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ORIGINAL STUDY

The current role of coronal plane alignment in Total Knee Arthroplasty in a preoperative varus aligned population : an evidence based review

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Background : **Based on historical data, the current standard of care in Total Knee Arthroplasty (TKA) is to restore the overall alignment to a neutral mechanical axis of 0° ± 3° or even slight valgus. However, there is significant controversy in literature regarding intentionally placing the TKA in the patient's physiologic, rather than neutral (0 ± 3°), mechanical alignment.**

Questions/purposes : **The goal of this review is to provide a concise update on the present knowledge of coronal plane alignment TKA in a varus population.**

Methods : **A systematic overview of the present literature was undertaken to determine basic science and clinical results in frontal plane alignment in primary TKA.**

Results : **Results of studies based on laboratory research, retrieval analysis, cadaver research, finite models, survival scores, clinical outcome, gait analysis and radiographic outcome upon today are provided.**

Conclusions : **Currently placement of a TKA in neutral alignment of 0° ± 3° of frontal plane alignment is the standard of care. However, frontal plane alignment in neutral may not be as strongly correlated to survivorship as previously thought. Caution needs to be exercised before changing the standard of care, and more research needs to be performed.**

Keywords : total knee arthroplasty ; coronal plane ; alignment ; outliers.

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This review has been performed in London, Ontario, at the department of Joint Reconstruction in collaboration with Johan Bellemans and Jan Victor (Belgium).

INTRODUCTION

Total knee arthroplasty (TKA) has yielded excellent results in terms of clinical outcome and survivorship for treatment of end-stage osteoarthritis of the knee. However, patient satisfaction has been reported to be only 70-84% (*13*). This is significantly less than satisfaction outcome scores in total hip arthroplasty (THA) (*12*). It remains unclear what the reason might be for this difference in outcome.

Based on historical data, the current standard of care in TKA is to restore the overall alignment to a

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neutral mechanical axis of 0° ± 3°. Restoration of alignment within this range has been shown to yield excellent survivorship and overall good clinical outcome. However, a recent report has shown that there is no difference in survivorship at fifteen years when comparing a neutrally aligned mechanical axis group of 0° ± 3° to outliers in valgus and varus (58). Moreover, superior clinical outcomes have been shown when patients with preoperative varus alignment were left slightly undercorrected after TKA (71). Recreating the patient's native varus alignment during the TKA has intuitive appeal. A recent study performed by Bellemans *et al* revealed that the physiologic alignment of healthy adults at the end of skeletal maturity is ≥ 3° varus in 32% of men and 17% of women (5). However, there is significant controversy in literature regarding intentionally placing the TKA in the patient's physiologic, rather than neutral (0 ± 3°), mechanical alignment.

The goal of this narrative review is to provide a concise update on the present knowledge of frontal plane alignment TKA in a varus population. A systematic review was undertaken to determine basic science (laboratory research and retrieval analysis, cadaver research and finite models) and clinical results (survival scores, clinical outcome and gait analysis).

METHODS

Using the MEDLINE database and google scholar a review was performed on coronal plane alignment in TKA. Publications in English literature, updated until August 2015, were evaluated using the search headings : total knee arthroplasty, coronal plane, frontal plane, mechanical, varus. All abstracts were analysed by two authors (PV and BL). Abstracts describing the outcome in TKA related to the changes in the coronal plane were further analysed. Articles were reviewed and cross-matched for references. Studies describing the in-vivo outcome of patients after TKA were included in the clinical results, which were further divided into survival scores, clinical outcome and gait analysis. Non patient-outcome studies were divided into laboratory research and retrieval analysis, cadaver research and finite models.

RESULTS

Basic Science

Retrieval analysis (Table I)

Three papers have used retrieval analysis to examine the effect of frontal plane alignment on the wear patterns of TKA and on tibial inserts (49,57,67). These papers had differences in implants, clinical measurements, alignment definitions and retrieval

Table I. — Retrieval analysis

Paper	Implant	Year implantation + mean follow-up	Radiographs	Type of Analysis	Alignment measurement	Outcome
Collier (15)	Primary CR-AMK with Enduron insert (Depuy, Warsaw, Indiana)	1987-1996 8 ± 4 years	Full length	89 inserts (thickness assessment)	Mechanical axis (varus : ≥ 1° HKA-angle)	Increase wear per overalll degree of varus of 0.021 mm/year No association with tibia vara
Srivastava (67)	Primary CR-PFC (Depuy, Warsaw, Indiana)	Jan 2000-Dec 2004 7.7 years (1-13)	Short films	16 inserts (laser mapping)	Anatomic alignment Analysis tibial component > 3° varus versus < 3°, in neutral femorotibial angle (5.4° ± 0.9)	Increased total and medial wear in tibial varus, even with overall alignment in range.
Pang (57)	PS - Genesis II (primary and revision) (Smith and Nephew, Massachusetts)	1999-2011 3.5 years (0.3-10.3)	Short films	83 inserts (damage score)	Anatomic alignment Femorotoibial angle (varus = < 3° anatomic valgus)	Anatomic alignment of < 3° was correlated with higher damage scores. No correlation with tibial varus.

methods. Different implant designs and manufactures as well as CR (49,67) and PS (55) implants were used. Polyethylene sterilized using gamma radiation in air was used in one paper (49). Retrieval measures used included laser mapping (67) as well as mechanical measurements (49,57). Radiographic measurements were done on full length (49) as well as on short films (57,67). Alignment definitions used were both mechanical (49) and anatomical (57,67).

In spite of these differences, some information can be withheld. Overall alignment in varus was found to be correlated with increased wear (49) and damage (57) in two papers. These two papers also indicated that if the tibial component was in varus, but the overall alignment was neutral, there was no increase in wear or damage. Collier *et al* calculated that as the mechanical axis approached neutral, the decrease in the rate of polyethylene wear medially was almost twice the increase in the rate of polyethylene wear at the lateral side (0.021 mm/year versus 0.012 mm/year) and that varus alignment increased wear at 0.021 mm/year per degree (49). The paper by D'Lima had a different outcome, reporting that the tibia being in varus is related to increase wear even if overall alignment was neutral as measured on their short films (67).

Laboratory analysis (Table II)

Three laboratory studies have been performed to determine the effect of malalignment in TKA (23,33,48). A variety of implant designs were tested. The testing devices consisted of a custom jig (33,48) or a knee wear simulator (23). All studies examined the effect of varus malalignment with a neutral alignment as reference. These studies show that 3°-5° of varus malalignment leads to an uneven load distribution, with higher compressive loading and wear medially. Knee designs with increased congruity were shown to have lower stress if malaligned (48).

Table II. — Laboratory Results

Paper	Implant	Type of analysis	Goal Study	Reference	Results
Hsu (34)	1. Kinematic (K) (Howmedica, New Jersey) 2. Total Condylar Knee (TC)	1500 N load on polyurethane foam artificial bone with a pneumatic test rig	Effect of malalignment on load	Even load distribution : - K : 9° femoral valgus, 2°tibial varus - TC : 7° femoral valgus, Tibia 0°	1. Increase of load in 5° malalignment : K : 7% TC : 40% 2. Increase of load in 10° malalignment K : 34% TC : 62%
Matsuda (49)	1. Advatim (Wright Medical, Tennesee) 2. LCS (Depouy, Iniana) 3. MG II (Zimmer, Indiana) 4. Omnifit (Osteonics, New Jersey) 5. Profix (Smith & Nephew, Tennessee)	A servohydraulic testing device was loaded to 3332N with a vice tilting the tibia in 0° and 5°	Effect of varus tilt on the contact stresses measured in 15° and 90° of flexion	0° versus 5° of tibial varus tilt	5° varus caused a shift of compressive load to one condyle. Lowest stress was seen in a congruous knee designs.
D'Lima (24)	CR-PFC (Depuy, Indiana)	Pneumohydraulic knee wear simulator	Effect of polyethylene wear after 5 million cycles in 3 testing conditions : low and high intensity and 3° varus malalignment	Low intensity group : 31 (± 1.2) mg/million cycles even wear distribution mediolaterally	3° varus malalignment : 9.2 (± 3.3) mg/million cycles relative more wear at the medial condyles

Table III. — Cadaver Research

Paper	Implant	Type of analysis	Goal Study	Reference	Results
Bargren (2)	Freeman Swanson (ICLH)	Loading a stripped cadaver tibia with a small (SC) and large (LC) tibial component	Assess amount of load for lift-off and compressive failure of bone in eccentric loading versus uniform failure loading	Uniform medial failure loading : SC : 6500N LC : 15,750 N	In eccentric loading : - Lift-off : SC : 1200 N (18%) LC : 1500 N (9.5%) - Eccentric failure : SC : 3200 N (51%) LC : 5400 N (34%)
Green (28)	CR-PFC (Depuy, Warsaw, Indiana)	14 paired stripped cadaver specimens loaded on a servohydraulic testing device at 3x body weight	Compare neutral versus 5° varus tibia in medial and lateral loading conditions. Measurement of surface microstrain on the bone.	1,037 microstrain in neutral alignment posteromedial quadrant tibia	Posteromedial hotspot in all loading conditions in 5° varus (1,935 microstrain)
Werner (73)	CR-TKA (undefined)	7 cadavers tested for surgical trial reduction and in a physiologic knee gait simulator.	Effect of malalignment (varus and valgus) on tibiofemoral mechanics by the use of five tibial inserts (neutral, 3° and 5°)	Neutral insert (0°)	Pressure distribution and total load significantly changed in as low as 3° of angulation

Cadaver Research (Table III)

Three cadaveric papers examined how loading in varus alignment effects knee arthroplasty biomechanics (2,28,73). In addition to the limitations of cadaveric testing, differences in loading algorithms, components, and definitions of alignment were present. Also, the outcome tools used were not uniform. However, in spite of these differences, there was a consistent message : varus alignment causes increased strain in the posteromedial area (28), increased medial pressures (73), and decreased loads to failure (2).

Finite models (Table IV)

Five finite element studies using different implant styles have been published so far on the impact of frontal plane alignment in TKA (22,42,59,68,69). Simulations were performed to determine cancellous bone stress (59) or von Mises stresses and contact stresses (22,42,68,69) in varus aligned conditions. All studies have shown higher stresses in varus conditions compared to neutral or equal mediolateral loading, yet none of the studies found that neutral alignment was correlated to equal mediolateral loading (22,42,69). One study has shown less cancellous bone stress in valgus than varus malalignment (59). The study performed by Taylor *et al* showed that if the ratio of mediolateral loading is 86:14 stresses did not change significantly, but stresses are up to 200% if the loading ratio is 95:5 (69). However, two studies have shown that the contact stresses and von Mises stresses were much lower in high conformity conditions (22,42). Finally, the study performed by Stan *et al* showed that 2-4 mm additional resection of the tibial plateau towards varus does not significantly affect the load distribution in a proper balanced knee (68).

Clinical Results

Clinical outcome and survival scores (Table Va-f)

Since the first study published in 1977 by Lotke *et al* (44), various studies have described the clinical outcome and survivorship of total knee replacement in relationship to the coronal plane alignment (7,10,16,25-27,31,32,37-39,41,45-47,49,53,58,61-63,65,60,72).

Among all studies are differences in patient characteristics, cohort size, implant type and design, follow-up, measurement of alignment, and outcome measures. Based on the mean time of follow-up, most studies reported short- (mean < 5 years), and mid-term follow-up (mean < 10 years) of functional outcome and survivorship data. However, only one long-term follow-up paper (mean > 15 years) was

Table IV. — Finite Models

Paper	Implant	Type of analysis	Goal Study	Reference	Results
Perillo-Marcone (*59*)	Dual Bearing Knee (MMT Ltd, Birmingham, UK)	Cadaver specimen Cancellous bone stress	Effect PA-angle (2.5°, 5° and 10° of varus and valgus) on cancellous bone stress	0° PA-angle : 1.952 MPa	Tibia valgus positioning results in lower stress. Tibia varus positioning results in higher stress. *10° varus : 2.527 Mpa* *5° varus : 2.398 MPa* *2.5° varus : 1700 MPa* *2.5° valgus : 1569 MPa* *5° valgus : 1,555 Mpa* *10° valgus : 1,806 Mpa*
D'Lima (*22*)	Undefined	Knee simulator Contact stress and von Mises stress	Effect of malalignment (single condyle loading or liftoff) in low and high conformity conditions	Neutral alignment	In liftoff conditions : significantly higher mean and peak stresses. High-conformity stresses were much lower than low conformity.
Liau (*42*)	U-Knee (United Orthopaedic, Taipei, Taiwan)	Contact stress and van Mises stress	Effect of femoral varus tilt (1°,3° and 5°) in a medium (curve on curve) -MCC- and high conformity (curve on curve -HCC- and flat on flat -HFF-) design	Neutral alignment	Higher contact and von Misses stresses in varus alignment. In 5° varus : Contact stress 145.9% Von Mises stress : 120.6% Minimal risk with HCC
Taylor (*69*)	PFC (Depuy, Leeds, UK)	Knee simulator Contact stress	Effect of progressive eccentric loading (ratio medial :lateral loading)	50:50 loading	Eccentric loaiding (medial :lateral) : Up to 86 :14 : minor variations contact stress 95: 5 Contact stresses ± 200% of 50:50
Stan (*68*)	Undefined	Image acquisition and analysis load distribiution	Effect of tibia varus 3°-8° (balanced vs unbalanced knee)	Neutral	2- and 4-mm additional medial plateau resection on a proper balanced knee does not significantly affect the load distribution

identified (58) Cohort size varied significantly, with the smallest group consisting of 20 TKA's (*47*), while most of the large populations (3152-6070) have been used in the studies from the Centre for Hip and Knee Surgery in Mooresville (*7,25,61,62*).

The studies describing alignment on short-film radiographs of the knee determined alignment in terms of anatomical alignment (*7,25,26,38,39,41,44,61-63,70*). Full leg standing radiographs were used to measure mechanical axis (*10,17,31,32,37,45-47,49,53,58,65,72*). One study did not define how alignment was measured (*27*) and another study used Maquet's line to determine the overall alignment on full length standing radiographs (*37*). Using short films, only seven studies investigated the position of the tibia in the frontal plane (*7,26,31,38,39,45,62*) and only 3 studies the position of the femoral component (*38,39,62*).

The results of these studies vary greatly, and are dependent on the type of radiographs used. Table Vb-f highlights the beneficial and detrimental position of the overall alignment and TKA component position for the short film radiographs studies and the full-length radiograph studies. Studies performed with short films radiographs tend to show

Table Va. — Clinical Outcome (* Knee Evaluation Index)

	Total	FU (mean)	Radiograph	Implant	Outcome	Alignment	Result
Lotke (*44*)	70	3	Short film	Geometric TKA	KEI*	Anatomic / overall	Strong correlation KEI and 'well positioning'
Gibbs (*27*)	58	2-5.7 (3.3)	Undefined	Freeman-Swanson ICLH Mark I	Survivorship	Undefined	- 0°-4° valgus : 19% - 5° valgus : 0% - Varus : 100%
Lewallen (*41*)	209	10	Short film	Gunston (Polycentric) TKA	Survivorship	Anatomic / overall	Failure rates : - * 2 for any varus or valgus > 8° - Lowest for 0°-8° valgus
Jonsson (*38*)	86	6.5	Short film	Townley semiconstrained bicondylar prosthesis	Freeman scale (functional score)	1. Total alignment 2. Tibial position 3. Femoral position	1. 1°-6° varus best functional scores valgus > 7° lowest functional scores 2. No correlation tibial component 3. Femur > 12° : inferior results
Tew (*70*)	428	0.5-9	Short film	6 different (Early and modified Freeman, Sheehan, Manchester, Oxford, Kinematic)	Survivorship	Anatomic	Failure rates : High in extreme varus (≥ 2°) and valgus (≥ 12°) Lowest if anatomic alignment ± 7°
Smith (*65*)	65	4	Full leg	Insall-Burstein	1. Outcome 2. Radiographic	Mechanical + Anatomic	No difference between anatomic varus, neutral and valgus group.
Jeffery (*37*)	115	0-12 (8)	Full leg	Denham TKA	Survivorship	Maquet's line	Failure rate at 8y : Maquet middle 1/3 : 3% Maquet outer 1/3 : 24%
Feng (*26*)	186	4-9 (6.1)	Short film	Microloc	Survivorship	1. Overall anatomic 2. Tibial position	Highest survival : 1. Anatomic axis 4°-8° valgus 2. Tibia varus < 5°
Ritter (*63*)	421	0.17-13	Short film	PCC (posterior Cruciate Condylar)	Survivorship	Anatomic	Higher failure rates in varus (≤4° valgus)
Matsuda (*47*)	20	2-9.8 (7.3)	Full leg	MG I (Zimmer, Warsaw, USA)	1. Wear 2. KSS	Mechanical (Weight-bearing ratio)	Higher wear in varus knees No correlation wear and KSS
Berend (*7*)	3152	2-14.2 (5.0)	Short film	AGC (Biomet, Warsaw, USA)	Survivorship	1. Overall anatomic 2. Tibial position	Higher failure rate 1. Overall anatomic varus (unspecified) 2. Tibia > 3° varus 3. BMI > 33.7 if tibia varus
Morgan (*53*)	197	(9)	Full leg	Kinemax	Survivorship	Anatomical	No difference between neutral (4°-9° valgus), valgus (> 9° valgus) and varus (< 4° valgus) groups.
Choong (*17*)	111	1	Full leg	PFC (Depuy, Warsaw, USA)	KSS, SF12	Mechanical	Superior outcome in 0° ± 3° (neutral)
Fang (*25*)	6070	2-22.5 (6.6)	Short film	AGC (Biomet, Warsaw, USA)	Survivorship	Anatomical	Best survival in 2.4°-7.2° valgus
Matziolis (*49*)	60	5-10	Full leg	PFC (Depuy, Warsaw, USA) Natural Knee II (Zimmer, Warsaw, USA)	1. Survivorship 2. KSS	Mechanical	No difference between outlier varus TKA and neutral matched control population

Parratte (58)	398	15 +	Full leg	Kinematic II (Howmedica, New Jersey, USA) PFC (Depuy, Warsaw, USA) Genesis (Smith&Nephew, Memphis, USA)	Survivorship	Mechanical	No higher survival in neutral (0° ± 3) alignment compared to outlier group (> 3°)
Ritter (61)	6070	2-22.5 (6.6)	Short film	AGC (Biomet, Warsaw, USA)	Survivorship	Anatomical	Failure rates lowest if tibia ≥90° valgus and femur < 8° valgus. Failure rate higher in higher BMI
Bonner (10)	501	(9.7-9.8)	Full leg	PFC (Depuy, Warsaw, USA)	Survivorship	Mechanical	No statistical significance in failure rate between neutral (0° ± 3) aligned group and outlier group (> 3°)
Magnussen (45)	553	2-19.8 (4.7)	Full leg	HLS2 (Tornier, St. Ismier, France)	1. Survivorship 2. IKS	1. Overall mechanical 2. Tibia position	1. Survival and IKS similar for neutral (0° ± 3) and varus (> 3°) 2. Lower IKS in tibial varus (> 3°)
Ritter (62)	5342	2-22.5 (7.1)	Short film	AGC (Biomet, Warsaw, USA)	Survivorship	Anatomical (preop alignment vs postopalignment)	Failure rate : - High if : Preop > 8° varus or > 11° valgus - Low if : Postop 2.5°-7.2° overall valgus
Matsuda (46)	500	2-11 (5)	Full leg	Undefinied	KSCRS and KSS	Mechanical	Varus (undefined) correlates with lower patient satisfaction
Howell (31)	198	2.6-3.6 (3.2)	Full leg	Vanguard (Biomet, Warsaw, USA)	OKS WOMAC	1. Mechanical 2. Anatomical 3. Tibia position	No difference in outcome in overall and tibia alignment between varus, neutral or valgus.
Vanlommel (72)	143	(7.2)	Full leg	Profix (Smith & Nephew, Memphis, USA)	KSS and WOMAC	Mechanical	Higher outcome in mild varus (3°-6°) group compared to neutral (0° ± 3°) and oulier (> 6° varus) for preoperative varus patients.
Howell (32)	219	6.3 (5.8-7.2)	Full leg	Vanguard (Biomet, Warsaw, USA)	survivorship	1. Overall mechanical 2. Tibia position	Overall and tibia varus alignment did not adversely affect implant survivorship.
Kim (39)	3048	15.8 (11-18)	Short film	LCS (Depuy, Warsaw, USA)	survivorship	1. Overall mechanical 2. Tibia position 3. Femoral position	Risk factors for failure: Anatomical knee alignment < 3° valgus Femoral component < 2.0° valgus Tibial component < 90°

better outcomes in an anatomical alignment towards more than 2° of valgus.

However, most studies performed with full leg radiographic analysis showed no difference between neutral and varus or valgus mechanical alignment. Two studies have shown better outcome with neutral (0° ± 3°) mechanical alignment or Maquet's line passing through the middle third of the knee (*17, 37*). And while one study shows lower satisfaction rates in varus aligned patients (*46*), Bellemans *et al* shows superior results in 3°-6° varus in preoperatively varus aligned patients (*72*).

Two studies analysed the position of the femur, suggesting that femoral component positioning between 2-8° valgus is correlated with less failure rate (*39,61*). Four studies by a single centre show a better survivorship is to be expected if the tibial component is positioned in less than 3°-5° varus or even towards valgus alignment (*7,25,39,61*). However, Howell *et al* could not show any difference in

Table Vb. — Results overall alignment (anatomic) on short film radiographs

Study	Outcome (O) / Survival (S)	Beneficiary	Detrimental
Gibbs (27)	S	5° valgus	Varus
Lewallen (41)	S	0°-8° valgus	
Jonsson (38)	O	1°-6° varus	Valgus > 7°
Tew (70)	S	Valgus 7°	Varus ≥ 2°, valgus ≥ 12°
Feng (26)	S	4°-8° valgus	
Ritter (63)	S		≤ 4° valgus
Berend (7)	S		varus
Fang (25)	S	2.4°-7.2° valgus	
Ritter (62)	S	2.5°-7.2° valgus	
Kim (39)	S		< 3° valgus

Table Vc. — Results tibia alignment on short film radiographs

Study	Outcome (O) / Survival (S)	Beneficiary	Detrimental
Jonsson (38)	O	No correlation	No correlation
Feng (26)	S	< 5° varus	
Berend (7)	S		> 3° varus
Ritter (61)	S	≥ 90° valgus	
Kim (39)	S		< 90° (any varus)

Table Vd. — Results Femoral alignment on short film radiographs

Study	Outcome (O) / Survival (S)	Beneficiary	Detrimental
Jonsson (38)	O		> 12° valgus
Ritter (61)	S	< 8° valgus	
Kim (39)	S		< 2° valgus

clinical outcomes and survivorship between neutral, varus and valgus aligned tibia positioning (*31,32*).

Gait analysis

No gait analysis compares varus patients with knee osteoarthritis treated with a neutral or physiologic aligned TKA.

The group of Andriacchi described a radiological and gait analysis on 21 TKA's performed in 14 patients, showing a strong correlation between the magnitude of the adduction moment and the postoperative varus alignment (*14*). However, significant differences in athropathy etiology, differences in pre-operative and post-operative alignment and small numbers limit the ability to apply these results.

Orishimo *et al* published a study describing gait analysis in 17 patients before TKA surgery and at 6 months and 1-year follow-up (*54*). The gait was correlated with the adduction moment and frontal plane alignment. Preoperative static knee alignment was 2.2° of varus, and 3.5° of valgus after surgery. TKA improved knee adduction moment at 6 months, but this effect was lost 1 year after surgery. It was suggested that pre-surgical levels of knee adduction

Table Ve. — Results overall alignment (mechanical) on full leg standing radiographs

Study	Outcome/ Survival	Beneficiary	Detrimental
Smith *(65)*	O	No correlation	No correlation
Jeffery *(37)*	S	Mid 1/3 Maquet	
Matsuda *(47)*	O	No correlation	No correlation
Morgan *(53)*	S	No correlation	No correlation
Choong *(17)*	O	0° ± 3°	
Matziolis *(49)*	S+O	No correlation	No correlation
Parratte *(58)*	S	No correlation	No correlation
Bonner *(10)*	S	No correlation	No correlation
Magnussen *(45)*	S	No correlation	No correlation
Matsuda *(46)*	O		Varus
Vanlommel *(72)*	O	3°-6° varus	
Howell	S+O	No correlation	No correlation

Table Vf. — Results tibia alignment on full leg standing radiographs

Study	Outcome/ Survival	Beneficiary	Detrimental
Magnussen *(45)*	S		> 3° varus
Howell *(31)*	O	No correlation	No correlation
Howell *(32)*	S+O	No correlation	No correlation

might return as early as 1 year after TKA, which may predispose medial polyethylene wear in TKA.

The most recent study was performed by Miller *et al* *(50)*. Based on full leg radiographs and gait analysis, they found that dynamic loading after TKA did not correlate with an equal static load distribution, challenging the idea that a neutral aligned TKA provides equal mediolateral loading. They stated that other factors, such as limb position, muscle contraction, soft-tissue stability and walking speed should be considered when addressing tibiofemoral loading in TKA.

Radiographic analysis (Table VI)

Based on short film radiographs, four studies have described the relationship to frontal plane alignment and tibial component position to the amount of radiolucencies *(1,35,40,60)*. Three of the studies were mid-term outcome studies *(1,40,60)*, while one was a short-term *(35)*. All implants used are no longer currently available.

Overall and tibial component varus alignment was shown to be associated with a greater incidence of radiolucencies in all studies. However, no differences in clinical outcome and/or survival rates were found *(1,35,60)*.

DISCUSSION

The original goals of surgery as described in 1977 for TKA was a neutral aligned lower extremity, with an overall alignment of 3°-7° (44) and a neutral tibial component ; supported in 1979 with a survivorship study *(52)*. In 1985, three articles were published on the technique of total knee arthroplasty *(34,36,71)*. Insall stated that neutral alignment was critical to the function and survival and that most failures occurred because of ligament imbalance and incorrect positioning, with no fixation failure if in excessive valgus. Hungerford and Krackow shared their experience in Total Condylar and Kinematic prostheses and recommended that the weight-bearing axis should pass through the centre of the prosthesis. Finally, Townley stressed the importance of maintaining anatomic alignment, which is crucial for the long-term success for TKA, but

Table VI. — Radiographic analysis

Paper	Total	Implant	FU (yrs)	Outcome	Radiographs	Results
Hvid *(35)*	138	Insall/Burstein TC knee	0.25-2	Radiolucency index (RI)	Short film	Higher RI : 1. In overall varus for RA patients, not OA 2. In tibia vara for RA and OA patients No correlation with clinical outcome
Aglietti *(1)*	85	TC I prosthesis	5	Radiolucent lines	Short film	More Radiolucent lines in: 1. Overall varus 2. Tibial varus > 2° No correlation with clinical outcome or survivorship
Rand *(60)*	102	Geometric TKA	10.8 ±1	Radiolucent lines	Short film	More Radiolucent lines in: 1. Axial alignment ≥ 3° varus 2. Tibial component ≥ 4° varus
Laskin *(40)*	61	TC prosthesis	9-10	Radiolucent lines	Short film	Significant higher radiolucency in improper (≤ 3° femorotibial valgus) versus proper (> 3° femorotibial valgus) positioning of the tibia

placement of the weight-bearing axis somewhat to the medial side of the midpoint of the joint may improve the cosmesis of the lower extremity. Subsequently, Lewallen advised placing a knee replacement in an overall anatomical alignment of 0°-8° valgus, related to the lowest failure rates in his study *(41)*.

This current standard of care of neutral alignment has been supported in ex-vivo studies. Retrieval analysis has shown increased wear (both medial and total) when positioning the tibia in more than 3° of varus, even in the presence of an acceptable overall alignment *(15,57,67)*. Limitations of these retrieval studies include selection bias, no quantification of re-revision knee stability, a lack of full leg radiographs, no control population and subjective evaluations *(15,30,57,67)*. Most of the laboratory analysis and finite models confirmed the findings of increased medial loading and increased stress on the medial compartment in an overall varus alignment or tibia varus positioning *(22,23,33,42,48,59,69)*. However, one study showed that in a proper balanced knee, there was no significant difference in contact pressure when knee was aligned in varus *(68)*. Cadaver research also revealed higher loading and pressure distribution in the medial compartment with resultant higher failure rates of the tibial component when aiming for an overall varus alignment or tibia's varus position. Limitations of these cadaver studies include disruption of the soft tissues, and non-physiologic motion and loading *(2,28,73)*.

While revision rate data indicates that malalignment in TKA was present in up to 11.8% of revisions, the possible consequences of malalignment, such as aseptic loosening and polyethylene wear, contribute to 49.1% of all reasons for revision *(64)*. However, current clinical literature concerning the controversy of frontal plane alignment is varied and many survivorship studies present mid-term results or limited patient cohort size. The largest clinical studies evaluating frontal plane alignment and survivorship, were performed by one group. In 1994, Ritter *et al* recommended positioning a TKA in neutral or slight valgus for long-term survival rate *(63)*. This study was confirmed later on by Fang. Based on 6070 TKA's with a mean follow-up of 6.6 years, higher survival rates were seen for neutral alignment of 2.4°-7.2° of anatomical valgus alignment *(25)*. The initial studies performed were based on old implants and fixation techniques and while the impact of their results should not be underestimated, their work has limitations of short film radiographs (18,20). The most recent large population study (3048 knees) confirmed these findings but was also based on short film radiographs (39).

The theoretical advantages of physiologic TKA positioning has been discussed for some time. It is classically understood that the overall limb alignment is approximately 3° off the perpendicular, with the tibia in slight varus and the femur in slight valgus (16,19,55). Bellemans found that in an adult population, the overall alignment of a native knee is ≥ 3° varus in 32% of men and 17% of women, supporting the concept of physiologic varus (5). This needs to be understood in light of the functional work by Dror Paley, illustrating that when walking, the feet progress one in front of the other in the same line, adducting the leg approximately 3° (56). This relative varus position allows the knee to obtain an optimal parallel orientation to the ground during gait. In a bipodal position, with the feet apart equal to the distance of the width of the pelvis, the knee joint is 3° inclined to the ground and the mechanical axis is perpendicular to the ground (56). When performing a TKA in neutral alignment, the knee would be in a relative valgus position of the knee joint to the ground in unipodal stance and during gait, which would theoretically result in a lower adduction moment. This may result in a broader gait pattern than physiologically perceived and a 'less normal feeling'.

It wasn't until 2008 that TKA frontal plane alignment was questioned as the most important factor in survival (53). Afterwards, three studies discussed the outcome of survivorship using modern TKA-designs and fixation techniques (10,49,58). Two of them described a long-term follow-up and had a similar study design (10,49,58). Within a total population of 218 TKA's with a minimum follow-up of 5 years, Matziolis found no difference in outcome between the 30 most malaligned varus knees and a control population (49). Parratte and Bonner also did not show any difference in survival rate between a neutral (0° ± 3°) alignment group and the outliers in varus and valgus (10,49,58). However, these papers were limited as there was no difference made between a varus outlier and a valgus outlier (51).

Although there is a significant body of literature regarding the effect of coronal plane alignment on survivorship, the effect on patient satisfaction is not as well described. Data provided by Bourne have shown that nearly one in five TKA's is not satisfied (13). One of the theories presented is that a common surgical objective neutral alignment does not respect the native anatomy and biomechanics of the patient. Patient satisfaction at mid-term have shown inferior, identical and superior outcome scores comparing a neutral aligned population and varus outliers (17,31,38,44-46,49,65,72). These studies include small patient numbers and don't take into account pre-operative alignment or the change in alignment after TKA. A recent paper demonstrated that in patients who were in varus alignment prior to surgery showed superior outcomes when undercorrecting the alignment during their TKA's (73). While reviews of current literature regarding physiologic alignment of TKA have resulted in supportive conclusions (6), Lombardi did not find any scientific evidence to make a deviation from the standard of care (43). Improving patient satisfaction after TKA is important and this needs further study. However, if the current literature indications of improved patient satisfaction are correct, but the literature indicating decreased survivorship is also correct, clinicians and patients would be faced with a challenging question. Can we undermine the long-term outcome for a superior outcome ? Therefore, further research in this area is critical prior to widespread acceptance of changing the surgical goals. To answer these questions further research is necessary.

Careful assessment of how physiologic tibial component position effects femoral component rotation to avoid patellofemoral problems should further be investigated (3,8,29). How alignment correlates to balance of the knee and outcomes as well as how changes in the surgical goals of alignment to achieve a physiologic knee position effects knee balance is not well understood (2,28,73). The recent study performed by Miller showing that dynamic equal mediolateral joint loading is not correlated to a neutral mechanical aligned knee also questions the role of neutral alignment after TKA and indicates that frontal plane alignment is only one of the contributing factors to joint loading (50). Computer-assisted surgery (CAS) might allow precise achievement of surgical goals, but it has not been utilized to determine the relative contributions of the femur and the tibia in physiologic varus alignment (*4,9,11, 24,66*). Further research is necessary to determine whether higher congruity could be of value in undercorrrection TKA since these designs did show a significantly lower stress in ex-vivo studies (*22,48*). Prospective, randomized studies describing clinical outcome and survivorship data of modern implant designs and fixation techniques are necessary to understand the effect by frontal plane alignment. As suggested by Cooke, alignment should be standardized to improve conformity in literature (*21*).

CONCLUSION

Currently placement of a TKA in neutral alignment of 0° ± 3° of frontal plane alignment is the standard of care. However, frontal plane alignment in neutral may not be as strongly correlated to survivorship as previously thought. New implant designs, surgical techniques and more accurate surgical measurement tools may allow the opportunity to individualize alignment and potentially optimize patient satisfaction. Notably, caution needs to be exercised before changing the standard of care, and more research needs to be done.

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