



Coronal alignment after total knee arthroplasty

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- Recent studies have challenged the long-held notion that neutral mechanical alignment after total knee arthroplasty leads to optimal function and survivorship.
- The ideal alignment for function and survivorship may actually be different.
- Kinematic alignment, where components are implanted to re-create the natural flexion/extension axis of the knee, may lead to improved functional results.
- Residual varus alignment may not adversely impact survivorship provided the tibial component is implanted in neutral alignment.

Keywords: knee; total arthroplasty; coronal alignment; mechanical alignment; kinematic alignment; functional results; survivorship

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A long-held principle in total knee arthroplasty (TKA) is that long-term survival and optimal function are dependent on achieving a post-operative leg alignment within 3° of the neutral mechanical axis. To this end, computer navigation and now patient-specific instrumentation have been developed, to improve accuracy in implantation and maximise the number of arthroplasties falling within these limits. At the neuvièmes Journées Lyonnaises de Chirurgie du Genou in 1999, Rivat and Neyret presented a view that residual varus of femoral origin was acceptable, but neutral mechanical alignment of the tibial component was mandatory.¹ More recently, a number of authors have challenged this principle, suggesting “malalignment” of the mechanical axis may have little effect on the outcome of knee arthroplasty performed with modern prostheses.

The aim of this review is to assess the historical and contemporary evidence regarding the impact of coronal plane alignment in TKA on function and survivorship.

Anatomy and deformity

To describe the anatomy and coronal alignment of the leg, a number of descriptive terms are used.² The anatomical axis of each bone refers to a line drawn along the centre of the intramedullary canal. The mechanical axis of the femur refers to a line drawn from the centre of the femoral head to the centre of the knee. For the tibia, the mechanical axis refers to a line between the centre of the knee and the centre of the ankle. The anatomical and mechanical axes of the femur form an angle of approximately 6°, while the two axes of the tibia are usually equivalent (Fig. 1).

The global mechanical axis, sometimes referred to as Maquet’s line, describes a line drawn from the centre of the femoral head to the centre of the talus³ (Fig. 1). Normally, this line passes through the centre of the knee. The anatomical femorotibial angle (aFTA) describes the angle between the anatomical axes of the femur and tibia, and is usually about 6° of valgus. The mechanical femorotibial angle (mFTA), formed by the mechanical axes of the two bones, is usually 0° or neutral, although variation exists in nature. This is sometimes referred to as the hip-knee-ankle angle (HKA).

Care must be taken when performing standardised radiographs for determination of coronal plane alignment. Variance in limb rotation and knee flexion may have significant impact on the observed angles.^{4,5} In a valgus knee model with a true aFTA of 18°, Swanson measured a change of almost 7° in the apparent aFTA with 20° of internal and external rotation.³ Hence, radiographs are generally taken with the patient standing and the feet together.

Deformity affecting leg alignment may occur at any level. In general, the closer an extra-articular deformity to the knee, the greater is its importance.⁶

Historical evidence supporting neutral alignment

In 1977, Lotke and Ecker first examined the correlation between implant positioning and functional outcome in 70 TKAs.⁷ Alignment and functional outcome were both evaluated using the author’s own 100-point scales. Long-leg films were not used and component rotation was not assessed. They noted a significant correlation between good clinical results and good alignment. In four of their

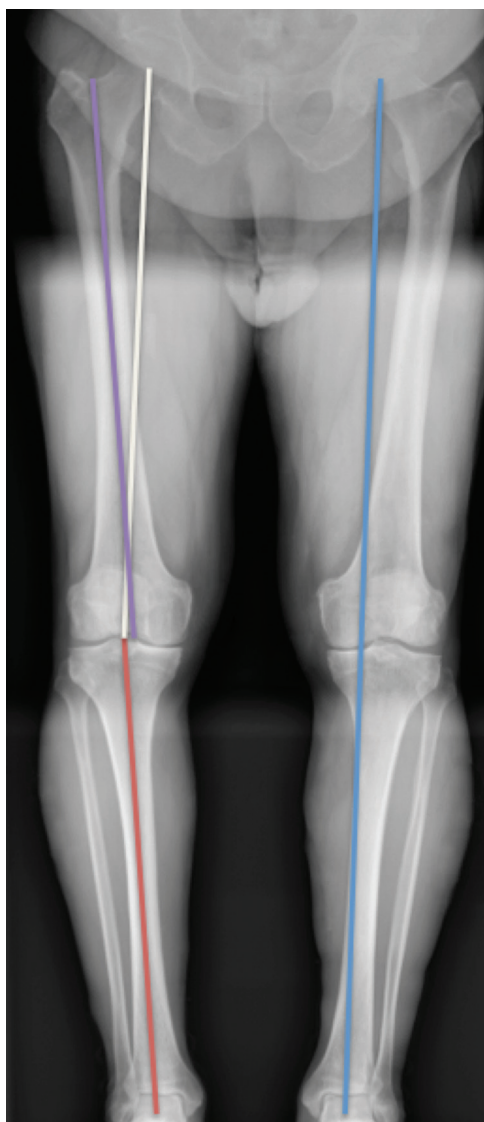


Fig. 1 Long-leg radiograph. Right leg demonstrates mechanical axis (white line) and anatomical axis (purple line) of the femur. The anatomical and mechanical axes of the tibia are usually the same (red line). On the left leg, Maquet's line passes through the medial compartment of the knee, indicating varus alignment.

five failures, the tibial component was positioned in varus. Denham and Bishop, in a 1978 study of biomechanics in relation to knee reconstruction, defined optimal positioning to be $7^\circ \pm 4^\circ$ of anatomical valgus for the femoral component and $90^\circ \pm 4^\circ$ to the anatomical axis for the tibia, to ensure the weight-bearing line passed through the centre of the joint.⁸ Hvid and Nielsen reported an increased incidence of radiolucent lines at two years surrounding tibial components implanted with $> 4^\circ$ tilt in any direction, with the interesting exception of varus angulation in osteoarthritic knees.⁹

In an important 1991 study, Jeffrey et al published the results of 115 early Denham knee arthroplasties, with a median follow-up of eight years.¹⁰ Using long-leg radiographs to assess coronal plane alignment, they found a significant difference in the rate of loosening between those aligned within $\pm 3^\circ$ of the mechanical axis Maquet's line (3% loosening), and those outside these limits (27% loosening; $p = 0.001$). This target range has subsequently been supported by numerous clinical and laboratory studies.¹¹⁻¹⁸ These studies are summarised in Table I.

Interestingly, not all studies from this period supported a neutral mechanical axis. Bargren et al reported a failure rate of 2.3% for the Freeman Swanson (ICLH) knee when aligned between 1° to 5° of anatomical valgus (1° to 5° varus mechanical alignment), against an overall failure rate of 27%.¹⁹

Recent evidence challenging neutral alignment

In the last few years, several reports have been highlighted challenging the superiority of neutral mechanical alignment. These studies are summarised in Table II.

Regarding survival, in 2007 Morgan et al reviewed the outcomes of 197 Kinemax™ TKAs at a mean of nine years post-operatively, and found no difference in revision rate between those in neutral, varus or valgus alignment.²⁰ In a larger study, Parratte et al published a retrospective review of 398 cemented primary knee arthroplasties performed at the Mayo Clinic using three modern prostheses.²¹ Long-leg

Table I. Summary of early studies supporting neutral mechanical alignment

Author	Year	Number	Prosthesis	Follow-up (yrs)	Outcome measures	Findings	Comments
Lotke ⁷	1977	70	Geometric	1 to 3	Own 100-point scales for clinical and radiographic outcomes	Significant correlation between clinical and radiographic scores	4/5 failures had tibial component in varus
Hvid ⁹	1984	138	Insall/Berstein	2	Radiographic alignment, radiolucency, Insall score	Increased radiolucencies with global varus alignment, not significant for OA/Increased radiolucencies with any tibial tilt $>4^\circ$	3/3 failures had tibial component in varus
Jeffery ¹⁰	1991	115	Denham	8 to 12	Radiographic alignment, BASK score	3% loosening when Maquet's line within middle 1/3 of knee/24% loosening when Maquet's line outside middle 1/3	Study used long-leg radiographs

Table II. Summary of studies challenging the aim of neutral alignment

Author	Year	Number	Prosthesis	Follow-up (yrs)	Outcome measures	Findings	Comments
Morgan ²⁰	2007	197	Kinemax	9	Radiographic alignment, revision or intention to revise	No difference in revision rate for neutral (4° to 9° anatomical valgus), varus or valgus alignment	Retrospective study
Parratte ²¹	2010	398	Kinematic Condylar II PFC	15	Radiographic alignment, Kaplan-Meier survival analysis	No difference in revision rate for mechanical axis 0° ± 3° compared with outliers	Retrospective study
Bonner ²²	2011	501	Genesis PFC	15 (min 9)	Radiographic alignment, Kaplan-Meier survival analysis	Weak trend towards improved survivorship in aligned group (mechanical axis 0° ± 3°) (p = 0.47)	Retrospective study
Matziolis ²³	2010	218	PFC Sigma Natural Knee II	5 to 10	Radiographic alignment, KSS, WOMAC, SF-36	No difference in revision rate or any outcome measure	Case control study comparing 30 most varus TKA to neutrally aligned, matched controls
Magnussen ²⁴	2011	553	HLS I HLS II HLS Evolution Noetos HLS	2 to 19	Radiographic alignment, revision rate, KSS	No difference in revision rate or IKS for neutral or residual varus > 3°/Lower IKS scores with tibial component varus	Compared patients with pre-operative varus alignment based on neutral or varus post-operative alignment
Vanlommel ²⁵	2013	143	Profix	7.2	Radiographic alignment, KSS, WOMAC	Total KSS and function subscore, total WOMAC, stiffness and ADL subscores better in mild varus group (3-6° mechanical varus) compared to neutral and >6° varus groups	Compared patients with pre-operative varus alignment based on degree of post-operative varus

Notes: KSS, Knee Society Score; WOMAC, Western Ontario and McMaster University Osteoarthritis Index; IKS, International Knee Society Score; SF-36, Short Form-36; ADL, activities of daily living.

radiographs were performed for all patients pre- and post-operatively. The outlier group comprised 106 knees with post-operative mechanical alignment outside 0° ± 3°. They found no difference in survivorship at 15 years between the well-aligned and outlier groups, and concluded that describing alignment as a dichotomous variable was of little value for predicting durability. In a similar study of 501 TKAs using a single prosthesis, Bonner²² and co-workers found a weak trend towards a higher revision rate in those outside the 0° ± 3° range; however, this fell short of statistical significance (p = 0.47). They concluded that the relationship between mechanical alignment and survival for primary TKA is weaker than previously reported.

With regards to function, two medium-term studies have suggested that functional outcome is not adversely affected by residual post-operative varus alignment. From a series of 218 primary TKAs, Matziolis and colleagues compared the results of the 30 knees with the greatest post-operative varus alignment, to neutrally aligned, matched controls.²³ The varus group had a mean post-operative mechanical axis deviation of 6.3° (3.9° to 10.7°). There was no difference in functional results using multiple validated measures, and no revisions in either group at a minimum five-year follow-up. Magnussen and colleagues, from the Centre Albert Trillat in Lyon, examined the results of 553 TKAs for varus

osteoarthritis, comparing those with neutral post-operative mechanical alignment (0° ± 3°) and those with residual varus alignment > 3° at a mean follow-up of 4.7 years.²⁴ They found no difference in Knee Society Score (KSS) or revision rate between the two groups, provided the residual varus was femoral in origin. Tibial component varus and femoral component valgus were both associated with inferior KSS results.

One recent study has found superior functional results for TKAs with mild residual varus. In a study of 143 consecutive TKAs for varus osteoarthritis, Vanlommel et al observed that the 46 knees with residual varus of 4° to 7° (FTMA 174° to 177°) demonstrated significantly better KSS and Western Ontario and McMaster University Osteoarthritis Index (WOMAC) scores than the neutral and significant varus groups at a mean of 7.2 years.²⁵

Discussion

A number of criticisms have been made of early studies showing decreased survivorship with non-alignment of the mechanical axis. Most used only short-leg radiographs for assessment^{7,9,19} and involved early prosthesis designs no longer in use today.¹⁰ Polyethylene quality was inferior, and the sterilisation methods employed are now known to cause material property degradation.¹⁸

The literature regarding the impact of coronal alignment on functional outcomes is unclear. Most data comes from studies into navigation in TKA, examining short- to medium-term results. Some authors have reported improved knee function with more ideal alignment.²⁶⁻²⁸ Others have found no improvement and even poorer functional results using navigation.²⁹⁻³² A systematic review in 2012 concluded that there was improved coronal plane alignment but no functional improvement with navigation;³³ however, a recent meta-analysis did find improved function in the navigation group.³⁴

Recently, Bellemans and co-workers have introduced the concept of constitutional varus, suggesting a neutral mechanical axis may be abnormal and even undesirable for many patients.³⁵ In their study, 32% of men and 17% of women had a natural mechanical alignment $\geq 3^\circ$ of varus. Similarly, others have explored the cylindrical axis of the knee³⁶ and the concept of kinematic alignment.³⁷

Kinematic alignment is based on the finding that the true axis about which knee flexion and extension occur is not perpendicular to the mechanical axis,³⁸ and places the femoral and tibial components accordingly to recreate this anatomical axis. Howell and co-workers reported equivalent or slightly better WOMAC and Oxford knee scores (OKS) for varus and valgus outlier groups in 198 kinematically-aligned TKAs, although this did not reach significance. A more recent study of 219 consecutive, kinematically-aligned TKAs from the same author reported a comparable revision rate to registry data for the same prosthesis at six years, regardless of tibial component varus or overall limb alignment.³⁹ There were three revisions reported, including one for tibial component loosening, with two further revisions pending for patellar component loosening. Dossett et al, in a randomised control trial, evaluated the short-term outcomes of 41 kinematically- and 41 mechanically-aligned TKAs.⁴⁰ While the overall limb alignment was similar, the kinematic alignment group had 2.3° more tibial component varus and 2.4° more femoral component valgus. KSS, WOMAC and OKS were superior in the kinematically-aligned group. While there were no catastrophic early failures in these studies, the long-term survival of kinematically-aligned TKAs is unknown. Ishikawa et al, in a recent computer simulator and finite element analysis, found near-normal knee kinematics in kinematically-aligned TKAs; however, both patellofemoral and tibiofemoral peak contact stresses were increased by as much as 200% and 270% respectively in the kinematically-aligned model.⁴¹ Furthermore, the accuracy of the patient-specific instrumentation systems typically required to achieve kinematic alignment are still being investigated^{42,43} and may be inferior to traditional or navigated systems.⁴⁴

Tibial component varus

Contrary to these results, a number of authors have reported inferior results associated with tibial component varus.^{7,16,24,45,46} Berend and colleagues, in a study of a cohort of 3152 knees with a mean five-year follow-up, found tibial component varus $> 3^\circ$ to significantly increase the odds of failure (hazard ratio 17.2, $p < 0.0001$).¹⁶ In a later study from the same centre on an expanded cohort of 6070 TKAs, Ritter et al found increased revision rates when the tibial component was implanted in varus, when the femoral component was implanted with $> 8^\circ$ of anatomical valgus, and when one component was implanted to “correct” for malalignment of the other component, despite resulting in neutral global limb alignment.⁴⁵ There was no difference in survivorship between those with neutral tibial component and neutral overall alignment and those with neutral tibial alignment and overall varus limb alignment ($< 2.5^\circ$), suggesting some residual varus global alignment in itself does not compromise results.

Residual valgus alignment after TKA is associated with inferior results. Karachalios et al found residual deformity to be much more common in valgus knees and associated with significantly inferior clinical results using the Bristol Knee Score.⁴⁷ Fang et al reported a revision rate of 1.5% for those with post-operative valgus alignment compared with 0.5% for those in neutral alignment, noting that those with residual valgus tended to fail from ligament instability.⁴⁸ Koskinen, in a study of 48 valgus knees implanted with cruciate-retaining prostheses, found residual valgus deformity to significantly increase the risk of revision with an odds ratio of 2 (95% confidence interval 1 to 3, $p = 0.025$).⁴⁹ Eight of the 14 revisions were for progressive medial collateral ligament (MCL) instability. Consistent with these clinical reports, Bryant and coworkers, in a recent cadaveric study, found valgus loading of a TKA to significantly increase lateral tibio-femoral contact pressures and MCL strain.⁵⁰

Conclusion

As noted by Tew and Waugh in 1985, while coronal alignment is certainly a factor in the outcome of TKA, it may not be the most important factor and may serve to compound failure from other causes.⁵¹ Other technical factors, such as sagittal and rotational alignment, joint line restoration, and soft-tissue balance all influence the final outcome. Recent work on kinematic alignment would suggest that the ideal alignments for patient function and prosthesis longevity may in fact be different. If so, advances in materials technology may allow for implant survival in a more functional but non-optimal mechanical environment. While mild residual global varus deformity may not negatively impact outcomes, survivorship may be negatively affected by varus of the tibial component.

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CONFLICT OF INTEREST

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