

Impact of Coronal Alignment in Total Knee Arthroplasty and Functional Outcome

Maharjan Promish, Chen Wang*, Yudong Guo

Department of Orthopaedics, Zhongda Hospital Affiliated to Southeast University, Nanjing, China

Email: *chen_wang@seu.edu.cn

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Abstract

Total Knee Arthroplasty (TKA) is a procedure to replace the diseased or damaged knee joint with artificial prosthesis for the relief of disabling pain and restoring the function of knee. Total Knee Arthroplasty (TKA) is one of the most common and successful procedures in modern orthopedics and is spreading through the world. Many surgeons are developing their skill but it needs experience and patience for successful outcomes. There are different factors which affect the outcome after total knee arthroplasty, among them; the coronal alignment of lower limb plays a major role. Many studies have supported that neutral mechanical alignment after total knee arthroplasty leads to better function. The aim of this review is to evaluate clinical outcome with reference to the coronal alignment of the limb and safety based on Western Ontario and McMaster Universities (WOMAC), Knee Society Score (KSS) score.

Keywords

TKA, Mechanical Axis, Coronal Alignment

1. Introduction

Total Knee Arthroplasty (TKA) is one of the most common and successful procedures [1] in modern orthopedics. TKA is a procedure to replace the diseased or damaged joint surface of the knee with artificial prosthesis for the relief of disabling pain and restoring function of the knee. It is relatively new procedure that has undergone as many evolutionary changes to arrive at the procedures in use today. The first successful knee arthroplasty was a resection arthroplasty performed by Ferguson in 1861 [2]. Since then there have been great innovations in operative techniques as well as post-operative protocols that have been very effective in improving patient's outcomes following the surgery. TKA is now

spreading through the world and many surgeons are developing their skill but it needs experience and patience for successful outcomes. In this review, we are explaining the basic technique of TKA surgery, coronal alignment measurement and its relationship on outcome of the surgery.

Indications and Contraindications of TKA

TKA is one of the most successful operations in terms of patient satisfaction, improvement in function, alleviation of pain and suffering. There are various conditions of knee requiring TKA surgery. But in some situations, surgery is contraindicated.

As mentioned (**Table 1**), the primary indication for TKA is to relieve pain caused by severe arthritis, with or without significant deformity. Failed conservative treatment including physical therapy, anti-inflammatory medications, intraarticular injections, activity modifications, and the use of a cane for ambulation is another indication for surgery. TKA is also indicated in younger patients [3] who have a significant functional impairment due to systemic arthritis with multiple joint involvement or osteonecrosis with subchondral collapse of a femoral condyle. Deformity can become the principal indication for arthroplasty in patients with moderate arthritis and variable levels of pain when the progression of deformity begins to threaten the expected outcome of an anticipated arthroplasty. As flexion contracture progresses beyond 20 degrees, gait is significantly hampered and difficulty with regaining extension may warrant surgery.

Recent or current knee sepsis is absolute contraindications to TKA [3]. Relative contraindications are numerous such as medical conditions that compromise the patient's ability to withstand anesthesia, the metabolic demands of surgery and wound healing. A severely osteoarthritic ipsilateral hip joint also should be considered for arthroplasty before the symptomatic osteoarthritic knee, because rehabilitation is easier with a total hip arthroplasty and an osteoarthritic knee than with a TKA and an osteoarthritic hip joint. Other relative contraindications include atherosclerotic disease of the operative leg, skin conditions such

Table 1. Indications and Contraindications of TKA.

Indications	Contraindications
Severe arthritis	Knee infection
Failure of conservative treatment including anti-inflammatory medications, activity modifications	Medical conditions that compromise the patient's ability to withstand anesthesia, the metabolic demands of surgery and wound healing
Osteonecrosis with subchondral collapse of a femoral condyle	Severe osteoarthritic of ipsilateral hip joint, history of osteomyelitis in the proximity of the knee
Severe deformity	Atherosclerotic disease of leg,
Flexion contracture of knee beyond 20 degrees and difficulty in knee extension	Skin conditions like psoriasis, fungal infection, neuropathic arthropathy, venous stasis disease with recurrent cellulitis

as psoriasis within the operative field, venous stasis disease with recurrent cellulitis, neuropathic arthropathy, recurrent urinary tract infections, and a history of osteomyelitis in the proximity of the knee (**Table 1**).

2. Surgical Technique of TKA

For the treatment of knee problems such as severe arthritis, various deformities, patient is treated surgically. Patients are selected according to the result of physical examination, their radiological investigations such as Plain X-ray including Antero-Posterior view, Lateral view, computed tomography (CT), suitable for anesthesia and failure of conservative treatment.

- The patient is kept in supine position. All patients had antibiotic prophylaxis at induction of anesthesia.
- The medial parapatellar approach is the most commonly used approach in TKA. After medial parapatellar approach, in order to obtain a neutral mechanical axis, the bone cuts are directed using the intramedullary jig for the distal femur and the extra-medullary jig for the proximal tibia (**Figure 1**). This is tested using tested using guide rods placed through the cutting blocks.
- The posterior cruciate ligament is resected. The implant system Smith and Nephew Genesis II contains a cobalt-chrome femoral component articulating with a polyethylene insert mounted on a fixed-bearing titanium tibial tray [4]. These components are secured using bone cement. The patella is resurfaced usually (**Figure 1**).
- After the meticulous hemostasis wound is closed with proper dressing. Bandage is applied and knee is immobilized for 48 hours. Later on rehabilitation with mobilization is started.

The clinical assessment is usually performed with history, clinical examination, radiological assessment and a Knee Society Score (KSS).

During the surgery femoral, tibial and patellar components should be well maintained, which decrease both the mechanical stress placed on the weight bearing surfaces and the shear stress on the bone/prosthesis or bone/cement/prosthesis interfaces. This also helps to balance the forces transmitted to the soft-tissue envelope that is important for proper function of the joint [5].

3. Coronal Alignment in Total Knee Arthroplasty

3.1. Alignment and Functional Outcome

The coronal alignment of the lower limb is usually assessed using various axes [6]. The one is the mechanical axis which is defined as the line drawn on a standing long-leg anteroposterior radiograph from the center of the femoral head to the center of the talar dome. This line is also referred as Macquet's line (**Figure 2**). It is measured on Antero-Posterior view of long leg radiograph. Coronal alignment is usually measured using this line [5]. The mechanical axis usually passes through medial to the tibial spine. But this can vary according to the patient height and pelvic width [7]. This axis typically should project

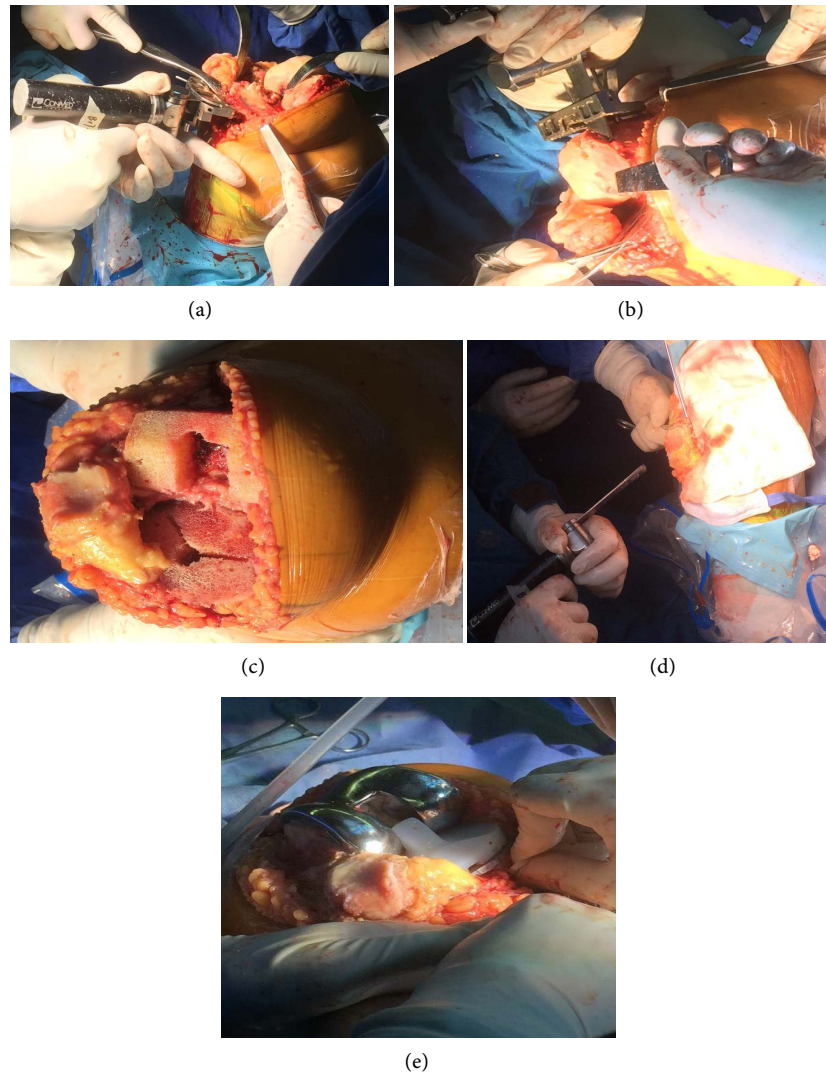


Figure 1. Procedure for Total Knee Arthroplasty surgery. (a) Tibial part preparation; (b) Femoral preparation; (c) After Tibial and Femoral preparation; (d) Patellar Resurfacing; (e) Insertion of the Femoral and Tibial Component.

through the center of the knee joint, described as a “neutral” mechanical axis (**Figure 2**). It should be 0° at neutral, following TKA surgery [8]. Insall mentioned that when the mechanical axis lies to the lateral side of the knee center, the knee is in mechanical valgus alignment [9]. In mechanical varus alignment (**Figure 2**), the mechanical axis of the limb lies to the medial side of the knee center as mentioned by Townley in his study [10]. The amount of varus or valgus deformity is determined on an antero-posterior radiograph by first drawing the mechanical axis of the femur, a line from the center of the femoral head to the center of the intercondylar notch, and extending this line distally.

The other way is the anatomical axis. The anatomical axis of both femur and tibia is a line drawn along the center of the intramedullary canal of the bone. The mechanical axis of the femur is a line drawn from the centre of the femoral head to the centre of the knee. For the tibia, the mechanical axis means a line

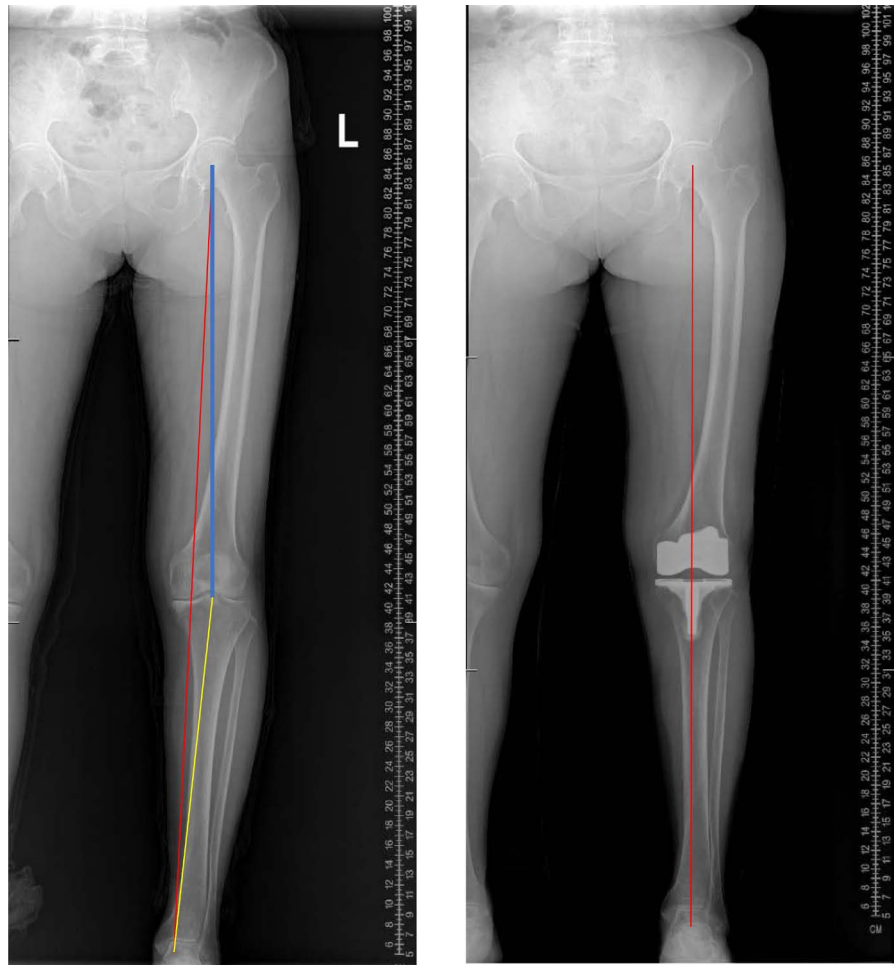


Figure 2. Long-leg radiograph, the red line indicating Macquet's line. The blue line on left figure line refers to mechanical axis of femur, and yellow line refers to that for tibia. This Left side of figure showing the leg in varus alignment. The one on right of figure showing mechanical axis well aligned after the TKA surgery.

between the centre of the knee and the centre of the ankle (**Figure 2**). The anatomical and mechanical axes of the femur form an angle of approximately 6° , while that of the tibia are usually equivalent or zero degree.

According to Knee Society Radiological Score, Short leg radiographs or full length weight bearing radiographs are used for measurement of alignment [11] [12]. But full length radiographs are more useful for assessing mechanical alignment and the position of the implants on load-bearing position. With the use of standard radiography and clinical outcome score, a correlation between a well-aligned prosthesis and a good functional outcome is analyzed.

One study suggested that there is problem with short knee radiographs that is it do not allow for accurate calculation of the mechanical axis [13].

3.2. Importance of Alignment

Outcome after TKA is multifactorial. In this multisurgeon series, other contributing factors may also play a role for the outcome after the surgery. Coronal

alignment after the surgery is important determinants of functional outcome in TKA. The differences in functional outcome between good and bad alignment groups are clinically important. Better function with quicker rehabilitation and earlier hospital discharge is usually seen in good aligned knees following TKA surgery. Mal-alignment of the limb can be assessed using different parameters such as the hip-knee-ankle angle, the coronal tibio-femoral mechanical angle, the coronal tibio-femoral anatomical angle.

For the correlation of the alignment and its outcome, radiograph analysis is used in one hand and some score scales are also used in other hand. There are various scoring system developed for the assessment of outcome of knee after TKA such as the joint-specific Western Ontario and McMaster Universities (WOMAC) osteoarthritis index and Knee Society Score (KSS). The WOMAC Index was developed by Bellamy *et al.* [14] is one of the most commonly used indexes for the evaluation of knee. The WOMAC score includes three scores: pain, stiffness and function. So this score gives a subjective evaluation of the knee. The WOMAC questionnaire is widely used for assessing knee OA. It has been considered as good index for OA evaluation [15]. It includes 24 questionnaire and is divided into three sections: pain (5 questions), stiffness (2 questions), and function (17 questions). The WOMAC score includes 0 - 100 scale. The result is given as an arithmetic average of the relevant questions. Results range from 0 - 100, where 0 indicates no pain, stiffness, and functional limitation and 100 indicates the most severe pain, stiffness, and functional limitation.

Next is the Knee Society Score which is also widely used scoring system for evaluation after TKA. The KSS includes a knee score and a function score [16]. Assessment of the knee joint itself for knee pain, range of motion and stability is done by the knee score. The functional score helps to measure the patient's ability to walk and to climb stairs, the use of ambulatory aids. The score is based on a 75% of subjective and 25% objective assessment.

Hospital for Special Surgery Knee Rating scale (HSS) [17] is another form of evaluation. It includes Pain, Function, and Range of motion, Muscle strength, Flexion Deformity, Instability and Subtraction components. It includes a questionnaire as 100 points at full mark, with best condition equaling 100 points (Excellent ≥ 85 , Good = 70 - 84, Fair = 60 - 69, Poor ≤ 60). Based on this criteria, the study done by Zhou Xinhua *et al.* [18], the HSS knee score was improved from 50.33 ± 11.60 to 90.06 ± 3.07 ($P < 0.001$), indicating good result following Total knee arthroplasty.

Mal-alignment leads to complications such as aseptic loosening, instability, polyethylene wear and dislocation of the patella [19]. The post-operative alignment of the knee has been considered as the key of success and predictor for the revision surgery for better outcome [20]. The definition of good and bad alignment is entirely arbitrary. Sikorski made an arbitrary unit that within 2° of neutral was defined as good alignment [21]. Some other authors also described that limb alignment after TKA to within 3° of the normal mechanical axis is important for good alignment in order for good post TKA outcome [22] [23].

Table 2. Results showing correlation between the alignment and better outcome in TKAs.

Author	Year	Number	Follow-up (years)	Evaluation	Results
Nathaniel F.R. Huang [24]	2012	111	2 - 5	IKS score, SF-12	Coronal alignment within 3° of neutral has superior International Knee Society and SF-12 scores
Longstaff [4]	2009	159	1	Radiograph/KSS	Better outcome with good coronal femoral alignment
Lotke [25]	1977	70	1 - 3	Radiograph/Insall score	Good alignment had a significantly better outcome
Blakeney [8]	2014	107	3.8	Radiograph/KSS SF-12	Significant correlation with radiographic sore and IKS and SF-12
Jeffery [19]	1991	115	Soon after surgery - 12	Radiograph/BASK score	Accurate alignment prevents component loosening
Choong [26]	2009	115	6 weeks - 12 months	Radiograph/IKS/SF-12 score	Better IKS and SF-12 scores when correlated with mechanical within 3 degree of neutral

The study conducted by Nathaniel F.R. Huang *et al.* in 111 patients (**Table 2**), found better IKS score in post-operative mechanical axis within 3° neutral at 2 years ($P < 0.001$) and at 5 years ($P = 0.028$). They also found better pain score in patients whose alignment was within 3° neutral. They also found better SF score as well in those aligned groups. So, better coronal alignment of total knee prosthesis (to within 3° of neutral) results in better function and better quality of life, improved pain scores postoperatively [24].

Longstaff *et al.* [4] performed 159 TKA surgeries between May 2003 and July 2004 (**Table 2**). They observed computed tomography (CT) scan for assessing post-operative alignment and found better functional scores (KSS score) and a shorter hospital stay with a neutral mechanical axis compared to mal-aligned groups at 1 year follow-up ($P = 0.013$).

In an important 1977 study, Lotke *et al.* [25] published the results of 70 cases with follow-up period of 1 - 3 years. Using radiographs to assess coronal plane alignment, they found a strong correlation between good alignment and the clinical results (**Table 2**).

From a series of 115 TKAs (**Table 2**), Jeffery *et al.* [19] compared the results of Macquet's line with the post-operative results using a long leg radiographs. They observed 3% incidence of subsequent loosening in well aligned groups and 24% of loosening in mal-aligned groups (error of approximately $\pm 3^\circ$), which was highly significant ($P = 0.001$). This suggested that accurate coronal alignment is a confounding factor preventing loosening following TKA surgery.

Similarly a randomised control study comparing conventional versus computer-assisted TKR done by Choong PF *et al.* [26] found better post-operative International Knee Scores (IKS) in a good aligned knees with a mechanical axis within 3° of neutral (**Table 2**).

The retrospective study done by Fang *et al.* [27] in 3992 patients in 2009 for primary TKRs (**Table 2**) found that the implant survivorship rate was higher in the neutral group (2.4° to 7.2° valgus). The revision rate for this group was 0.5% compared to 1.8% (varus) and 1.5% (valgus)—which was different from the neutral group. The implant survival rate was statistically significant: 99% in the

neutral group, 95% in the varus group and 97% in the valgus group in the 20 years follow up period.

Similarly Kennedy WR *et al.* [28] also found superior results when the mechanical axis falls in the center of the knee. Some of the failed TKRs also found a high degree of polyethylene thickness loss in the medial compartment of the tibial component where the mechanical axis > 5 degree valgus/varus groups [29].

Conflicts on alignment

It is quite important maintain neutral alignment for better outcome of the surgery, such as durability of the implant and maximizing the function of the knee joint. But the alignment in total knee arthroplasty is only based on two variables, either aligned within $0^\circ \pm 3^\circ$ of a neutral axis or malaligned [30]. So this fact has still been in debate for the better result of TKA. There are some studies published in the literature that challenges the coronal alignment.

Parratte *et al.* [31] studied 398 primary TKAs between 1985 and 1990. They stratified the patients into aligned (achieving a mechanical axis of $0^\circ \pm 3^\circ$) and malaligned groups. In the 15 year Kaplan Meier implant survival rate they didn't found any significant results between those two groups. The results showed in the well aligned groups there is revision rate of 45 in 292 (15.4%) and in malaligned groups there is a revision rate of 14 in 106 knees (13%). This shows that mechanical alignment is not a perfect marker for measuring patient satisfaction and durability of the implant.

In 2010 Matziolis *et al.* [32] retrospectively studied 218 patients. Among them 30 malaligned varus groups (post-operative mechanical axis deviation of 6.3° (3.3° to 10.7°)), they didn't found any worst medium-term clinical or radiological outcome compared to neutrally aligned groups.

Regarding the post-operative alignment, the study done by Vanlommel and colleagues observed residual varus in 46 knees out of 143 cases. In those post-operative residual varus cases, they found significant better Western Ontario and McMaster University Osteoarthritis Index (WOMAC) and KSS score [33].

In a large study, Bonner and co-workers [34] studied 501 TKAs using long leg AP weight bearing radiograph. They didn't found much statistical difference ($p = 0.47$) in implant survival between aligned (neutral mechanical axis $\pm 3^\circ$) and malaligned (mechanical axis deviated from neutral by more than 3°). They concluded that the relationship between survival of a primary TKR and mechanical axis alignment is weaker than previous reports.

Similarly, Magnussen and colleagues studied 553 primary TKAs patients retrospectively. They compared neutral post-operative mechanical alignment group ($0^\circ \pm 3^\circ$) and post-operative lower limb varus malalignment group ($>3^\circ$). They didn't found any difference in revision rate or Knee Society Score (KSS) in these two groups [35].

4. Discussion

Most of the studies in this review have reported significant effect of coronal

alignment in the outcome of TKA surgery. With better alignment the outcome of the surgery is also better. The clinical outcome on the basis of HSS, WOMAC and KSS osteoarthritis index all showed significant clinical improvement in well aligned patients. These studies show that there has been improvement in outcome of the surgery with less re-surgery rate. Most of the studies were concentrated on the good coronal alignment. Although there has been positive impact on results, there are some studies which explain coronal alignment alone cannot determine the outcome of the TKA surgery.

Besides the mechanical axis, obesity also leads to poor outcome because it has impact on tibial component failures. Body Mass Index has also been found that influence the alignment in TKA surgery. One study found a failure and requiring revision surgery despite achieving neutral coronal alignment (valgus 1°) in a patient with body mass index, 44.6 at the time of first surgery [26]. Similarly, the study done by Pieter-Jan T.K *et al.* [36] found a more chance of varus alignment with high BMI with significant result ($P = 0.02$). They also found more damage to medial component damage in valgus groups and damage towards lateral side in varus groups. Whereas they did not found any significance results in neutral HKA groups.

Another factors also plays a role in TKA such as skeletal, neuromuscular factors, dynamic loading around the knee, body posture, genetic factors. But less studies has been gone through it regarding these factors and effect on the TKA surgery. Neutral mechanical alignment produces balanced static knee loading. But there is another factor called dynamic loading which affects knee loading more than static loading of knee. The study done by Miller EJ, Pagnano MW *et al.* [37] regarding relationship between tibiofemoral angle and static medial plateau loading found that 13 of 15 patients (87%) having static mechanical alignment of $0 \pm 3^\circ$, only seven of 15 patients (47%) had balanced dynamic loading if knee joint. This concludes that the cause of bad outcome despite well-aligned knee following TKA, as the mechanical alignment does not predict dynamic loading after modern knee arthroplasty.

Knee radiographs has an important role in the evaluation of the patients with knee arthritis. The post-operative long leg radiographs taken after TKA is used for assessing the alignment for the long term outcome. However, there is chance of errors of parallax and poor control of patient positioning in the normal standing radiographs [38]. Thus for the accurate assessment of mechanical axis and the axial alignment of the lower extremity full length weight bearing radiograph of the lower limb including the hip, knee and ankle is essential.

Some studies suggested that the post-operative radiograph alone cannot predict functional outcome. The rotational alignment may also be a significant factor affecting the accuracy of the assessment which cannot be observed in plain radiograph. So, measuring the mechanical axis using the plain radiograph has been reported to be inferior to other superior system like CT scan [39].

One study suggested that alignment assessed by the long leg radiographs is

only 2 dimensional so the kinematics assessment of knee is superior since it provides 3 dimensional alignment components [40].

5. Conclusion

In summary, following TKAs, accurate coronal alignment of total knee prosthesis (to within 3° of neutral) results in better function and better quality of life. Improved pain scores are also seen in accurately aligned prostheses [4] [8]. However, there are number of recent studies challenging and criticizing the effect of alignment on functional outcome. Alignment may contribute to better outcome but single factor implant alignment alone cannot determine it. Other factors such as surgeon, kinematic alignment, body mass index, knee loading, environmental factors also play a role but not defined well in the literature. Poor preoperative function and the existence of other joint abnormalities may also impair subsequent postoperative function.

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Conflict of Interest

The authors have no conflict of interest relevant to this article.

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Abbreviations

TKA:	Total Knee Arthroplasty
WOMAC:	Western Ontario and McMaster Universities Index
KSS:	Knee Society Score
HSS:	Hospital for Special Surgery Score
SF-12:	Short Form Survey-12
IKS:	International Knee Score