without influencing clinical outcomes: a study comparing restored and unrestored joint line obliquity

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Résumé en français

Introduction

Dans le cadre des prothèses totales de genou (PTG), le phénotype du genou dont l'obliquité de l'interligne articulaire sont des paramètres importants à considérer notamment dans la stratégie de réalignement postopératoire. Cette étude a pour but d'évaluer les résultats cliniques selon la restauration du phénotype du genou.

Méthodes

Une étude rétrospective monocentrique a été réalisée à partir de données colligées de façon prospective, incluant 1078 arthroses essentielles du genou chez 936 patients. Le score « International Knee Society (IKS) » et une pangonométrie étaient collectés en préopératoire et au suivi à 2 ans. Les patients étaient catégorisés selon la classification « Coronal Plane Alignment of the Knee » (CPAK) comprenant l'angle fémoral latéral distal (LDFA) et l'angle tibial médial proximal (MPTA). Ceci permet la catégorisation des phénotypes du genou selon l'angle Hip-Knee-Ankle arithmétique (aHKA) (MPTA-LDFA) correspondant à l'alignement constitutionnel, et l'obliquité de l'interligne articulaire (OIA) (MPTA+LDFA). Les patients ayant un phénotype préopératoire constitutionnel restitué ont été comparés aux patients pour lesquels le phénotype constitutionnel du genou n'a pas été restauré.

Résultats

33,4% des patients avaient un varus constitutionnel (aHKA < -2°) avec une OIA en varus (OIA<177). 63,5% des patients avaient une OIA en varus (OIA<177). En postopératoire, 57,8% des patients avaient un aHKA neutre (compris entre -2° à 2°) et une OIA neutre (comprise entre -3° et 3°), avec seulement 18% des patients avec un phénotype constitutionnel restitué. Parmi ces patients, une diminution des douleurs postopératoires était retrouvée pour ceux où l'OIA en varus était restituée par rapport à ceux où l'OIA en varus n'était pas restaurée (score douleur 46,7 versus 44,6 ; $p=0,02$). Les autres catégories d'OIA ou d'aHKA n'étaient pas associées avec une amélioration des résultats cliniques.

Conclusion

Cette étude a permis de montrer que l'alignement mécanique ne restituait pas le phénotype du genou préopératoire dans la plupart des cas. Ceci souligne la nécessité d'une stratégie chirurgicale de réalignement personnalisée dans le cadre des PTG considérant non seulement l'angle HKA, mais également l'obliquité de l'interligne articulaire.

Abstract

Purpose

In Total Knee Arthroplasty (TKA), knee phenotypes including joint line obliquity are of interest regarding surgical realignment strategies. The hypothesis of this study is that better clinical results, including decreased postoperative knee pain, will be observed for patients with a restored knee phenotype.

Methods

A retrospective analysis was performed on prospective data, including 1078 primary osteoarthritic knees in 936 patients. The male:female ratio was 780:298, mean age at surgery was 71.3 years \pm 8.0. International Knee Society Scores and standardized long-leg radiographs (LLR) were collected preoperatively and at two years follow-up after TKA. Patients were categorized using the Coronal Plane Alignment of the Knee (CPAK) classification including the Lateral-Distal-Femoral-Angle (LDFA) and Medial-Proximal-Tibial-Angle (MPTA) measured on LLR by a single observer, allowing knee phenotypes to be categorized considering the arithmetic Hip-Knee-Ankle (aHKA) angle (MPTA-LDFA) as measure of constitutional alignment, and Joint Line Obliquity (JLO) (MPTA+LDFA). Clinical results were compared between patients with surgically restored preoperative constitutional knee phenotype to patients without restored constitutional knee phenotypes. Descriptive data analysis such as means, standard deviations and ranges were performed. T tests for independent samples were performed to compare group differences. Comparisons of categorical data were performed using the chi-square test. Significance was set at $p < 0.05$.

Results

A third of patients (33.4%) had constitutional knee varus with apex distal JLO. 63.5% of patients had preoperative apex distal JLO. Postoperatively, 57.8% of patients had a neutral HKA (-2° to 2°) and a neutral JLO (-3° and 3°), with only 18% of patients with restored constitutional knee phenotype. Of these patients, statistically less postoperative pain was observed in patients where apex distal JLO was restored compared to non-restored apex distal JLO (pain score 46.7 vs. 44.6; $p = 0.02$) without clinical relevance. Other categories of restored JLO or arithmetic HKA angle were not associated with improved outcomes.

Conclusion

This study showed that performing mechanical alignment for primary TKA resulted in most cases in a change of the preoperative knee phenotype. These results emphasize the relevance of

considering joint line obliquity to better understand preoperative knee deformity and better restore knee phenotypes with a more personalized realignment strategy to potentially improve TKA postoperative results.

Level of evidence III

Keywords Knee coronal alignment, kinematic alignment, knee phenotype, joint line obliquity, total knee arthroplasty, total knee replacement, CPAK classification

Introduction

Traditionally, TKA procedures are performed using the mechanical alignment (MA) concept, aiming for a neutral leg axis (180° mechanical femorotibial angle) (13,149). MA results in better force distribution between medial and lateral femorotibial compartments and thus decreases potential polyethylene wear and loosening (13). Despite good outcomes in most TKAs with MA alignment, there are still up to 20% of patients that remain dissatisfied after TKA (155,264). Many studies report similar dissatisfaction rates and registries such as the Arthroplasty Clinical Outcomes Registry in Australia (264) also confirm this. Over time, advances in prosthetic design, fixation and improved wear characteristics of the bearing surface have resulted in improved implant survivorship (265). Despite this, outcomes have remained consistent with the same percentage of dissatisfied patients (4).

Faced with this plateau in patient satisfaction, some surgeons have proposed a more personalized realignment strategy focusing on individualized knee phenotypes (146–148). Indeed, a recent study (235) showed a wide distribution of coronal knee alignment in osteoarthritic knees, supporting the need for a more personalized TKA procedure. Several realignment strategies were described in order to better reproduce the preoperative knee phenotype (5,151). Kinematic alignment most closely reproduces the preoperative knee phenotype when considering the coronal deformity and the joint line obliquity (191).

A recent classification for coronal alignment of the knee (CPAK) (233) has simplified categorization of knee phenotypes based on two independent variables, constitutional (pre-arthritis) alignment, termed the arithmetic HKA (aHKA) (234), and joint line obliquity (JLO). The CPAK classification provides simple algorithms and nomenclature for estimation of these two variables using joint line angles. Nine knee phenotypes have been described, with six being common and sharing similar frequencies in both normal and arthritic subjects.

The aim of this study is to determine the patients for whom their knee phenotype was restored and compare the clinical results at two years postoperatively to those for whom their knee phenotype was not maintained. The hypothesis is that better clinical results, including decreased postoperative knee pain, will be observed for patients with a restored knee phenotype.

Material and methods

A total of 2477 osteoarthritic knees undergoing primary TKA procedures were retrospectively included in this study of prospectively collected data from January 2000 to December 2016. From this cohort, patients with a previous history of limb or knee surgery were excluded (fractures, tumor, infection, ligament injuries or reconstructions, tibial and femoral osteotomies and patella surgery). Measuring coronal knee alignment on long-leg radiographs can be inaccurate because of flexion contracture (152,153). Thus, to avoid measurement errors, all patients with severe bone deformity and bone loss (Ahlbäck classification > 3) and knee flexion contractures greater than 5° were excluded. A total of 1078 primary TKAs in 936 patients were included for final analysis. The flow chart is illustrated in Figure 1.

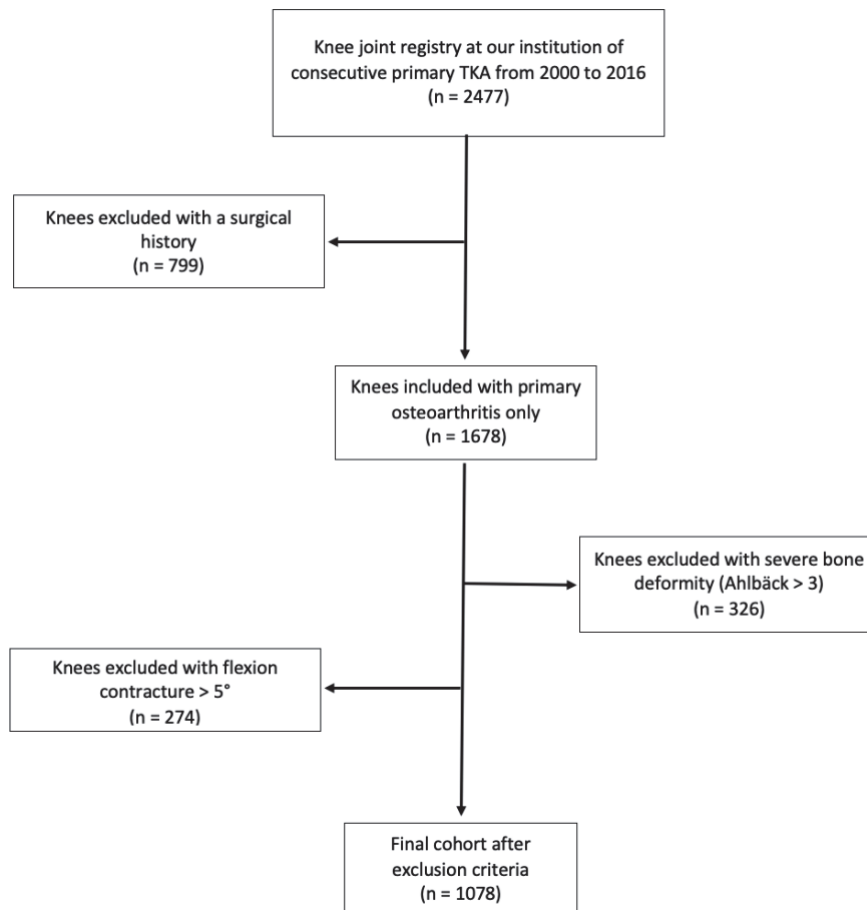


Figure VI-1: Flow chart

Clinical analysis included the International Knee Society Score (KSS) (214) gathered preoperatively and postoperatively at 2 months, one year and two years follow-up. The KSS includes two sub-scores: knee and function scores. Pain score is part of the knee score. Pre and postoperative radiological assessment consisted of anteroposterior and lateral views during supported single-leg stance, and an axial patellar view. Furthermore, all patients underwent pre and postoperative full weight-bearing long-leg standing radiographs (LLR), including the entire pelvis and feet, performed according to a standardized protocol that was published in a previous study (235).

A previously published technique was used for measurement of the joint center and joint axes (154,235). The mechanical femoral axis was defined as the line from the center of the femoral head to the center of the knee. The mechanical tibial axis was defined as the line from the center of the knee to the center of the ankle.

The Coronal Plane Alignment of the Knee (CPAK) classification was used for categorization of constitutional knee phenotypes (233). The Lateral Distal Femoral Angle (LDFA) and the Medial Proximal Tibial Angle (MPTA) were measured pre- and postoperatively, by a single observer (ESM) on the LLR using techniques described by Bellemans et al. (155) (Figure 2). In this study, soft tissue laxity under full weight-bearing may induce errors in the measurement of the Hip-Knee-Ankle (HKA) angle. Thus, the authors focused only on bony landmarks and measured the LDFA and MPTA. The CPAK classification considers the joint line obliquity (MPTA+LDFA) and the aHKA angle (MPTA-LDFA) as illustrated in Figure 3. Knees were classified preoperatively and postoperatively at the last follow-up using this technique.

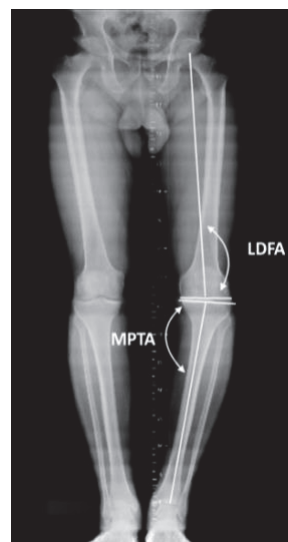


Figure VI-2: Measurements of the lateral distal femoral angle (LDFA) and the medial proximal tibial angle (MPTA)

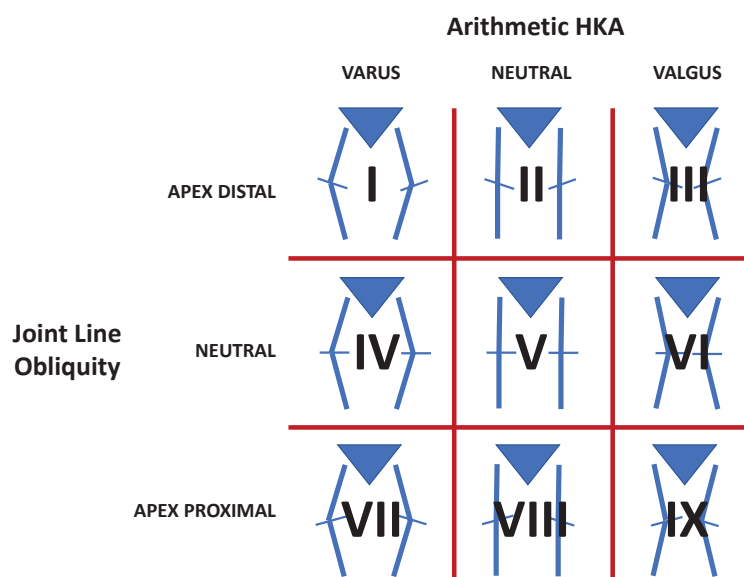


Figure VI-3: Specific knee classification (CPAK) considering the joint line obliquity (Medial Proximal Tibial angle + Lateral Distal Femoral Angle) arithmetic HKA (Medial Proximal Tibial Angle – Lateral Distal Femoral Angle).

During the study inclusion period, surgeons who performed TKA used the MA technique. However, a neutral MA was not always achieved. Firstly, according to the specific knee classification, the percentage of knees for which CPAK knee phenotype had been restored were identified, and then clinical and radiological results were compared between patients with and without a restored constitutional knee phenotype. All cohort demographic characteristics are presented in Table 1. No significant differences were found between genders for LDFA and MPTA. Thus, overall results did not need to be gender weighted.

Table VI-1: Demographic characteristics, measurements of LDFA and MPTA and clinical scores pre- and post-operatively according to gender in the entire population

	Entire population (n= 1078)	Male (n=780)	Female (n=298)	p value
Mean age ± SD (range)	71.3 ± 8.0 (26–93)	71.4 ± 8.2 (26–91)	71.1 ± 7.6 (50–93)	0.57
Mean BMI ± SD (range)	29.2 ± 5.1 (16–47)	29.4 ± 5.5 (16–47)	28.8 ± 4.2 (16–45)	0.11
Mean preoperative LDFA ± SD (range)	88.5 ± 2.6 (80–94)	88.3 ± 2.7 (80–94)	89.0 ± 2.5 (80–94)	0.09
Mean postoperative LDFA ± SD (range)	90.5 ± 2.3 (82–102)	90.1 ± 2.3 (82–102)	90.7 ± 2.5 (82–102)	0.19
Mean preoperative MPTA ± SD (range)	86.8 ± 3.1 (80–94)	87.1 ± 3.0 (80–94)	85.8 ± 3.1 (80–94)	0.10
Mean postoperative MPTA ± SD (range)	89.5 ± 1.8 (76–95)	89.4 ± 1.7 (76–94)	89.9 ± 2.1 (77–95)	0.21
Preoperative KSS ± SD (range)	111.5 ± 29.7 (0–200)	109.7 ± 30.0 (0–200)	112.6 ± 27.7 (0–193)	0.22
Postoperative KSS ± SD (range)	176.2 ± 33.2 (0–200)	175.0 ± 33.9 (0–200)	179.0 ± 30.5 (29–200)	0.08
Follow-up (months) ± SD (range)	30.8 ± 5.5 (24–40)	31.0 ± 5.6 (24–40)	31.3 ± 5.1 (25–38)	0.54

SD=standard deviation; LDFA=Lateral distal femoral angle; MPTA=Medial proximal tibial angle; KSS=International Knee Society Score

The French advisory committee on health research data processing (*Comité Consultatif sur le Traitement de l'Information en matière de Recherche dans le domaine de la Santé* [CCTIRS]) approved this study on the 24th January 2012 and then 9 March 2015 (approval #11-681). All procedures performed were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Two surgeons performed fifty measurements of the two different angles twice in order to assess intra and inter-observer reliability with a period of one month between measurements. Intra-observer reliability was found to be good, with a Pearson correlation coefficient, of $\rho=0.79$ (95% CI [0.72 ; 0.89]; $p<0.001$) for LDFA and $\rho=0.89$ (95% CI [0.80 ; 0.92]; $p<0.001$) for MPTA. Inter-observer reliability was also found to be good, with a Pearson correlation coefficient of $\rho=0.83$ (95% CI [0.78 ; 0.91]; $p<0.001$) for LDFA and $\rho=0.81$ (95% CI [0.74 ; 0.88]; $p<0.0001$) for MPTA.

Statistical analysis

Statistical analysis was performed using XLSTAT software. Descriptive data analysis such as means, standard deviations and ranges were performed. T tests for independent samples were performed to compare group differences. Comparisons of categorical data were performed using the chi-square test. Significance was set at $p < 0.05$.

Results

Preoperative and postoperative patient distribution according to the knee classification

Preoperative and postoperative patient's categorization is reported in Table 2. Preoperatively, the majority of the patients had an apex distal JLO (63.5%) (CPAK Type I-II-III). Very few patients had an apex proximal JLO (1.1%).

Postoperatively, more than half of the population (57.8%) had a neutral HKA (between -2° and 2°) and a neutral JLO (between -3° and 3°) as a result of using a mechanical alignment technique. For the remaining 42.2% of the population, a neutral mechanical alignment was not achieved. Most non-mechanically aligned TKAs were implanted in varus (27.4%).

Table VI-2 : Overall absolute and relative preoperative (A) and postoperative (B) knee phenotypes distribution among the entire population

		MPTA-LDFA (aHKA)			Total
		< - 2°	- 2° to 2°	> 2°	
(A) Preoperative patient distribution					
MPTA + LDFA	< 177°	360 (33.4%)	210 (19.5%)	115 (10.6%)	685 (63.5%)
(joint line obliquity)	177° to 183°	110 (10.2%)	204 (18.9%)	68 (6.3%)	382 (35.4%)
	> 183°	4 (0.4%)	6 (0.6%)	1 (0.1%)	11 (1.1%)
Total		474 (44%)	420 (39%)	184 (17%)	1078
(B) Postoperative patient distribution					
MPTA + LDFA	< 177°	36 (3.3%)	32 (3.0%)	24 (2.2%)	92 (8.5%)
(joint line obliquity)	177° to 183°	184 (17.1%)	623 (57.8%)	76 (7.0%)	883 (81.9%)
	> 183°	75 (7.0%)	22 (2.0%)	6 (0.6%)	103 (9.6%)
Total		295 (27.4%)	677 (62.8%)	106 (9.8%)	1078

aHKA: arithmetic HKA

MPTA: Medial Proximal Tibial Angle

LDFA: Lateral Distal Femoral Angle

Comparison of postoperative clinical results

Patients for whom the constitutional preoperative knee phenotype had been restored are shown in Table 3. Only 18% of the entire cohort had a restored knee phenotype. Most of the restored knee phenotype was for patients with preoperative CPAK category Type 4. Clinical results between patients with and without a restored knee phenotype were compared according to the JLO and HKA. Clinical comparisons are reported in Tables 4 and 5 according to joint line obliquity and HKA, respectively. There was statistically less postoperative pain observed in patients with a restored knee phenotype when the joint line obliquity was apex distal (< 177°). No other significant difference was observed for all other clinical results.

Table VI-3: Overall absolute and relative postoperative distribution of restored preoperative CPAK category among the entire population

		MPTA–LDFA (aHKA)			Total
		< - 2°	- 2° to 2°	> 2°	
MPTA +LDFA (joint line obliquity)	< 177°	21 (5.6%)	8 (3.3%)	5 (4.4%)	34 (5.0%)
	177° to 183°	24 (21.8%)	123 (60.3%)	11 (16.2%)	158 (41.4%)
	> 183°	1 (25.0%)	1 (16.7%)	0 (0%)	2 (18.2%)
		46 (9.7%)	132 (31.3%)	16 (8.7%)	194 (18.0%)

aHKA: arithmetic HKA

MPTA: Medial Proximal Tibial Angle

LDFA: Lateral Distal Femoral Angle

Table VI-4: Comparisons of clinical results according to the restoration of the joint line obliquity

	Apex distal JLO (< 177°)			Neutral JLO (177° to 183°)			Apex proximal JLO (> 183°)		
	Restored obliquity	Non-restored obliquity	p value	Restored obliquity	Non-restored obliquity	p value	Restored obliquity	Non-restored obliquity	p value
Number	34	651	NA	158	224	NA	2	9	NA
Gender (men)	19	458	0.08	122	173	0.99	2	6	0.34
Mean age ± SD	71.1 ± 6.2	71.2 ± 8.2	0.87	70.9 ± 8.3	72.0 ± 7.6	0.26	72 ± 1.4	68.1 ± 8.6	0.12
Mean pain score ± SD	46.7 ± 4.5	44.6 ± 8.9	0.02	43.4 ± 10.1	43.9 ± 8.8	0.6	45 ± 14.1	47.2 ± 5.7	0.21
Mean maximum knee flexion ± SD	119.8 ± 12.9	118.9 ± 13.2	0.68	120.4 ± 11.9	119.8 ± 12.5	0.65	120 ± 14.1	116.9 ± 18.9	0.12
Mean knee score ± SD	88.4 ± 8.1	90.6 ± 9.3	0.08	90.2 ± 11.9	88.6 ± 11.7	0.2	87.1 ± 9.9	91.2 ± 4.9	0.24
Mean function score ± SD	80.2 ± 19.9	79.3 ± 21.1	0.82	78.6 ± 18.9	77.9 ± 18.8	0.74	82.1 ± 20.1	77.9 ± 16.9	0.18

JLO=Joint Line Obliquity ; NA=not applicable ; SD=standard deviation

Table VI-5: Comparisons of clinical results according to the restoration of the aHKA

	Varus aHKA (< - 2°)			Neutral aHKA (- 2° to 2°)			Valgus aHKA (> 2°)		
	Restored aHKA	Non-restored aHKA	p value	Restored aHKA	Non-restored aHKA	p value	Restored aHKA	Non-restored aHKA	p value
Number	46	428	NA	132	288	NA	16	168	NA
Gender (men)	27	275	0.56	105	216	0.37	12	145	0.39
Mean age ± SD	71.5 ± 7.8	71.1 ± 7.5	0.76	70.9 ± 8.3	71.3 ± 8.6	0.67	71.1 ± 5.3	71.3 ± 8.5	0.76
Mean pain score ± SD	44.1 ± 8.9	44.4 ± 8.5	0.83	45.0 ± 9.8	43.6 ± 7.7	0.16	45.3 ± 8.7	43.3 ± 10.6	0.47
Mean maximum knee flexion ± SD	118.9 ± 12.9	118.9 ± 12.2	0.99	120.3 ± 12.1	118.8 ± 15.0	0.28	122.2 ± 8.9	119.8 ± 11.2	0.34
Mean knee score ± SD	86.5 ± 10.4	89.0 ± 13.4	0.13	91.0 ± 11.5	90.5 ± 10.6	0.67	89.7 ± 11.3	89.6 ± 12.9	0.97
Mean function score ± SD	80.1 ± 19.2	81.0 ± 20.0	0.77	78.9 ± 18.2	79.5 ± 20.2	0.77	78.8 ± 23.9	72.7 ± 24.5	0.34

NA=not applicable ; SD=standard deviation ; aHKA= arithmetic Hip Knee Ankle angle

Discussion

The main finding of this study was that performing mechanical alignment for primary TKA resulted in most cases in a change of the preoperative knee phenotype. No clinically significant differences were found between patients with or without restored preoperative coronal knee alignment. This is the first study to correlate clinical results according to restoration of the knee phenotype in a large cohort.

In this study, no significant differences were observed between men and women regarding femoral and tibial angles distribution. The current literature is not unanimous. Indeed, some studies found similar distribution according to gender (155,235) whereas other studies found more valgus overall limb alignment in females (157,160).

In this study, surgeons aimed to obtain neutral coronal alignment with a postoperative HKA between 178° and 182° and a joint line parallel to the ground. However, for more than 40% of the included patients, neutral alignment was not achieved. These results remind surgeons that accuracy of bone cuts is very important and that the surgical alignment plan may not always be ultimately achieved. This is particularly important, especially when performing kinematic alignment, to avoid coronal alignment outliers with potentially worse clinical results (13). Abdel et al. (266) showed similar clinical results and survivorship at 20 years follow-up between the neutral mechanical alignment group and the outlier group. This is in agreement with the present study where no significant differences were observed while comparing the clinical results between patients with or without their preoperative HKA alignment.

Many studies (161,183,267–270) showed superior clinical results while maintaining a postoperative varus alignment for patients with preoperative varus. These studies support the fact that restoring the preoperative knee alignment would improve the postoperative results. The present study determines more precisely that the joint line obliquity may be more important than the overall limb alignment. The CPAK knee classification used in this study allows a better and simpler comprehension of knee phenotypes compared to other knee classification. Moreover, the present study emphasized the importance of considering joint line obliquity. Preoperatively the most frequent JLO category was apex distal (177°). And when performing TKA with MA, most of the patients had a postoperative neutral JLO. Therefore, most of the population was changed from an apex distal to a neutral JLO. This change in JLO could possibly be one of the reasons for patient dissatisfaction after TKA. Indeed, the authors of the present study found statistically less postoperative pain when an apex distal JLO was restored.

However, the minimal clinical difference for KSS is 5 points, therefore this difference is not clinically significant (271–273).

When surgeons aim for mechanical coronal alignment, soft tissue releases may be necessary to achieve a balanced knee. By contrast, when restoring the constitutional knee alignment, less soft tissue releases are required, allowing for better soft tissue balance without creating ligament injuries (191). Blakeney et al. showed less gap imbalance and a more normal gait with kinematic alignment (190,232). Also, An et al. showed that kinematic alignment allowed bone and soft tissue preservation (230). McEwen et al., in a randomized controlled trial of bilateral simultaneous TKAs comparing kinematic and mechanical alignment, found that patients preferred their kinematically aligned TKA and that fewer soft tissue releases were needed for kinematic alignment technique (182). Thus, in the present study, the less postoperative pain (not clinically relevant) for patients with preoperative apex distal JLO may be explained by the restored JLO with improved gap balancing and less soft tissue releases.

This study has several limitations. Firstly, the authors were limited by the retrospective nature of the study. Secondly, all radiological measurements were performed on long-leg radiographs, which may be considered as less accurate compared to measurements on 3D images such as CT scans (159). However, many authors have previously reported comparable results between long-leg radiographs and supine CT scanograms (162–165). Also, the authors considered a specific knee classification, avoiding measuring HKA under weight-bearing in a standard manner. Thirdly, to avoid any inaccuracy in measurements, selection criteria were very strict and only primary knee osteoarthritis without any previous history of knee conditions were included. Fourth, as only one historical outcome score was available for used, other joint specific scores, particularly those that assess joint awareness may better discern differences between knee phenotypes for higher levels of function. A fifth limitation should be considered about three-dimensional positioning (axial and sagittal) of TKA as this study only addresses coronal plane. Finally, the follow-up remains short-term at this stage. However, although knees have clinically stabilized after 2 years, no long-term conclusions can be made.

This study is clinically relevant highlighting the change of knee phenotype while performing mechanical alignment for TKA. Indeed, the kinematic alignment technique appears as a solution to improve clinical results. This study showed that the surgical goal should be to achieve constitutional knee alignment considering both constitutional coronal alignment and joint line obliquity.

Conclusion

This study showed that performing mechanical alignment for primary TKA resulted in most cases in a change of the preoperative knee phenotype. These results emphasize the relevance of considering joint line obliquity to better understand preoperative knee deformity and better restore knee phenotypes with a more personalized realignment strategy to potentially improve TKA postoperative results.

En résumé, cette étude a permis de montrer que l'alignement mécanique modifiait dans la plupart des cas le phénotype natif du genou. Aussi, de potentiels meilleurs résultats cliniques pourraient être observés après PTG en cas de restauration du phénotype préopératoire du patient et notamment de l'obliquité de son interligne articulaire.

3.2 Article 7 – Comparaison des résultats cliniques entre alignement cinématique restreint et alignement mécanique avec une PTG postéro-stabilisée

Nous avons montré de potentiels meilleurs résultats cliniques lors de la restitution de l'alignement constitutionnel et notamment de l'obliquité de l'interligne articulaire (274). Nous avons aussi rapporté de bons résultats après PTG avec la technique d'alignement cinématique lors de notre revue de la littérature (7). Cependant, la plupart des études incluses dans ces revues systématiques comparent des PTG à conservation du ligament croisé postérieur (PTG CR). Il est donc incertain que les résultats rapportés par ces revues systématiques (7,178,208,211,212) s'appliquent aux PTG postéro-stabilisées (PTG PS) avec un système plot-came. Nous avons donc réalisé une étude cas-témoin comparant les résultats cliniques et radiologiques entre alignement cinématique restreint et alignement mécanique pour une même PTG PS.


Ce travail a abouti à une publication dans le journal *Knee Surgery Sports Traumatology Arthroscopy*.

Knee Surgery, Sports Traumatology, Arthroscopy
<https://doi.org/10.1007/s00167-021-06714-5>

KNEE



Restricted kinematic alignment may be associated with increased risk of aseptic loosening for posterior-stabilized TKA: a case–control study

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Résumé en français

Introduction

Plusieurs études affirment les potentiels bénéfiques de l'alignement cinématique (AC) permettant de réduire le taux de dissatisfaction après prothèse totale de genou (PTG). Cependant, aucune étude n'a évalué les résultats cliniques et radiologiques entre un AC et un alignement mécanique (AM) avec une PTG postéro-stabilisée à came centrale avec un suivi minimum de 3 ans.

Matériels et Méthodes

Une étude cas témoin rétrospective monocentrique a été réalisée incluant 150 patients consécutifs entre janvier 2016 and octobre 2017. 100 patients étaient inclus dans le groupe AM contre 50 dans le groupe AC. Tous les patients ont bénéficié de la même prothèse de genou (GMK primary posterior-stabilized, Medacta®, Switzerland). Des guides de coupe sur mesure étaient utilisés dans les deux groupes et un AC restreint était visé dans le groupe AC. Une cimentation hybride était réalisée ; le composant fémoral n'était pas cimenté, et l'implant tibial était toujours cimenté. Pour les deux groupes, l'évaluation clinique reposait sur le « New Knee Society Score » et l'analyse radiologique étaient colligées en préopératoire et au dernier recul en décembre 2020. Les deux groupes étaient comparables en préopératoire.

Résultats

Le suivi moyen était respectivement de 42,9 mois \pm 3,6 (37,6 – 46,7) et 53,3 mois \pm 4,1 (45,5 – 59,8) pour les groupes AC et AM. Au dernier recul, aucune différence significative entre les deux groupes n'a été retrouvée pour les scores cliniques (New KSS ($p=0,11$), attente des patients ($p=0,06$), satisfaction des patients ($p=0,94$), activités physiques des patients ($p=0,67$) et la flexion maximale du genou ($p=0,38$). L'analyse radiologique a retrouvé un angle Hip Knee Ankle (HKA) similaire entre le groupe AC et AM (178° versus 179° respectivement, $p=0,47$). Un risque significativement plus important de descellement tibial était observé dans le groupe AC (OR=0,11, 95%IC [0,01 ; 0,58] ; $p=0,002$). Au dernier suivi, la survie globale était significativement meilleure pour le groupe MA par rapport au groupe AC (97% versus 84% ; $p=0,002$).

Conclusion

Un risque augmenté de descellement de l'implant tibial a été trouvé avec un alignement cinématique restreint par rapport à un alignement mécanique en utilisant une PTG postéro-stabilisée avec une came centrale à court terme. Une attention particulière devrait être prêtée quant au choix de design de PTG lors de la réalisation d'un alignement cinématique.

Abstract

Purpose

The purpose of the study was to compare clinical and radiological results between kinematic alignment (KA) and mechanical alignment (MA) with a posterior-stabilized (PS) total knee arthroplasty (TKA) with a post cam mechanism at a minimum follow-up of 3 years. The authors hypothesized a higher risk of aseptic loosening when performing KA using PS TKA.

Methods

A retrospective monocentric single surgeon case control study was performed comparing 100 matched patients who had TKA performed using a MA philosophy to 50 patients receiving TKA with a KA technique between January 2016 and October 2017. All patients had the same knee prosthesis (GMK primary posterior-stabilized, Medacta®, Switzerland). Patient specific cutting blocks were used in both groups and a restricted KA (rKA) was aimed in the KA group. A hybrid cementation technique was performed. The new Knee Society Score (KSS) and radiological assessment were collected preoperatively and at the final follow-up. Comparisons between groups were done with the T test or Fisher exact test. Global survival curves were estimated with Kaplan–Meier model. Significance was set at $p < 0.05$.

Results

Mean follow up was 42.9 months ± 3.6 (range 37.6–46.7) and 53.3 months ± 4.1 (range 45.5–59.8) for rKA and MA groups. Postoperatively, no significant differences were found for clinical scores between both groups. Radiological assessment found similar postoperative Hip Knee Ankle angle for rKA and MA groups (178° versus 179° respectively, NS). At last follow-up, a significant higher survivorship was found for the MA group compared to the rKA group (97% versus 84%; $p < 0.001$) for aseptic loosening revision as the endpoint.

Conclusion

An increased risk of tibial implant loosening was found with rKA compared to MA using a posterior-stabilized TKA with a post cam system at short-term follow-up. Caution should be taken when choosing the TKA design while performing rKA.

Keywords Tibial loosening, restricted kinematic alignment, mechanical alignment, posterior-stabilized, knee arthroplasty, knee replacement

Level of evidence Level IV, retrospective case control study

Introduction

Total Knee Arthroplasty (TKA) is considered the gold standard treatment for severe knee osteoarthritis (18). For the last four decades, mechanical alignment (MA) has been the most common and widely seen as the gold standard (13). Despite MA having reliable long-term implant survival and good to excellent patient reported outcomes in most of the population (13), nearly 20% of patients remain dissatisfied after TKA (4,200). Many authors have suggested that this dissatisfaction rate may be at least partially as a result of the systematic approach of MA (142,143) as wide distribution of knee coronal alignment in osteoarthritic (235) and non-osteoarthritic (155) populations have been observed. Subsequently, alternative alignment philosophies (5,6) have been developed including kinematic alignment (KA), which aims to reproduce constitutional knee alignment based on bony landmarks (275). Venditelli et al. proposed a restricted kinematic alignment (rKA) philosophy to avoid excessive coronal deviation in TKA (189,276).

The KA philosophy reduces the need for ligament releases and achieves soft tissue balancing through bony cuts (191,232). Advocates of KA offer the rationale that this will improve clinical results in terms of pain and function compared to a MA technique (183,204,205). Recent systematic reviews suggest that MA and KA in TKA achieved similar functional and radiological results (7,208) and that KA may be an alternative alignment philosophy to MA in TKA. However, most studies included in these systematic reviews compared cruciate retaining (CR) TKA implants. It is unclear if these results apply to posterior-stabilized (PS) TKA implants with a post cam mechanism.

The aim of this study was to compare clinical and radiological results between restricted kinematic and mechanical alignment using a PS TKA with a post cam. The authors' hypothesis was that an increased risk of tibial implant loosening will be observed in the rKA group because of shearing stress of the plot on the post cam especially when the tibial implant is put either in varus or valgus.

Materials and Methods

All procedures were performed in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This study received institutional review board approval (number 2019-A02567-49), and all participants gave valid consent to participate.

Patients

A monocentric single surgeon (EM) retrospective analysis of consecutive patients who underwent primary TKA between January 2016 and October 2017 was performed. All PS TKA, performed with either a mechanical or restricted kinematic alignment philosophy, were included with a minimum follow-up of 3 years. Exclusion criteria were all TKA performed with another type of implant, patients not consenting to data collection or revisions TKA.

Demographics

Patient demographics are summarized in Table 1. One hundred and fifty patients were eligible for review. There were 100 patients in the mechanical alignment group and 50 patients in the KA group. Mechanical alignment was performed from January 2016 to March 2017 and KA was done from March to October 2017. Of the participants, 92 were females and 58 males. The female:male ratio was 58/42 for the MA group and 34/16 for the rKA group. There was no significant difference between patients for age, BMI or pre-operative range-of-motion. The MA group had a lower mean pre-operative patella tilt (0.3 vs 1.4 degrees) compared to the rKA group and the mean KSS functional score was higher in the rKA group (45.7 vs 39.5) compared to the MA group (NS). However, neither of these differences reached statistical significance.

Table VII-1: Comparison of patient demographics by group at surgery.

	Mechanical alignment group (n = 100) ^a	Kinematic alignment group (n = 50) ^a	p value
Age at surgery (year)	70 ± 8.5 [49–86]	68.2 ± 8.9 [53–85]	NS
Sex (female)	58/100 (58%)	34/50 (68%)	NS
BMI	29.7 ± 5.2 [17.9–46.7]	29.4 ± 5.5 [19.1–41.4]	NS
Preoperative flexion ROM (°)	114.9 ± 9.3 [90–130]	115 ± 10.0 [80–130]	NS
Preoperative mFTA (°)	176.3 ± 7.7 [158–193]	176.0 ± 6.3 [165–195]	NS
Preoperative FMA (°)	90.5 ± 3.8 [79–98]	91.3 ± 2.4 [86–96]	NS
Preoperative TMA (°)	87.3 ± 3.7 [77–95]	87 ± 3.0 [82–96]	NS
Preoperative tibial slope (°)	86.1 ± 1.4 [83–89]	86 ± 1.7 [83–90]	NS
Preoperative patellar tilt (°)	0.3 ± 3.1 [– 10–10]	1.4 ± 3.2 [– 10–10]	NS
Preoperative new KSS score	122.1 ± 24.5 [87–167]	122.1 ± 11.7 [12–69]	NS
Patient expectations	13.4 ± 2.6 [3–15]	13.9 ± 1.9 [9–15]	NS
Satisfaction	17.9 ± 7.4 [4–34]	17.1 ± 6.0 [10–34]	NS
Functional activities	39.5 ± 8.1 [27–69]	45.7 ± 17.3 [15–78]	NS

^aData are presented as mean ± standard deviation [minimum – maximum] or number (proportion)
 BMI : body mass index (kg/m²); ROM: Range of motion; mFTA : mechanical femorotibial angle ; FMA : femoral mechanical angle; TMA : tibial mechanical angle; KSS : Knee society score.
 NS: not significant

Surgery

All patients had a medial sub-vastus approach performed for exposure without a tourniquet. In both groups, patient specific cutting blocks were used. For the MA group, femoral and tibial cuts were performed to place implants perpendicular to the mechanical axis of the bone. For the rKA group, a restricted KA philosophy was planned according to a technique that has previously been described by Venditelli (276). The algorithm involves modifications of bone cuts within a “safe range” defined by criteria: independent femoral and tibial cuts must be within ± 5 of the mechanical axis and the HKA angle must fall within ± 3 of neutral. The same knee prosthesis was implanted for all patients (GMK Primary posterior-stabilized, Medacta®, Switzerland). Uniform hybrid cementation was performed in all cases; femoral component was uncemented, and tibial component was always cemented. To obtain an optimal cementation mantle without tourniquet, a karcher high-pressure cleaning, followed by packing and drying was performed on the tibial cut surface. Palacos-RG high viscosity cement was used in all cases and was prepared in a mixing bowl. Application was first performed on the tibial surface using a blunt instrument to pressurize the cement into the interstices, and was also applied to the bone-implant interface of the prosthesis prior to implantation and impaction. Patella was selectively resurfaced according to the degree of patellar osteoarthritis found at the time of surgery.

Clinical and radiological assessment

For both groups, clinical evaluation scores were collected preoperatively and at the last follow-up during December 2020 using the new Knee Society Score (KSS) (277). Radiological analysis (standard antero-posterior and lateral knee radiographs, full-length bilateral standing radiograph and patellar axial view radiograph) were performed preoperatively and at the last follow-up to assess the mechanical femorotibial angle (mFTA), the femoral and tibial mechanical angles measured medially (FMA and TMA, respectively), tibial slope, patellar tilt, incidence of radiolucent lines greater than 2 mm and implant loosening.

The complication rate was evaluated at the last follow-up, including all reintervention procedures (component exchange, debridement and irrigation, mobilization under anesthesia and arthrolysis).

Statistical analysis

Statistical analysis was performed using XLSTAT software. Baseline descriptive data analysis using means, standard deviations and ranges was performed on each group. T test for independent samples were performed to compare group differences. Categorical variables were compared using a Fisher exact test. Survival analysis was conducted with reintervention as the endpoint. Global survival curves were estimated with Kaplan–Meier model and the comparison of survivorship between the different initial etiologies was estimated with log-rank. Significance was set at $p < 0.05$.

A post hoc analysis was performed with an Odds ratio at 9.2, proportion of controls exposed at 0.02, a power at 0.8 and an alpha risk at 0.05. A minimum sample size of 46 cases and 92 controls was necessary for this study with a one case for two controls.

Results

Clinical outcomes

Mean follow up was 42.9 months \pm 3.6 (range 37.6–46.7) and 53.3 months \pm 4.1 (range 45.5–59.8) for rKA and MA groups. In both groups, postoperative KSS scores were significantly improved compared to preoperative scores. No significant differences were observed between both groups for clinical scores. All clinical results are reported in Table 2.

Table VII-2: Clinical assessments (including clinical scores and maximum knee flexion) at the last follow-up

	Mechanical alignment group	Kinematic alignment group	<i>p</i> value
Follow-up ^a (months)	53.3 \pm 4.1 [45.5–61.1]	42.9 \pm 3.6 [37.6–46.7]	<0.001
Clinical assessment			
New KSS ^a	179.6 \pm 19.6 [93–221]	173.2 \pm 19.6 [121–206]	NS
Gain KSS ^a	57.5 \pm 29.8 [– 27–122]	52 \pm 30.4 [– 23–130]	NS
Patient expectation ^a	13.0 \pm 2.1 [4–15]	11.5 \pm 3.4 [3–15]	NS
Satisfaction ^a	30.7 \pm 6.5 [12–40]	30.6 \pm 7.4 [8–40]	NS
Functional activities ^a	63.1 \pm 11.0 [26–85]	62.1 \pm 12.5 [24–85]	NS
Maximum knee flexion ^a (°)	119.6 \pm 9.0 [90–135]	121.3 \pm 11.2 [95–140]	NS

NS not significant

^aThe values are given as mean and SD, with the range in parentheses

Radiological outcomes

There was no significant difference in mean mFTA between the 2 groups postoperatively (NS). Significant differences were found for FMA, TMA and tibial slope between both groups postoperatively (respectively $p=0.002$, $p=0.03$ and $p<0.001$). In the rKA group, femoral components were slightly more in valgus (91.3 ± 2.4 versus 89.8 ± 1.3), tibial components were slightly more in varus (88.6 ± 2.6 versus 89.5 ± 0.9) and tibial slope was slightly increased (86.6 ± 1.4 versus 88.6 ± 1.1). Two outliers were $>5^\circ$ proximal tibia varus and eight outliers were $>3^\circ$ HKA varus. Anteroposterior radiographs revealed a significantly increased risk of tibial radiolucent lines in the rKA group (9 cases – 30%) compared to the MA group (15 cases - 30%); OR=0.21, 95%CI [0.07 ; 0.56] ; $p<0.001$). All radiological results are reported in Table 3. Comparisons of all radiological parameters for both groups were performed for TKA with and without loosening and are reported in Table 4.

Table VII-3: Radiological assessment at the last follow-up

	Mechanical alignment group	Kinematic alignment group	<i>p</i> value
Patellar tilt ^a	0.7 ± 3.5 [- 10 to 10]	0.8 ± 3.4 [- 10 to 5]	NS
mFT angle ^a	179.3 ± 2.7 [171–186]	178.8 ± 3.8 [173–188]	NS
Femoral mechanical angle ^a	89.8 ± 1.3 [88–92]	91.3 ± 2.4 [86–96]	0.002
Tibial mechanical angle ^a	89.5 ± 0.9 [88–92]	88.6 ± 2.6 [82–94]	0.03
Tibial slope ^a	88.6 ± 1.1 [86–91]	86.6 ± 1.4 [84–90]	<0.001
Progressive radiolucent lines	9 (9%)	15 (30%)	<0.001

NS not significant

^aThe values are given as mean and SD, with the range in parentheses

Table VII-4: Comparisons of tibial alignment between mechanical and kinematic groups for TKA with and without loosening

	Mechanical alignment group		<i>p</i> value
	Without loosening (<i>n</i> =98)	With loosening (<i>n</i> =2)	
mFT angle ^a	179.3 ± 2.7 [171–186]	180 ± 0 [180–180]	NS
Femoral mechanical angle ^a	89.8 ± 1.3 [88–92]	90 ± 0 [90–90]	NS
Tibial mechanical angle ^a	89.5 ± 0.9 [88–92]	89.5 ± 0.7 [89–90]	1
Tibial slope ^a	88.6 ± 1.1 [86–91]	87.5 ± 0.7 [87–88]	NS
	Kinematic alignment group		
	Without loosening (<i>n</i> =42)	With loosening (<i>n</i> =8)	
mFT angle ^a	178.8 ± 3.8 [173–188]	177.4 ± 2.3 [175–181]	NS
Femoral mechanical angle ^a	91.3 ± 2.4 [86–96]	91 ± 1.3 [89–93]	NS
Tibial mechanical angle ^a	88.6 ± 2.6 [82–94]	87.8 ± 1.5 [86–90]	NS
Tibial slope ^a	86.6 ± 1.4 [84–90]	86.8 ± 1.0 [85–88]	NS

mFT mechanical femorotibial, NS not significant

^aThe values are given as mean and SD, with the range in parentheses

Complications and revision

In the MA group, there were four complications during the follow-up period. One patient developed an early infection two months postoperatively and a complete revision with component exchange was performed. Another patient developed postoperative stiffness and underwent arthroscopic arthrolysis at four months postoperatively. Two other patients were revised because of aseptic tibial loosening at 38.4 and 45.1 months.

In the rKA group, all revisions (8 patients (16%)) for aseptic tibial loosening were performed between 11.9 and 25.5 months. Also, one patient presented tibial loosening and was advised to undergo revision surgery, but refused it.

For all septic and aseptic revisions, a Condylar Constrained Knee prosthesis was implanted.

At 50 months follow-up, the overall implant survivorship was significantly higher for the MA group compared to the rKA group (97% versus 84%; $p=0.002$) (Figure 1). When considering aseptic loosening revision as the endpoint, a significantly higher survivorship was found for the MA group compared to the rKA group (98% versus 84%; OR=9.2, 95%CI [1.7 ; 92.4] ; $p<0.001$) (Figure 2).

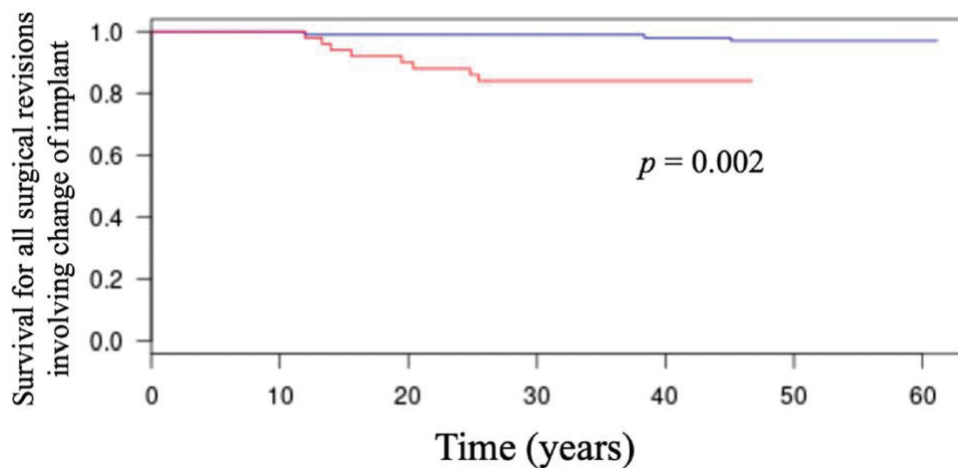


Figure VII-1: Survival for all surgical revisions involving complete change of implant for MA (blue) and rKA (red) groups

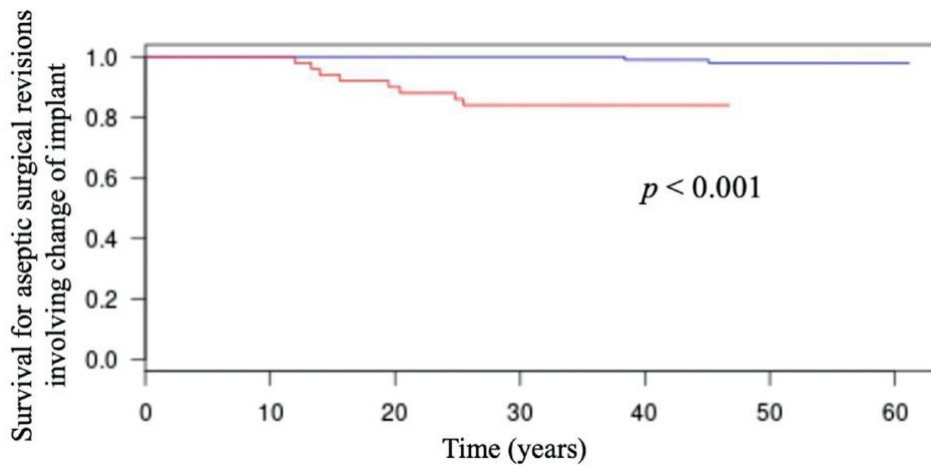


Figure VII-2: Survival for aseptic surgical revisions involving complete change of implant for MA (blue) and rKA (red) groups

Discussion

The most important finding of this case-control study is that an increased risk of aseptic tibial implant loosening was observed with rKA compared to MA using a posterior-stabilized TKA.

Limited data is available regarding survivorship of the GMK PS implant with hybrid fixation. The Australian National Joint Registry 2020 report recorded 23 revisions out of 643 TKA's performed at 5-year follow-up using the GMK primary implant with hybrid fixation (278). This represents a 4.1% cumulative revision rate. The number of PS versus CR constrained implants was not available in the report and this, along with a difference in reporting time frame may explain the differences between the present study and data reported in the Australian Registry. The authors of the present study believe the increased tibial loosening seen in the rKA group is possibly due to implant design. When the tibial component is placed either in varus or valgus, an excessive shearing stress may be applied on the post-cam interface directly linked to the tibial implant leading increased shear forces and potentially early aseptic loosening even with a cemented tibial component. Even if no significant difference was found for mFTA between both groups, significant differences were found for FMA, TMA and tibial slope which could be a plausible reason of tibial loosening. Supporting this theory is that many studies showed increased failure rates with postoperative alignment in the outlier category (beyond $0^\circ \pm 3$) compared to neutral alignment when using posterior-stabilized TKA (279,280). Countering this argument are several studies (266,281) that did not find significant difference in implant durability between the neutral alignment and outlier alignment group at long term

follow-up. Moreover, Nedopil et al. (229) reported higher incidence of tibial component failure when tibial slope was superior to 5° while using a KA philosophy. The authors of the present study did not consider tibial component failure due to loosening to be associated with any significant differences in tibial alignment, although it should be noted that baseplates with loosening tended to have slightly more varus femoro-tibial angles and tibial mechanical angles. Also in the present study, it should be noted that some patients had tibial component placement much more in varus without loosening. Maybe with a longer follow-up these patients would also have tibial loosening.

Restricted kinematic alignment is increasingly being accepted as a surgical technique for TKA as the body of evidence supporting its use grows. Proponents of rKA argue the restoration of the tibio-femoral joint line back to its pre-arthritis position maintains the native soft tissue anatomy, preserving normal joint kinematics and ultimately an improvement in patient outcomes. Two randomized controlled trials involving CR implants reported improved short term clinical results in favor of rKA (183,282). Whilst the reason for this observation is not fully understood, several studies have shown a reduction in the need for soft tissue releases with a rKA approach compared to MA, potentially explaining decreased postoperative pain (182,191). Another possible explanation for improvement in outcomes is tibio-femoral balancing, with a number of studies reporting less gap imbalance and a more natural gait with KA (232,239). Recent systematic reviews and meta-analyses have shown that KA achieves similar clinical and radiological similar to those of MA without increasing the complication rate (7,208,283).

Despite the growing enthusiasm in KA, concerns remain about longevity of implant survival. Indeed, there still is a concern that varus alignment of the tibial component may result in early implant loosening (224,225). However, studies of short- and mid-term follow-up have not shown an increased risk of implant loosening between KA and MA groups (7,208,283). Furthermore, Howell et al. (177) in a long-term follow-up study reported no significant difference in complication rate in KA compared to MA TKAs at 10 year follow-up. These results differ from the present study where a significant increased risk of aseptic tibial implant loosening was observed in the rKA group. It is important to point out that in a vast majority of studies comparing implant survivorship between KA or rKA and MA alignment philosophy thus far have been with the use of CR TKA design (284). The authors of the present study are only aware of two studies that have reported survivorship with the use of a PS TKA implants

and a rKA philosophy, and in both cases there was short-term follow-up (191,239), with the principal outcome measured not including implant survival.

This study has several limitations. Being retrospective, it constitutes the first major limitation. Second, a hybrid cementation was performed which could lead to potentially worse radiological results. However, recent studies found similar results between hybrid and full cementation TKA at long term follow-up (285,286). Furthermore, all tibial components were cemented, and loosening was always observed on the tibial component in the present study. Third, follow-up was short- to mid-term and not identical for both groups due to this being a consecutive series, therefore MA group follow-up was longer.

This study is clinically relevant since it serves as a cautionary note to surgeons performing rKA TKA, with prosthetic design potentially impacting on survival outcomes using this technique.

Conclusion

An increased risk of tibial implant loosening was found with rKA compared to MA using a posterior-stabilized TKA with a post cam system at short-term follow-up. Caution should be exercised when choosing the TKA design whilst performing rKA.

En résumé, cette étude a permis de montrer un potentiel risque de l'alignement cinématique. En effet, une PTG postéro-stabilisée par un système plot-came positionnée selon un alignement cinématique pourrait être amenée à se desceller plus précocement à cause des forces en cisaillement exercées sur le plot tibial.

3.3 Etude préliminaire afin d'évaluer si l'alignement cinématique permettait d'équilibrer le genou en extension et en flexion

Nous avons réalisé une étude préliminaire afin de savoir si l'alignement cinématique permettait d'obtenir un genou équilibré sur les espaces en extension et en flexion après prothèse totale de genou. Pour évaluer l'équilibrage ligamentaire, les PTG étaient réalisées à l'aide d'un outil robotique (Mako, Stryker).

Introduction

Il est de plus en plus évident que les résultats cliniques après prothèse totale de genou (PTG) sont liés à l'équilibrage des compartiments fémoro-tibiaux. L'alignement cinématique (AC) pour la PTG a été développé dans le but de restaurer la cinématique naturelle de l'articulation. Cependant, le positionnement de l'implant est basé sur des repères osseux et ne tient pas compte de la laxité ligamentaire. De plus, la plupart des études utilisent la même approche pour les genoux alignés en varus et en valgus, malgré des différences significatives dans le comportement et l'anatomie entre les groupes. Le but de cette étude était d'évaluer si une philosophie cinématique permettait d'obtenir un genou équilibré en extension et en flexion dans le cadre d'une arthrose en varus.

Méthodes

Il s'agissait d'une étude de cohorte prospective monocentrique de patients subissant une PTG à l'aide d'une plateforme robotisée (Mako, Stryker Corp, Mahwah, NJ, USA). Au total, 110 PTG ont été réalisées à l'aide du système robotique. Les patients étaient inclus s'ils avaient eu une planification chirurgicale préopératoire basée sur les principes de l'alignement cinématique. Les critères d'exclusions étaient les chirurgies de reprise de PTG, les gonarthroses post-traumatique, les antécédents d'ostéotomie fémorale ou tibiale et les gonarthroses en valgus. Tous les cas ont été réalisés par un seul chirurgien utilisant une PTG postéro-stabilisée (Triathlon, Stryker Corp, Mahwah, NJ, USA).

Après l'évaluation de la laxité ligamentaire en peropératoire, des écarts virtuels ont été évalués à l'aide de la plateforme robotisée pour voir si le plan originel de l'AC permettait d'obtenir un genou équilibré dans deux situations. L'équilibre était considéré comme atteint si les espaces des compartiments fémoro-tibiaux (médial/latéral) étaient égaux ou inférieurs à 1,5 mm, ou si

l'espace final estimé était inférieur à 2 mm par rapport à l'épaisseur globale de l'implant (17 mm). Le positionnement de l'implant était modifié dans les limites définies pour la philosophie de l'alignement fonctionnel (AF) afin d'atteindre un équilibre. L'épaisseur de la résection et le positionnement de l'implant ont été comparés avant et après l'évaluation de la laxité ligamentaires, et entre les groupes ayant obtenu des écarts équilibrés dans les deux états susmentionnés. Les caractéristiques descriptives entre les groupes ont été décrites et les moyennes comparées à l'aide de tests T appariés.

Résultats

Après exclusion, un total de 51 patients ont été inclus pour l'analyse finale. L'âge moyen était de $68,7 \pm 7,5$, l'IMC moyen était de $29,1 \pm 4,7$, l'alignement coronal préopératoire moyen était de $178,8^\circ \pm 3,4^\circ$ et l'alignement sagittal de $2,9^\circ \pm 6,5^\circ$. Le rapport hommes/femmes était de 21:31 (40,4% et 59,6%). La plupart des patients présentaient une arthrose de grade 3 (55,8%) ou 4 (28,8%) selon Alhback et étaient de type 1 (61,5%) ou 2 (15,4%) selon la classification CPAK. L'alignement coronal postopératoire moyen était de $177^\circ \pm 2,1^\circ$ et l'alignement sagittal de $0,9^\circ \pm 1,9^\circ$.

Le plan « alignement cinématique » a permis d'équilibrer le compartiment fémoro-tibial médial/latéral dans 31 cas (59,6 %) et d'équilibrer les espaces à moins de 2 mm de l'épaisseur de l'implant dans 16 cas (30,8 %). La majorité des déséquilibres se sont produits en flexion. Toutes les profondeurs de résection osseuse mesurées étaient inférieures pour le plan « alignement fonctionnel » par rapport au plan « alignement cinématique » d'origine. Concernant l'espace en extension, la moyenne de la résection osseuse médiale était de 16,5 mm (plan AC) contre 15,1 mm (plan AF) ($p < 0,001$) et la résection osseuse fémorale latérale était de 16,2 mm (plan AC) contre 14,0 mm (plan AF) ($p < 0,001$). Concernant l'espace en flexion, la résection médiale moyenne était de 16,8 mm (plan AC) contre 15,7 mm (plan AF) ($p = 0,002$) et la résection osseuse fémorale latérale de 16,2 mm (plan AC) et 14,3 mm (plan AF) ($p < 0,001$).

Les différences d'alignement de la prothèse ont été comparées dans les 3 plans. Afin d'atteindre les objectifs d'équilibrage, la position finale du composant fémoral était plus en rotation externe (RE) par rapport à la ligne bicondylienne postérieure, $0,82^\circ$ dans le groupe AC contre $1,97^\circ$ RE dans le groupe AF ($p < 0,001$), et le tibia plus en varus ($2,5^\circ$ plan AC contre $3,1^\circ$ plan AF ; $p = 0,035$). Une libération ligamentaire a été nécessaire pour un cas afin d'obtenir un genou équilibré.

Conclusion

Le plan AC n'a pas permis d'obtenir une PTG équilibrée dans 40% des cas. La majorité des déséquilibres ont été observés sur l'espace en flexion. La prise en compte de la laxité ligamentaires a conduit à une résection osseuse significativement moindre, avec un positionnement des composants plus en rotation externe au niveau fémoral et plus en varus au niveau tibial. L'alignement cinématique ne permet pas toujours d'obtenir un espace en flexion bien équilibré dans les PTG.

En résumé, l'alignement cinématique après PTG ne permet pas d'obtenir un équilibrage ligamentaire dans tous les cas, notamment concernant l'espace en flexion. Un alignement personnalisé sur l'espace en extension et en flexion semble nécessaire. Ceci est permis avec l'alignement fonctionnel possible à l'aide d'outils robotiques.

4. Partie 3 – Protocole de recherche

4.1 Protocole de l'essai clinique randomisé

4.1.1. Type d'étude

Il s'agissait d'une étude prospective, monocentrique, randomisée, en ouvert, de type « Recherche interventionnelle à risques et contraintes minimales mentionnée au 2° de l'article L. 1121-1 du code de la santé publique ».

4.1.2. Hypothèse

L'hypothèse testée était la supériorité d'un alignement cinématique versus un alignement mécanique lors de la pose d'une PTG médialement stabilisée en termes d'amélioration de la vitesse de marche à 12 mois post opératoire. Les caractéristiques biomécaniques du genou lors de la marche après PTG avec un alignement cinématique seraient plus proches de celles d'un genou natif qu'avec un alignement mécanique à 12 mois post opératoires. Les scores fonctionnels à 12 mois seraient similaires ou supérieurs après PTG avec un alignement cinématique versus un alignement mécanique.

4.1.3. Critères d'inclusion et d'exclusion

Les critères d'inclusion étaient :

- Homme ou femme
- Age compris entre 55 et 80 ans
- Diagnostic de gonarthrose fémorotibiale invalidante interne ou globale
- Indication d'arthroplastie totale de genou de première intention (unilatérale), de type Sphere (Medacta)
- Déformation constitutionnelle en varus comprise entre 3° et 10°
- Remplissant les conditions de passage d'un test de marche KneeKG : Appui unipodal possible pendant 1 minute, marche pendant 5 min à une vitesse d'au moins 0,8 km/h. social
- Affilié à un régime de sécurité sociale
- Sujet habilité à comprendre et à suivre les tenants et les aboutissants de l'étude

Les critères d'exclusion étaient :

- PTG bilatérale dans le même temps opératoire
- Changement de PUC ou PTG
- Antécédent de fracture fémorale ou tibiale
- Antécédent d'ostéotomie fémorale ou tibiale
- Geste associé dans le même temps (allogreffe, ostéotomie)
- Gonarthrose fémorotibiale externe
- HKA > 178°
- Déformation constitutionnelle >10°
- Refus de participer à l'étude
- Personnes privées de liberté par une décision judiciaire ou administrative, personnes faisant l'objet de soins psychiatriques, personnes admises dans un établissement sanitaire ou social à d'autres fins que celle de la recherche
- Personnes majeures faisant l'objet d'une mesure de protection légale
- Patient enceinte ou allaitante
- Patient participant à une recherche interventionnelle à l'exclusion des recherches de soins courants (ancienne réglementation) et des recherches de catégorie 2° n'interférant pas avec l'analyse du critère principal.

4.1.4. Méthodologie

L'intervention de l'étude était la pose d'une prothèse totale de genou (type « medial-pivot » Sphere, Medacta), soit selon un alignement mécanique, soit selon un alignement cinématique. Les deux techniques chirurgicales sont décrites dans la partie 2. Le type d'alignement utilisé était randomisé le matin ou la veille de la chirurgie.

Les données évaluées incluaient :

- Une analyse de la marche avec le système KneeKG à 12 mois post opératoires. Cet examen était réalisé selon la technique décrite dans la partie 2 par un seul examinateur.
- Des scores cliniques à 12 mois post op (IKS fonction et genou, satisfaction, Forgotten joint score).
- Un bilan radiologique avec des radiographies standard en charge de face, de profil, une incidence fémoro-patellaire et une pangonométrie à 12 mois postopératoires.
- Les complications et révisions au dernier recul.

Le nombre de sujet nécessaire avait été calculé pour retrouver une supériorité significative sur la variation de la vitesse de marche après PTG dans le groupe alignement cinématique. Ce nombre de sujet avait été déterminé à 52 patients par groupe, soit 104 au total.

4.1.5. Comité d'éthique

Le Comité de Protection des Personnes Ile de France V a donné un avis favorable pour cet essai clinique. L'étude est enregistrée sur ClinicalTrials.gov (Identifiant: NCT04226339) et a été approuvée par le comité de l'hôpital en tant qu'essai contrôlé randomisé (study ID Number: 69HCL19_0497 et 2019-A02288-49). Tous les patients ont signé un consentement éclairé.

4.2 Avancée du protocole de recherche

Le début des inclusions dans le protocole de recherche a été retardé à cause de la crise sanitaire Covid 19. En effet, les inclusions ont débuté début septembre 2020. Les différentes vagues de la crise sanitaire ont mis partiellement voire totalement en arrêt les services de chirurgie non essentielles. L'orthopédie a donc été lourdement impactée. Ainsi à ce jour, 22 patients ont pu être inclus sur les 104 : 11 patients dans chaque groupe. Sept patients ont été revus à leur contrôle post opératoire à 1 an.

A ce jour, l'activité chirurgicale est maintenue et les inclusions continuent.

5. Partie 4 - Discussion générale

5.1 Evolution de l'alignement dans les PTG

Les techniques d'alignement ont eu tendance à se concentrer sur l'alignement coronal, sans tenir compte de facteurs tels que la hauteur de l'interligne articulaire, l'équilibrage des espaces et l'obliquité de l'interligne. Les premières philosophies d'alignement visaient à obtenir un alignement neutre pour tous les patients (12,172). L'équilibrage dans l'alignement mécanique nécessite souvent des libérations ligamentaires importantes (287). Les anomalies retrouvées à l'analyse de la marche (288) et l'insatisfaction après PTG atteignant jusqu'à 20 % des patients (200) ont conduit les chirurgiens à réexaminer la question des techniques d'alignement optimales. Howell a décrit la philosophie d'alignement cinématique basée sur les repères osseux et l'usure du cartilage, sans limites dans le positionnement des implants (203). Les préoccupations concernant l'effet des positions extrêmes des implants ont conduit au développement de "zones de sécurité", d'abord avec l'alignement cinématique restreint (189), puis avec l'alignement cinématique inverse (187). Seul l'alignement cinématique inverse prend en compte la laxité articulaire en équilibrant uniquement par l'ajustement du composant fémoral. L'alignement fonctionnel prend en compte des zones pour les objectifs d'alignement, mais vise des cibles de laxité ligamentaire définissables et reproductibles (6).

L'alignement cinématique a montré de bons résultats cliniques parfois mêmes meilleurs par rapport à l'alignement mécanique (7). Moins de libérations ligamentaires étaient nécessaires lors de la réalisation d'un alignement cinématique par rapport à un alignement mécanique (182,191,238). De plus, un meilleur équilibre ligamentaire et une démarche plus naturelle ont été constatés par certains auteurs lors de la réalisation d'un alignement cinématique (190,232,239).

Nous avons montré que l'alignement cinématique correspondait à l'alignement fonctionnel concernant l'espace en extension (Article 5). Graichen et al. (244) ont montré une grande variabilité interindividuelle concernant les laxités ligamentaires dans les genoux varum. Comme les genoux varum ne sont pas tous identiques, surtout en ce qui concerne l'espace en flexion, les espaces ligamentaires individuels doivent être analysés et traités en conséquence avec une technique d'équilibrage individualisée telle que l'alignement fonctionnel. Ainsi l'alignement cinématique pourrait ne pas correspondre parfaitement à l'alignement

constitutionnel notamment concernant l'espace en flexion. Enfin, nous avons réalisé une étude préliminaire afin de savoir si l'application de l'alignement cinématique permettait d'obtenir un genou équilibré sur les espaces en extension et en flexion après prothèse totale de genou. Pour évaluer l'équilibrage ligamentaire, les PTG étaient réalisées à l'aide d'un outil robotique (Mako, Stryker). Nous avons montré que l'alignement cinématique après PTG ne permettait pas d'obtenir un équilibrage ligamentaire dans tous les cas, notamment concernant l'espace en flexion. Un alignement personnalisé sur l'espace en extension et en flexion semble nécessaire. Ceci est permis avec l'alignement fonctionnel possible à l'aide d'outils robotiques.

5.2 Limitations de ce travail

Plusieurs limites sont présentes dans ce travail.

5.2.1 Analyse radiographique

Pour l'ensemble des études réalisées, une analyse radiologique a été effectuée sur des radiographies de télémétrie en charge, en appui bipodal. Les mesures de paramètres radiologiques sur ce type de radiographies peuvent être critiquées pour être moins précises que les mesures effectuées à l'aide d'autres modalités d'imagerie telles que le scanner ou l'IRM (159). Pourtant, de nombreux auteurs (162–165) ont observé une bonne concordance entre les scanogrammes en position couchée et les radiographies des membres inférieurs en charge. De plus, nous avons considéré, dans la majorité de nos études, les mesures de l'angle mécanique fémoral et tibial, qui sont mesurées par des repères osseux de façon précise à partir de télémétrie des deux membres inférieurs en charge. Le fait de ne pas analyser l'angle HKA a permis d'éviter le facteur de confusion que constitue la laxité du genou lors de la mise en charge. De plus, pour éviter toute imprécision de mesure des paramètres radiologiques, des critères d'inclusion très stricts ont été respectés, et seuls les genoux sans antécédents médicaux ou chirurgicaux ont été pris en compte. Les radiographies ont toutes été réalisées selon un protocole standardisé afin d'éviter toute écart de rotation, qui pourrait altérer les mesures d'alignement coronal.

5.2.2 Suivi des études

L'article 4 présente une revue systématique comparant les PTG avec alignement mécanique versus cinématique à un recul minimum de 2 ans. Le suivi était donc trop court pour évaluer la survie à moyen ou long terme. L'article 6 présente des résultats à un suivi court, au minimum de 2 ans également. Bien que la condition du genou après PTG se trouve souvent stabilisée à un délai postopératoire de 2 ans, aucune conclusion ne peut être faite sur les résultats à long terme. Enfin, l'article 7 présente des résultats allant de court à moyen terme. L'évaluation à long terme de ces différentes techniques d'alignement personnalisé reste nécessaire afin d'évaluer les résultats cliniques et radiologiques et la survie des implants prothétiques.

5.2.3 Retard inclusion protocole de recherche

La crise sanitaire de la Covid-19 a conduit à l'arrêt des chirurgies orthopédiques non urgentes entraînant un retard dans l'inclusion des patients du protocole de recherche. Ainsi, il n'est pas possible de présenter les premiers résultats cliniques, radiologiques et après analyse de la marche entre les deux groupes. Les inclusions ont pu reprendre néanmoins et ce protocole sera poursuivi en post-doctorat.

5.3 Conclusions générales

L'objectif principal de ce travail était de montrer l'évolution de l'alignement dans les prothèses totales de genou et d'en évaluer les nouvelles alternatives. Pour répondre à cet objectif, nous avons dans un premier temps réalisé une revue de la littérature sur les différentes « nouvelles technologies » en prothèse de genou, leurs avantages et leurs limites (Article 1). Certaines de ces nouvelles technologies permettent d'améliorer le positionnement des implants mais n'améliorent pas pour autant les résultats. Nous avons donc ensuite réalisé une analyse radiographique sur plus de 2800 radiographies afin de mieux comprendre l'alignement coronal du genou pour des patients atteints d'arthrose primaire (Article 2). Nous avons montré que les patients atteints d'arthrose présentaient une déformation coronale fémorale plus en varus par rapport à une population jeune sans arthrose. Cette étude a permis d'établir les différences d'alignement coronal entre les genoux arthrosiques et natifs. Ensuite, nous avons fait une revue de la littérature sur les principes et résultats des différents types d'alignements personnalisés dans le cadre des PTG (Article 3). Le but de l'alignement cinématique est de restaurer l'anatomie et l'équilibrage du genou pré-arthrosique à partir de repères osseux. L'alignement fonctionnel, possible avec assistance robotique, adapte en peropératoire le positionnement des implants prothétiques selon l'anatomie et la laxité ligamentaire constitutionnelles. Afin d'évaluer l'intérêt de l'alignement cinématique, nous avons réalisé une revue systématique comparant les résultats après PTG entre alignement mécanique et cinématique à un recul minimum de 2 ans (Article 4). L'alignement cinématique apparaissait comme une technique envisageable et alternative à l'alignement mécanique. Une nouvelle classification radiologique Coronal Plane Alignment of the Knee (CPAK) de l'alignement coronal du genou a été décrite considérant l'alignement coronal et l'obliquité de l'interligne. Nous avons comparé l'alignement coronal obtenu avec cette méthode à des radiographies dynamiques en valgus compensant l'usure cartilagineuse et la laxité ligamentaire. Nous avons trouvé des résultats similaires indiquant que l'alignement cinématique évalué avec la classification CPAK permettrait d'anticiper l'alignement fonctionnel sur l'espace en extension du genou.

Nous avons comparé les résultats cliniques après PTG, réalisée avec une technique d'alignement mécanique, selon la restauration des différents phénotypes du genou à partir de la classification CPAK (Article 6). Nous avons montré que l'alignement mécanique ne permet pas de restituer la catégorie préopératoire CPAK dans la majorité des cas. Aussi, moins de douleurs post opératoires étaient retrouvées lors de la restauration de l'obliquité de l'interligne

articulaire. Enfin, la majorité des études présentant les résultats de PTG avec alignement cinématique sont réalisées avec des prothèses à conservation du ligament croisé postérieur. Nous souhaitons savoir si ces résultats s'appliquent aussi à une PTG postéro-stabilisée (PS) puisque nous utilisons ce type d'implant (PTG (PS)). Nous avons donc comparé les résultats entre alignement mécanique et cinématique restreint en utilisant une PTG PS par un système plot-came (Article 7). Nous avons trouvé un risque augmenté de descellement tibial aseptique dans le groupe cinématique potentiellement expliqué par des forces de cisaillement exercées sur le plot tibial en cas de position des implants en varus/valgus. Nous avons donc montré que l'alignement cinématique permettait d'obtenir de bons résultats cliniques et radiologiques. L'alignement cinématique déterminé à partir de repères osseux semble correspondre à l'alignement fonctionnel en extension. En revanche, l'assistance robotique nous a permis de réaliser que le comportement ligamentaire était différent en flexion et que l'alignement cinématique ne permettait pas d'obtenir un bon équilibre ligamentaire en flexion dans tous les cas (étude préliminaire).

Plusieurs études ont évalué le schéma de marche des patients afin d'obtenir un examen plus objectif sur la récupération fonctionnelle en post opératoire de prothèses de genou. Le but était d'évaluer la récupération d'un schéma de marche le plus proche possible de celui d'un genou natif. Nous avons initié une étude prospective randomisée comparant l'analyse de la marche chez des patients opérés de PTG type « medial-pivot » avec un alignement mécanique versus un alignement cinématique. Les objectifs étaient de comparer l'analyse de la marche, les résultats cliniques et radiologiques pour 52 PTG dans chaque groupe à un recul minimum de 12 mois.

Enfin, l'évaluation du schéma de marche après PTG implantées avec assistance robotique selon l'alignement fonctionnel serait intéressante. Par ailleurs l'analyse de la marche évalue des patients lors d'un mouvement assez simple. Il pourrait être intéressant d'évaluer des mouvements ou activités plus complexes afin de rechercher une différence entre ces différents groupes de patients pour des activités se rapprochant plus des activités de la vie quotidienne, telles que la marche forcée, la montée/descente d'escaliers.

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7. Communications orales – Poster

7.1 Communications orales

L'article 6 présenté dans la thèse a été accepté à 3 reprises pour une présentation orale :

❖ 3rd World Arthroplasty Congress – Virtual meeting 2021

- Is restoring knee phenotype and joint line obliquity important after primary TKA ?

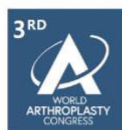
❖ Société Française de Chirurgie Orthopédique et Traumatologique (SOFOT) 2021

- Intérêt de la restauration du phénotype du genou et de l'obliquité de l'interligne après PTG de première intention.

❖ International Society of Arthroscopy Knee surgery and Orthopaedic Sports medicine 2021

- Restoring knee phenotype and joint line obliquity reduces postoperative pain after primary TKA

3rd World Arthroplasty Congress – Virtual meeting 2021
 SOFCOT 2021
 ISAKOS – Global congress 2021



Is restoring knee phenotype and joint line obliquity important after primary TKA ?

E. Sappey-Marinier

C. Batailler, L. Cheze, S. MacDessi, E. Servien, S. Lustig

Orthopaedic surgery and sport medicine department
 Lyon University Hospital, France



Introduction

- 900 000 TKA in 2019 USA / 1.1 million Europe
- **Systematic mechanical alignment** at 180°
 - Better load distribution on the medial and lateral compartment
 - Reduce polyethylene wear
 - Decrease risk of loosening



> J Arthroplasty. 2009 Jun;24(4):570-8. doi: 10.1016/j.arth.2008.03.002. Epub 2009 May 19.

Good alignment after total knee arthroplasty leads to faster rehabilitation and better function

Lee M Longstaff¹, Karen Sloan, Nikki Stamp, Matt Scaddan, Richard Beaver

> J Arthroplasty. 2009 Sep;24(9):Suppl:39-43. doi: 10.1016/j.arth.2009.04.034. Epub 2009 Jun 24.

Coronal alignment in total knee arthroplasty: just how important is it?

David M Fong¹, Merrill A Ritter, Kenneth E Davis

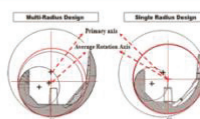
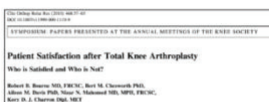
> Clin Orthop Rel Res. 1994 Feb;(299):163-6.

Postoperative alignment of total knee replacement. Its effect on survival

M.A.Ritter¹, P.M.Faris, C.M.Keating, J.B.Medley

TKA : where are we ?

- Imperfect results
- Anterior knee **pain** reported by **4 to 49%** patients
- Up to **20%** patients **dissatisfied** by their knee prosthesis



MANAGEMENT FACTORIALS IN TOTAL KNEE ARTHROPLASTY

Patient dissatisfaction following total knee replacement

A GROWING CONCERN?

D. Nam,
 R. M. Nunley,
 R. L. Barrack

How to improve these results ?

- Better understanding the native and osteoarthritic knee
- Wide individual variation

2019
Phenotyping the knee in young non-osteoarthritic knees shows a wide distribution of femoral and tibial coronal alignment.
N=308 CT scan

2020
Primary osteoarthritic knees have more varus coronal alignment of the femur compared to young non-arthritic knees in a large cohort study
N=2859 Xrays

Orthopaedics & Traumatology: Surgery & Research
Elsevier
Volume 120, Issue 7, November 2017, Pages 1247-1264

Alignment options for total knee arthroplasty: A systematic review

ANNOTATION
Alignment in total knee arthroplasty
WHAT'S IN A NAME?

Native KA rKA aMA AA MA
Patient-specific technique Hybrid technique Systematic technique

Question ?

Are clinical outcomes after primary TKR related to



- coronal alignment
- joint line obliquity



Methods

- 1078 osteoarthritic knees
- Aiming mechanical alignment
- IKS score
- 2 years FU min



=> Arithmetic HKA
=> Joint line obliquity

ORTHOPÉDIE
Lyon Croix Rousse

KNEE
Coronal Plane Alignment of the Knee
(CPAK) classification
A NEW SYSTEM FOR DESCRIBING KNEE PHENOTYPES

		Arithmetic HKA		
		VARUS	NEUTRAL	VALGUS
MECHANICAL AXIS	VARUS	I	II	III
	NEUTRAL	IV	V	VI
MECHANICAL AXIS	VARUS	VII	VIII	IX



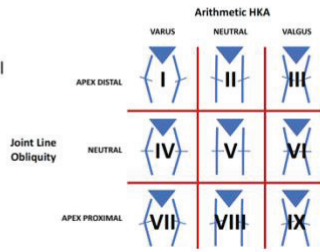
Coronal Plane Alignment of the Knee classification

Joint line obliquity = MPTA + LDFA

Arithmetic HKA = MPTA - LDFA

- 3 categories:
 - Apex distal
 - Neutral
 - Apex proximal

- 3 categories:
 - Varus
 - Neutral
 - Valgus



Methods

• 1078 osteoarthritic knees

=> Arithmetic HKA
=> Joint line obliquity

KNEE
Coronal Plane Alignment of the Knee (CPAK) classification
A NEW SYSTEM FOR DESCRIBING KNEE PHENOTYPES

ORTHOPÉDIE
Lyon Croix Rousse

S. J. MacDessi



n=1078 TKAs



MPTA-LDFA (Obliquity)	MPTA - LDFA (aHKA)			Total
	< -2°	-2° to 2°	> 2°	
	< 177°	388 (35.1%)	238 (21.9%)	
177° to 187°	188 (17.5%)	284 (26.3%)	163 (15.1%)	635
> 187°	4 (0.4%)	4 (0.4%)	1 (0.1%)	9
Total	474	426	184	1078

Methods

• 1078 osteoarthritic knees

=> Arithmetic HKA
=> Joint line obliquity

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Total	474	426	184	1078

MPTA-LDFA (Obliquity)	MPTA - LDFA (aHKA)			Total
	< -2°	-2° to 2°	> 2°	
	< 177°	34 (3.1%)	32 (2.9%)	
177° to 187°	184 (17.1%)	423 (39.2%)	54 (5.0%)	661
> 187°	79 (7.3%)	22 (2.0%)	4 (0.4%)	105
Total	297	477	184	958

N=1078
2 years FU minimum

Outcomes – aHKA - JLO

	Apex Distal (JLO < 2°)			Neutral (JLO 2° to 7°)			Apex Proximal (JLO > 7°)		
	Number	Mean (SD)	p value	Number	Mean (SD)	p value	Number	Mean (SD)	p value
	Gender (male)	27	71.1 ± 13.6	0.76	102	71.1 ± 13.3	0.87	12	71.1 ± 13.3
Mean age ± SD	71.1 ± 13.6	71.1 ± 13.6	0.76	70.9 ± 13.3	71.1 ± 13.3	0.67	70.9 ± 13.3	71.1 ± 13.3	0.76
Mean post op ± SD	40.1 ± 8.9	40.1 ± 8.9	0.85	40.1 ± 8.9	40.1 ± 8.9	0.85	40.1 ± 8.9	40.1 ± 8.9	0.85
Mean post op Non-Resect ± SD	10.8 ± 12.9	10.8 ± 12.9	0.68	10.8 ± 12.9	10.8 ± 12.9	0.68	10.8 ± 12.9	10.8 ± 12.9	0.68

Functional relevance of restoring JLO vs aHKA alone

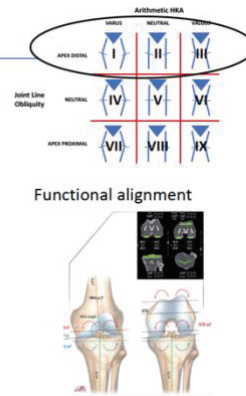
Discussion

- Less postoperative pain with restored JLO
 - WHY ? => Knee Function ?
 - => Ligament balance ?
- **Apex distal JLO**
 - => 64% of the preoperative population
- Supports the interest for robotic tools and sensors to understand and restore JLO in the context of personalized alignment



Conclusion

- Interest of CPAK classification
 - Joint line obliquity +++
 - Arithmetic HKA
- 1st study
 - Relevance of restoring JLO after TKA
 - Large database
- Functional alignment should consider JLO as a significant part of coronal alignment



7.2 Posters

❖ Société Française de Chirurgie Orthopédique et Traumatologique (SOFCOT) 2021

- Risque augmenté à court terme de descellement aseptique lors de la mise en place de PTG postéro-stabilisée avec un alignement cinématique restreint : une étude cas témoin.









Risque augmenté à court terme de descellement aseptique lors de la mise en place de PTG postéro-stabilisée avec un alignement cinématique restreint : une étude cas témoin.

E. Sappey-Marinier, J. Shatrov, C. Batailler, E. Servien, E. Marchetti, S. Lustig

Orthopaedic surgery and sport medicine department
Lyon University Hospital, France







9-11
NOVEMBRE 2021

Etude cas témoin rétrospective monocentrique

- PTG entre 2016 et 2017 (GMK PS, Medacta à plot central)
- Deux groupes:
 - Alignement mécanique: 100 PTG PS
 - Alignement cinématique restreint: 50 PTG PS
 - Cimentation hybride
 - Guides de coupe sur mesure dans les deux groupes
- Recul minimum 3 ans
- Evaluation clinique et radiologique



Hypothèse: risque de descellement prothétique en cas d'alignement cinématique avec PTG PS sur conflit avec le plot central

Résultats

- Résultats cliniques similaires
- Groupe alignement mécanique
 - 2 reprises (/100) pour descellement aseptique
- Groupe alignement cinématique restreint
 - 8 reprises (/50) pour descellement aseptique

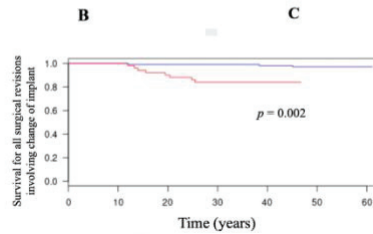
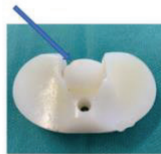
	Mechanical Alignment group	Kinematic Alignment group	p-value
Follow-up (months)	53.3 ± 4.1 (45.3 - 61.2)	42.9 ± 3.4 (37.6 - 48.2)	< 0.001
Clinical assessment			
New KSS*	179.6 ± 19.6 (153 - 222)	172.2 ± 19.6 (121 - 206)	0.11
Gain KSS*	37.3 ± 20.8 (21 - 122)	32 ± 26.4 (21 - 136)	0.34
Patient expectation*	13.8 ± 2.1 (4 - 15)	11.3 ± 3.4 (3 - 15)	0.06
Satisfaction*	38.7 ± 6.3 (22 - 48)	38.6 ± 7.4 (8 - 48)	0.94
Functional activities*	63.1 ± 11.8 (26 - 81)	62.1 ± 12.2 (24 - 85)	0.67
Maximum knee flexion* (degrees)	119.6 ± 6.8 (96 - 131)	123.3 ± 11.2 (89 - 146)	0.39

	Mechanical alignment group		p-value
	Without loosening (n=92)	With loosening (n=8)	
aFT angle*	179.2 ± 2.7 (175 - 186)	180.6 ± 2.8 (181 - 183)	0.68
Posterior mechanical angle*	89.8 ± 1.3 (88 - 92)	90 ± 0.9 (91 - 92)	0.75
Anterior mechanical angle*	89.3 ± 0.8 (88 - 92)	89.3 ± 0.7 (89 - 92)	1
Distal slope*	88.6 ± 1.1 (88 - 92)	87.5 ± 0.8 (87 - 88)	0.17
	Kinematic alignment group		p-value
	Without loosening (n=42)	With loosening (n=8)	
aFT angle*	178.8 ± 3.8 (175 - 186)	177.4 ± 2.2 (177 - 183)	0.35
Posterior mechanical angle*	91.2 ± 2.4 (88 - 92)	91 ± 2.3 (89 - 92)	0.76
Anterior mechanical angle*	90.4 ± 2.2 (87 - 92)	87.8 ± 1.1 (88 - 92)	0.23
Distal slope*	90.8 ± 1.2 (88 - 92)	90.8 ± 0.9 (87 - 92)	0.68

*The values are given as mean (SD), with the range in parentheses.
aFT: mechanical flexion angle.

Survie

- Risque augmenté de descellement aseptique



Conclusion

- Résultats cliniques similaires entre alignement mécanique et cinématique avec prothèse PS avec plot central
- Risque augmenté de descellement aseptique
- Potentiel conflit sur le plot central en cas d'alignement cinématique avec prothèse PS à plot central

- L'alignement arithmétique est un outil efficace pour anticiper l'alignement fonctionnel en cas d'arthrose essentielle en varus : une analyse consécutive de 749 genoux à l'aide de radiographies en stress.

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LYON KNEE SCHOOL OF SURGERY

UFR Lyon 1

UNIVERSITY OF LYON

L'alignement arithmétique est un outil efficace pour anticiper l'alignement fonctionnel en cas d'arthrose essentielle en varus : une analyse consécutive de 749 genoux à l'aide de radiographies en stress.

E. Sappey-Marinière, P. Meynard, J. Shatrov, A. Schmidt, L. Cheze, C. Batailler, E. Servien, S. Lustig

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FIFA MEDICAL CENTRE OF EXCELLENCE

ORTHOPÉDIE LYON ÉTOILE ROUGE

SOFCOT 9-11 NOVEMBRE 2021

Introduction

- 900 000 PTG en 2019 USA / 1.1 millions en Europe
- **Alignement mécanique systématique à 180°**
 - Meilleure distribution des charges sur le compartiment médial et latéral
 - Réduire usure du polyéthylène
 - Diminuer risque de descellement



J. Arthroplasty, 2009 Sep 24(9 Suppl):39-43. doi: 10.1016/j.arth.2009.04.034. Epub 2009 Jun 24.

Coronal alignment in total knee arthroplasty: just how important is it?

David M Fong¹, Merrill A Ritter, Kenneth E Davis

J. Arthroplasty, 2009 Jun 24(6):570-8. doi: 10.1016/j.arth.2008.03.002. Epub 2008 May 19.

Good alignment after total knee arthroplasty leads to faster rehabilitation and better function

Lee M Longstaff¹, Karen Sloan, Nikki Stamp, Matt Scaddan, Richard Brewer

Chir Orthop Relat Res, 1994 Feb;129(1):3-6.

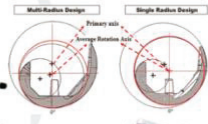

Postoperative alignment of total knee replacement. Its effect on survival

M.A Ritter¹, P.M Harris, E. G. Scadding, J. B. Medendorp

ABRE 2021

PTG : où en sommes nous ?

- Résultats imparfaits
- Douleurs antérieures rapportées par 4 à 49% des patients
- Jusqu'à 20% des patients non satisfaits de leur prothèse

MANAGEMENT FACTORIALS IN TOTAL KNEE ARTHROPLASTY
Patient dissatisfaction following total knee replacement
A GROWING CONCERN?


D. Nam,
R. M. Nunley,
R. L. Barrack

SOF COT

ABRE 2021

2 principaux alignements personnalisés après PTG pour tenter d'améliorer les résultats cliniques

- **Alignement cinématique**
 - Repères osseux
 - Objectif restituer la situation du genou natif
 - Préservation enveloppe ligamentaire
 - Pas de restriction
 - Fémur distal en premier puis coupe postérieure et adaptation tibia
- **Alignement fonctionnel**
 - Equilibrage ligamentaire 3D, dynamique ++
 - Résection osseuse symétrique et adaptation selon équilibrage ligamentaire
 - Outil robotique nécessaire
 - Fémur en premier puis adaptation tibia



SICOT

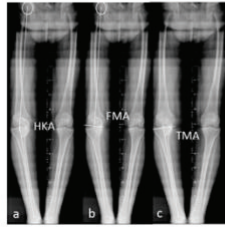
PERSONALIZED ALIGNMENT IN TOTAL KNEE ARTHROPLASTY: CURRENT CONCEPTS

Wolfgang Gombert¹, Elmar Fegert², Christian Kay³, Elmar Fegert⁴, Silvester Pankratz⁵, and Christof Bräuer⁶

ABRE 2021

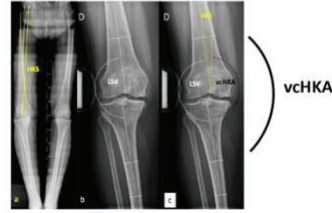
Etude comparative rétrospective radiologique sur 749 genoux en varus

- **Alignement constitutionnel**
 - cHKA = FMA + TMA
 - Repères osseux
 - Télémétrie de face en extension



VS

- **Stress valgus**
 - vcHKA = 360 - (HKS + LSV)
 - Mesures sur clichés en stress en valgus

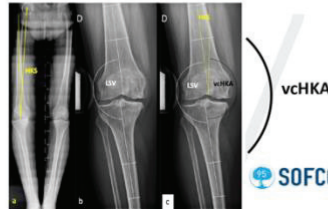


Objectif: déterminer si l'alignement constitutionnel évalué à partir de repères osseux tient compte de la laxité médiale en cas de déformation en varus

- **Alignement constitutionnel**
 - cHKA = FMA + TMA ⇒ Repères osseux

VS

- **Stress valgus**
 - vcHKA = 360 - (HKS + LSV)
 - ⇒ Usure cartilagineuse + Laxité ligamentaire



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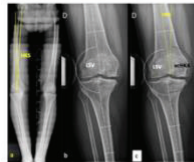
Résultats

- **Pas de différence significative entre**
 - cHKA: déformation constitutionnelle à partir de repères osseux
 - vcHKA: déformation après compensation usure cartilagineuse et laxité médiale
- **Concerne espace en extension**

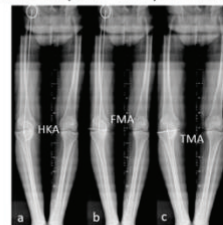
	cHKA	vcHKA	p Value
Overall population (n=749)	177.0 ± 3.3 (164-185)	176.9 ± 3.2 (165-192)	0.06
Preop HKA > 175 (n=224)	179.6 ± 2.2 (171-185)	179.8 ± 2.7 (173-192)	0.81
170 < Preop HKA < 175 (n=340)	177.1 ± 2.2 (170-184)	176.6 ± 2.3 (170-184)	0.003
Preop HKA < 175 (n=185)	173.8 ± 3.3 (164-181)	174.3 ± 2.7 (165-184)	0.16

Conclusion

- Mesure angle médial sur les clichés en valgus
 - Compensant usure cartilagineuse et laxité médiale
- Déformation constitutionnelle
 - Evaluée à partir de repères osseux



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L'alignement cinématique est un outil efficace pour anticiper l'alignement fonctionnel sur l'espace en EXTENSION

SAPPEY-MARINIER Elliot

Evolution et évaluation de l'alignement dans les prothèses totales de genou

39 figures. 21 tableaux.

Th. Sciences : Lyon 2022

Résumé.

La prothèse totale de genou (PTG) est une intervention fréquente en orthopédie. Lors de la réalisation de la PTG, l'objectif était d'obtenir un alignement mécanique (AM) systématique à 180°. Cette technique permet d'obtenir un membre rectiligne diminuant les contraintes articulaires et in fine améliorant la survie des implants. Malgré les avancées technologiques, les résultats des PTG restent imparfaits. Bien que la survie soit très bonne à long terme, jusqu'à 20% des patients ne sont pas satisfaits de leur prothèse.

Pour tenter d'améliorer ces résultats, de nouvelles propositions personnalisées d'alignement des implants ont été développées. Nous avons commencé par essayer de mieux comprendre l'alignement coronal fémoro-tibial d'une population arthrosique en montrant son importante variation individuelle et ses différences avec une population non arthrosique. Nous avons ensuite détaillé les différentes possibilités d'alignement personnalisé. Le but de l'alignement cinématique (AC) est de restaurer l'anatomie et l'équilibrage du genou pré-arthritique à partir de repères osseux. L'alignement fonctionnel, possible avec assistance robotique, adapte en peropératoire le positionnement des implants prothétiques selon l'anatomie et la laxité ligamentaire constitutionnelles. Nous avons réalisé une revue systématique comparant les résultats après PTG entre AC et AM. L'AC apparaissait comme une technique envisageable et alternative à l'AM. Une nouvelle classification radiologique CPAK d'AC a été décrite considérant l'alignement coronal et l'obliquité de l'interligne après PTG. Nous avons comparé l'alignement coronal obtenu avec cette méthode à des radiographies dynamiques en valgus compensant l'usure cartilagineuse et la laxité ligamentaire. Nous avons trouvé des résultats similaires indiquant que l'AC évalué avec la classification CPAK permettrait d'anticiper l'alignement fonctionnel sur l'espace en extension du genou.

Nous avons comparé les résultats cliniques après PTG en fonction de la restauration ou non des différentes catégories de la classification CPAK. Nous avons trouvé que l'AM ne restaure pas le phénotype du genou dans la majorité des cas. Aussi, nous avons montré moins de douleurs post opératoires lorsque l'interligne après PTG était maintenue par rapport au préopératoire. Enfin, la majorité des études présentant les résultats de PTG avec AC sont réalisées avec des prothèses à conservation du ligament croisé postérieur. Or, nous utilisons une PTG postéro-stabilisée (PS). Nous avons donc comparé les résultats entre AM et AC en utilisant une PTG PS par un système plot-came. Nous avons trouvé un risque augmenté de descellement tibial aseptique dans le groupe cinématique potentiellement expliqué par des forces de cisaillement exercées sur le plot tibial.

Plusieurs études ont évalué le schéma de marche des patients afin d'obtenir un examen plus objectif sur la récupération fonctionnelle en post opératoire de prothèses de genou. L'objectif était d'évaluer la récupération d'un schéma de marche le plus proche possible de celui d'un genou natif. Nous avons initié une étude prospective randomisée comparant l'analyse de la marche chez des patients opérés de PTG type « medial-pivot » avec AM versus AC. Les objectifs étaient de comparer l'analyse de la marche, les résultats cliniques et radiologiques pour 52 PTG dans chaque groupe à un recul minimum de 12 mois.

Nous avons donc montré que l'AC permettait d'obtenir de bons résultats cliniques et radiologiques. L'AC déterminé à partir de repères osseux semble correspondre à l'alignement fonctionnel en extension. En revanche, l'assistance robotique nous a permis de réaliser que le comportement ligamentaire était différent en flexion et que l'AC ne permettait pas d'obtenir un bon équilibrage ligamentaire en flexion dans tous les cas. L'évaluation du schéma de marche après PTG implantées avec assistance robotique selon l'alignement fonctionnel serait intéressante.

MOTS CLES

Prothèse totale de genou ; alignement cinématique ; alignement mécanique ; alignement personnalisé ; alignement fonctionnel ; analyse de la marche ; KneeKG.

JURY

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Membres :	Monsieur le Professeur Jean-Noël ARGENSON Monsieur le Professeur Matthieu EHLINGER Monsieur le Professeur Sébastien LUSTIG
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DATE DE SOUTENANCE : 11 janvier 2022

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