



# Sagittal radius of curvature, trochlea design and ultracongruent insert in total knee arthroplasty

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- Multi radius (MR) total knee arthroplasty (TKA) has been associated with mid-flexion instability.
- Single radius (SR) TKA may provide better anteroposterior stability through single flexion axis and biomechanical advantage for quadriceps function.
- Medial pivot (MP) TKA and gradually reducing (GR) radius TKA produce better knee kinematics.
- Clinical outcomes are equivalent for SR, MR and MP TKA.
- Short-term studies have shown better clinical outcomes and kinematics for GR TKA.
- Thinner and narrow anterior flange, deeper trochlea groove and more anatomical trochlea design reduces patellofemoral complications in TKA
- Ultracongruent inserts provide comparable clinical outcomes to posterior-stabilized TKA and cruciate retaining TKA.

**Keywords:** sagittal radius of curvature; trochlea geometry; ultracongruent insert

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## Introduction

The incidence of knee osteoarthritis has increased significantly in the last decade.<sup>1,2</sup> In the United States, the number of total knee arthroplasties (TKAs) performed is expected to exceed three million per year by 2030.<sup>1</sup> The National Joint Registry (NJR), which covers England, Wales, Northern Ireland and the Isle of Man, recorded 98,147 primary knee arthroplasties (of which 89.7% were total knee arthroplasties) in 2016.<sup>2</sup> Patients undergoing TKA are increasingly younger and demand improved function following their surgery.<sup>3</sup> Total knee arthroplasty design has evolved since it was first introduced following better understanding of knee biomechanics. This review aims to

discuss the biomechanics of the native human knee, some of the design philosophies in TKA, its effect on kinematics of the knee and clinical outcome. We set out to answer the following questions:

1. Does sagittal femoral radius of curvature affect kinematics and outcome in TKA (single radius, multi radius, gradually reducing radius and medial pivot)?
2. Does trochlea design affect patellofemoral kinematics and outcomes?
3. Do ultracongruent inserts provide equivalent anteroposterior stability to posterior stabilized implants?

## Method

We undertook a systematic search of all published studies in the English language on the PubMed database over the last 10 years. We ran the following search on PubMed Database: 'total knee replacement' OR 'total knee arthroplasty' AND ('2008'[Date - Publication]: '2019'[Date - Publication]) AND 'design' OR 'femoral geometry' OR 'trochlea geometry' OR 'kinematics' OR 'multi radius' OR 'multi radii' OR 'single radius' OR 'medial pivot' OR 'deep dish' OR 'poly conformity' OR 'mid flexion instability' OR 'quadriceps function'.

One author (JN) screened the titles and abstracts of all the studies and identified 92 papers to review. After reviewing all the papers, 52 papers were deemed to be relevant to this review. The authors also included an additional eight papers which were considered to be relevant to this review (Fig. 1).

## Biomechanics of the native human knee

The biomechanics of the knee are highly complex and influenced by the geometry of the articulating surfaces, ligaments, menisci and muscular forces acting on the knee. Range of movement of the knee can be divided into three arcs:<sup>1</sup> 'arc of terminal extension' or 'screw home' – full

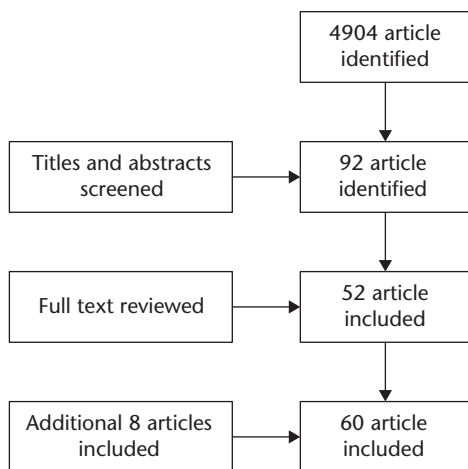


Fig. 1 Search strategy.

extension to 30° flexion;<sup>2</sup> ‘arc of active function’ – 30° to 120° flexion;<sup>3</sup> ‘arc of passive flexion’ – 120° flexion to full passive flexion.<sup>4,5</sup>

The sagittal sections of the femoral condyles are circular posteriorly. On the sagittal plane, the medial femoral condyle can be divided into four facets (AHF, anterior horn facet; EF, extension facet; FF, flexion facet; and PHF, posterior horn facet) based on its contact with the tibia through its range of movement. The extension facet has a radius of 32 mm with an arc of 50°, whereas the flexion facet has a smaller radius of 22 mm subtending an arc of 110°. The PHF has a smaller radius than the FF and comes into contact with the posterior horn of the medial meniscus during femoral rollback in deep flexion, but not with the tibia. The AHF articulates with the anterior horn of the medial meniscus during full extension.<sup>4,5</sup> Likewise, the lateral femoral condyle is also circular posteriorly. The FF has a radius of 21 mm and an arc of 114°. However, the PHF of the lateral femoral condyle does not have a reduced radius like the medial side. Anterior to the FF, the articular surface is relatively flat and articulates with the anterior part of the tibia and anterior horn of the lateral meniscus.<sup>4,5</sup>

The anterior part of the medial tibial surface has an anterior inclination of 11° and the posterior surface is horizontal. The central part of the lateral tibial surface is flat and slopes downwards anteriorly and posteriorly to receive the horns of the lateral meniscus.<sup>4,5</sup>

In the arc of active flexion, the medial femoral condyle acts as a sphere which rotates to produce flexion and longitudinal rotation. It functions like a constrained ball-and-socket joint. On the other hand, the lateral femoral condyle rolls and slides in the anteroposterior direction. The medial femoral condyle translates no more than 1.5 mm anterior or posteriorly whereas the lateral femoral condyle translates posteriorly by 15 mm. The resultant movement is tibial internal rotation around the medial axis by 30°.<sup>4</sup>

In the arc of terminal extension, the ‘screw home’ mechanism occurs when the tibia externally rotates as the knee moves into full extension. During the arc of passive flexion, both of the femoral condyles roll back onto their respective menisci.<sup>4</sup>

### Sagittal radius of curvature

There are four contemporary classes of femoral sagittal design in TKA: single radius (SR), multi radius (MR), gradually reducing radius (GR) and medial pivot (MP).

The single radius of curvature design has a uniform radius of curvature from 10° to 110° flexion. This design is based on the principle that superficial medial collateral ligament is isometric throughout its range of movement, therefore a uniform flexion arc centred around the transepicondylar axis will provide stable movement throughout flexion.<sup>6</sup> However, a less conforming polyethylene tibial insert is required to allow femoral rollback.<sup>7</sup>

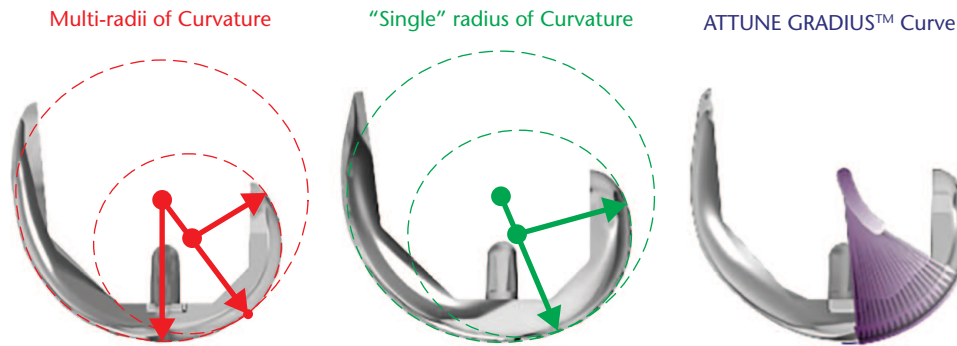
The multi radius (also known as J curve) TKA is the most commonly used design (e.g. PFC Sigma®, Depuy Synthes, Warsaw, Indiana; and NexGen®, Zimmer Biomet, Warsaw, Indiana). On the sagittal view, the femoral component has a large radius anteriorly and a smaller radius distally which reduces further posteriorly.<sup>7</sup> The smaller radius of curvature posteriorly aims to allow knee flexion by increasing the degree of freedom in the knee, allowing femoral rollback and rotation.

The gradually reducing radius design utilized by the ATTUNE TKA (DePuy Synthes, Warsaw, Indiana) has a gradually reducing radius of curvature (GRADIUS curve) from distal to posterior to prevent the abrupt transition seen in the traditional J curve design.

The medial pivot TKA (e.g. MRK®, MatOrtho, United Kingdom and GMK Sphere®, Medacta, Switzerland) has a conformed medial side acting like a ball-and-socket mechanism with a flat lateral tibial surface to allow anteroposterior (AP) movement (Fig. 2).

### Mid-flexion instability and kinematics

The recent National Joint Registry data from the United Kingdom showed that 17.7% of revision TKAs were performed for instability.<sup>2</sup> Some of these patients had mid-flexion instability. Mid-flexion instability is defined as instability of the knee after TKA between 0° and 90° knee flexion. Inadvertent elevation of joint line, iatrogenic damage/insufficiency of the superficial medial collateral ligament and MR design TKA are factors associated with mid-flexion instability.<sup>9</sup> This is thought to be due to paradoxical anterior translation of the femur as a result of abrupt transition in the sagittal radius of curvature. Finite element analysis by Clary et al<sup>7</sup> demonstrated that by eliminating the abrupt transition in the sagittal radius



**Fig. 2** Differences in sagittal femoral geometry.

(Reproduced with permission)<sup>8</sup>

of curvature, the paradoxical AP movement reduced significantly.

The SR TKA was thought to reduce mid-flexion instability by using a single radius of curvature and the MP TKA has a highly conforming medially stabilized insert acting like a ball-and-socket mechanism with a flat lateral tibial surface to allow AP movement. However, results from studies in the literature have been conflicting. Some studies<sup>6,10–14</sup> demonstrated better stability in SR or MP TKA when compared to MR TKA, whereas some studies<sup>15–17</sup> showed no difference between SR or MP and MR TKA.

The GR TKA allows smooth transition from extension to flexion by gradually reducing the sagittal radius of curvature. Early studies have shown that this minimizes the paradoxical anterior translation, providing better AP stability and reducing mid-flexion instability.<sup>7,18,19</sup>

Kinematics after TKA can also determine the functional outcome. The native knee exhibits a medial pivot pattern with posterior femoral rollback on knee flexion. Nishio et al reported that intraoperative medial pivot pattern after TKA positively influences deep knee flexion and functional outcomes.<sup>20</sup> Grieco et al and Renaud et al reported that there is no difference in kinematics between SR and MR TKA.<sup>16,17</sup> Both SR and MR exhibit abnormal knee kinematics.<sup>16</sup> There are also other studies which report better knee kinematics in SR than MR TKA.<sup>10,11,21</sup> However, MP TKA and more recently GR TKA have been shown to more closely mimic normal knee kinematics and produce a medial pivot pattern.<sup>13,19,22,23</sup>

## Quadriceps function

The SR TKA provides a biomechanical advantage for quadriceps function by increasing the patella tendon moment arm, and reducing the patella tendon angle and patella femoral angle.<sup>24</sup> There are biomechanical and clinical studies which have shown improved quadriceps strength and function in SR TKA as compared to MR TKA.<sup>11,21,25,26</sup> However, a recent randomized controlled trial by Kim

et al comparing SR TKA (Triathlon<sup>®</sup>, Stryker, Mahwah, New Jersey) and MR TKR (PFC Sigma<sup>®</sup>, Depuy Synthes, Warsaw, Indiana), showed no difference in quadriceps strength and recovery at one year postoperatively.<sup>27</sup>

## Clinical outcomes

The majority of the recent literature, including a meta-analysis by Liu et al in 2016, showed equivalent clinical outcomes between SR TKA and MR TKA.<sup>10,17,28–32</sup> Current evidence comparing clinical outcomes of MP TKA with SR or MR TKA is conflicting. Benjamin et al showed no difference between SR TKA and MP TKA, and Bae et al showed equivalent clinical outcomes between MR TKA and MP TKA.<sup>33,34</sup> On the other hand, Kim et al showed worse knee society scores and less satisfaction in MP TKA when compared to MR TKA.<sup>35</sup> In contrast, Hossain et al showed MP TKA had better range of movement, physical component of SF36, Total Knee Function Questionnaire and less pain on WOMAC subscale,<sup>36</sup> and Samy et al showed better forgotten knee scores in MP TKA.<sup>14</sup> More recently, GR TKA was shown to have better short-term outcomes when compared to MR and SR TKA.<sup>37,38</sup>

## Trochlea geometry

Residual anterior knee pain remains a common problem after TKA and can affect up to 50% of patients.<sup>39</sup> The exact aetiology remains unknown, but it is thought to be related to patellofemoral maltracking, patellofemoral joint overstuffing and patella tilt.<sup>39</sup> Trochlea geometry can significantly affect the patellofemoral joint kinematics, potentially influencing the outcome.

Studies have shown that TKA designs with a narrower and thinner anterior flange, and deeper trochlea groove can improve patellofemoral joint kinematics and produce less wear, thereby reducing the rate of anterior knee pain, patellofemoral crepitus or clunk, and intraoperative lateral retinacular release (which could damage blood

supply to the patella, causing patella fracture or avascular necrosis).<sup>39–43</sup>

Increased lateral trochlea height seems to cause less patella tilt but does not significantly affect patella tracking and patellar restraint behaviour.<sup>44,45</sup>

## Ultracongruent inserts

An ultracongruent (UC) insert is a highly conforming insert which has a high anterior lip. In the presence of posterior cruciate ligament deficiency, the UC insert was designed to provide AP stability without the use of a post cam mechanism as seen in posterior substituting (PS) TKA designs.<sup>46</sup> The advantages of UC inserts over PS TKA are avoidance of post cam wear and less bony resection. However, due to the highly conforming nature of the UC insert, it may also lead to higher volumetric wear and limit rotation.<sup>46</sup>

Studies have shown that PS TKA provides better kinematics and AP stability than UC inserts, resulting in less paradoxical anterior femoral translation.<sup>46–54</sup> A meta-analysis by Bae et al showed that PS TKA has more femoral rollback and better tibial sagittal stability when compared to UC inserts. Despite the kinematic differences, studies have found equivalent clinical outcomes between PS TKA and UC inserts.<sup>47,49,50,55,56</sup> Some studies have also shown that UC inserts have comparable clinical outcomes to cruciate retaining TKA.<sup>54,57–59</sup>

## Conclusion

In conclusion, there is insufficient evidence to support SR, MP or GR TKA over the traditional MR TKA design. Although the SR and MP TKA have some biomechanical advantages such as mechanical advantages for quadriceps function and better knee kinematics respectively, this has not translated into better clinical outcomes. Early results for GR TKA showed better knee kinematics and clinical outcomes than MR TKA but larger studies with long-term results are required before more definitive conclusions can be drawn.

The narrow and thinner anterior flange with deeper trochlea groove in modern TKA designs have reduced the rate of patellofemoral complications.

Despite offering less AP stability than PS TKA, short-term outcomes of UC inserts are comparable to PS and CR TKA.

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