



Posterior Tibial Slope in Anterior Cruciate Ligament Surgery: A Systematic Review

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Abstract

Background While the literature suggests a correlation between posterior tibial slope and sagittal stability of the knee, there is a lack of consensus relating to how to measure the slope, what a normal slope value would be, and which critical values should guide extra surgical treatment.

We performed a systematic literature review looking at the posterior tibial slope and cruciate ligament surgery. Our aims were to define a gold standard measurement technique of posterior tibial slope, as well as determining its normal range and the important values for consideration of adjuncts during cruciate ligament surgery.

Methods Electronic searches of MEDLINE (PubMed), CINAHL, Cochrane, Embase, ScienceDirect, and NICE in June 2020 were completed. Inclusion criteria were original studies in peer-reviewed English language journals. A quality assessment of included studies was completed using the Methodological Index for Non-Randomized Studies (MINORS) Criteria.

Results Two-hundred and twenty-one papers were identified; following exclusions 34 papers were included for data collection. The mean MINORS score was 13.8 for non-comparative studies and 20.4 for comparative studies, both indicating fair to good quality studies. A large variation in the posterior tibial slope measurement technique was identified, resulting in a wide range of values reported. A significant variation in slope value also existed between different races, ages and genders.

Conclusion Cautiously, the authors suggest a normal range of 6–12°, using the proximal tibial axis at 5 and 15 cms below the joint. We suggest 12° as a cut-off value for slope-reducing osteotomy as an adjunct to revision ligament reconstruction.

Keywords ACL · Knee · Ligament · Tibia

Introduction

Anterior cruciate ligament (ACL) rupture is a common injury [1], with risk factors for initial injury and success of reconstruction known to be multi-factorial [2, 3]. These include patient age, sex, graft choice, graft size, fixation method, tunnel position, femoral notch diameter, activity level and rehabilitation. Knowledge of modifiable factors is essential for the provision of high-quality treatment.

There has been growing interest recently in the association of posterior tibial slope (PTS) and sagittal stability of the knee. PTS is defined as the angle between the line

perpendicular to the tibial axis and the posterior inclination of the tibial plateau. However, controversy surrounds how to measure PTS, what imaging modality to use and what landmarks of the tibial plateau are measured [4, 5] PTS can also be influenced by ethnicity, sex, age, tibial rotation and the presence of osteoarthritis [6–9].

Several authors have reported increased PTS as a risk factor for non-contact ACL rupture [10–17]. Other authors have demonstrated increased failure rates for ACL reconstruction [2, 3, 18–22]. In their long-term prospective radiograph-based study, Webb et al. described a fivefold increase in graft failure with increased PTS [2]. This has led to several authors advocating slope-reducing osteotomies in conjunction with revision ACL reconstruction [6, 23–25].

The purpose of this study was to systematically review the literature relating to PTS and anterior cruciate ligament surgery. The study is required to address the lack of consensus in the literature relating to various facets of PTS,

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which makes assessment, communication and treatment challenging.

The aims of this study were firstly to define a gold standard measurement technique, secondly to determine “normal” ranges for PTS and thirdly to determine a maximum PTS value, above which corrective osteotomy should be considered.

Materials and Methods

Literature Search

A systematic search was performed following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [25]. The literature search was performed in June 2020 using MEDLINE (PubMed), Cumulative Index to Nursing and Allied Health Literature, Cochrane, Embase, ScienceDirect, and National Institute for Health and Care Excellence evidence. The search algorithm was “posterior tibial slope” OR “posterior inferior tibial slope” OR “tibial slope” in the title, AND language was limited to English.

After duplicate removal, the title and abstract of all potential studies were screened by two reviewers (MGRB and VIM), those remaining were evaluated by the same two reviewers on the inclusion and exclusion criteria. A review of the references of each included study was undertaken to identify any additional studies of interest.

Inclusion criteria were (I) original studies, (II) published in the English language and (III) articles studying PTS in ACL injuries or treatments. Exclusion criteria were (I) abstracts without full text, (II) articles in other languages, (III) animal studies, (IV) case reports, (V) review articles, (VI) description of surgical techniques, (VII) multiple studies reporting on the same cohort of patients and (VIII) articles of poor quality. Article quality was assessed using the MINORS criteria, with scores less than 8 for non-comparative studies or less than 12 for comparative studies not included.

Quality Assessment of Included Studies

A quality assessment of included studies was completed using the Methodological Index for Non-Randomized Studies (MINORS) criteria [26]. MINORS is a validated scoring tool for nonrandomized studies. Twelve items are given scores of 0 for not reported, 1 for reported but inadequately and 2 if reported adequately. This produces a maximum score of 16 for noncomparative and 24 for comparative studies. Two authors (MGRB and VIM) performed

MINORS scoring independently, and discrepancies were resolved by discussion until agreement on score. The level of evidence of all included papers was recorded.

Data Extraction

All data was collected using Microsoft Excel (Microsoft Corp., Redmond, WA, USA). A review template was developed to aid data collection. Baseline information for each article was recorded including, authors name, year of publication, journal of publication, study type and level of evidence. Specific data extracted for the review included methods of PTS measurement, imaging modality, patient demographics, number of subjects, mean values, ranges, number of subjects, population characteristics if any comparison was used and the presence of disease within the studied knees.

Statistical Analysis

All statistical analysis was performed using Microsoft Excel and *p*-values of 0.05 were considered significant. Information was presented in tablet form, with simple statistical analysis such as mean and range calculations performed.

Results

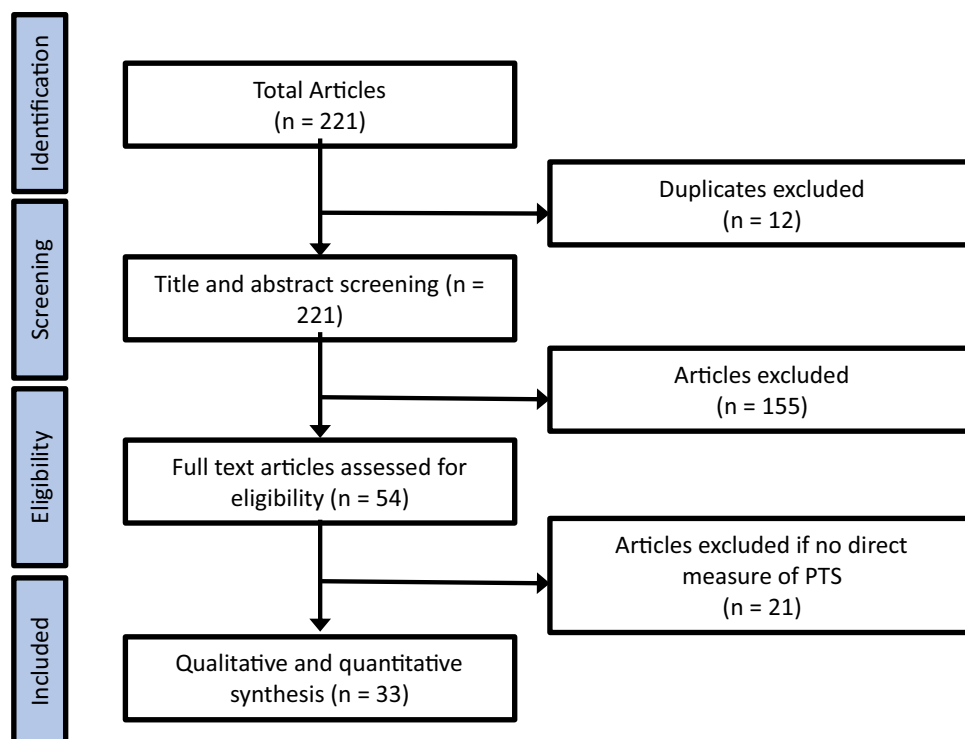
Literature Search

Two hundred and twenty-one articles were returned during the initial search. There were twelve duplicate studies. The remaining 209 abstracts were screened for eligibility and a further 155 articles were excluded. The full text of 54 articles was reviewed by the two observers in accordance with the described inclusion and exclusion criteria. These studies were evaluated for eligibility if a direct measure of PTS was undertaken; in total 33 studies were included for analysis (Fig. 1). Eleven papers were excluded since they were review articles, 6 were deemed to be of low quality, 3 described interventions and 1 paper was published in French with an English abstract. Finally, the references of all included studies were reviewed, and no other potential studies were identified for inclusion.

Study Quality

Included papers were assessed using the MINORS criteria (Table 1). The mean score was 13.8 (range 12–16) for non-comparative studies and 20.4 [17–23] for comparative

Fig. 1 PRISMA Flow diagram of studies' screening and selection



studies, both indicating fair to good quality studies. Thirty of the papers included were level 3 evidence and one paper was level 2 evidence.

'Normal Values' for Posterior Tibial Slope

Thirty-one of the 33 studies reported values for PTS in 'healthy' patients. Data from these papers were extracted and is shown in Table 2. Three papers compared imaging modalities [19, 42]. All other studies described results for a single imaging modality. In total 5,562 images from 5277 "healthy" knees were measured with a mean PTS across all imaging modalities of 7.2° (−8 to 17°).

Description of Methods of PTS Measurement

PTS is an angle between a line drawn on the tibial plateau and a line drawn at 90 degrees to the tibial axis, Fig. 2. The tibial plateau line is relatively easy to draw, irrespective of the imaging modalities. However, the landmarks for the longitudinal tibial axis can vary significantly depending on imaging modality.

Variants Used to Measure Longitudinal Tibial Axes

There was significant variation in the longitudinal axes used to calculate PTS. Five different axes were noted; the anterior tibial cortex (ATC), posterior tibial cortex (PTC), fibular shaft axis (FSA), central tibial axis (CTA) and proximal

tibial axis (PTA) [4, 27]. A description is provided in Table 3 as well as a pictorial reference in Fig. 3. Depending on which of these axes is chosen, the measurement of PTS can differ by more than 5° [4, 28]. Yoo et al. used lateral radiographs of the whole tibia to compare these different axes to the mechanical axis. They demonstrated that the proximal tibial axis was the closest with a mean slope of 10.8° compared to 10.6° [27].

Dejour described a method [29]. By marking the midpoint of the tibia at the level of the tibial tubercle as well as 10 cm distal to this, the two points are then connected to give the axis. This roughly correlates to 2 central points 5 and 15 cm [5], and is one of the most common interpretations of PTA as per our review [3, 9, 12, 13, 19, 33].

Various techniques have been described to define the PTA on MRI scans. Hudek et al. described a method utilising the centre of two circles in the proximal tibia to define the PTA. The proximal circle touches the joint surface, anterior and posterior cortices. The distal circle touches the anterior and posterior cortices with centre placed on the circumference of the proximal circle [30], Fig. 4.

Hudek et al. described the PTS on MRI measuring on average 3.4° less than lateral radiographs [34] Fig. 5 demonstrates this difference, by comparing Hudek's et al. method to Dejour's method of measuring proximal tibial axis using two landmarks at approximately 5 and 15 cm distal to the joint on an MRI.

Table 1 Quality assessment of all included articles using MINORS criteria

Author	Year	Journal	Evidence	Study design	MINORS Score
B Beynnon et al. [4]	2014	Am J Sports Med	III	Case-control	22 (C)
S Bisicchia et al. [5]	2017	J Orth Traumatol	III	Cross sectional	15 (NC)
M Brandon et al. [6]	2006	Arthroscopy	III	Case-control	17 (C)
J Christensen et al. [7]	2015	Am J Sports Med	III	Case-control	20 (C)
D Dare et al. [8]	2015	AM J Sports Med	III	Case-control	23 (C)
H Dejour et al. [10]	1994	JBJS (Br)	III	Cross sectional	12 (NC)
N DePhillipo et al. [11]	2018	Am J Sports Med	III	Case-control	21 (C)
M. Faschingbauer et al. [13]	2014	KSSTA	III	Cross sectional	14 (NC)
A Grassi et al. [15]	2019	Arthroscopy	III	Case-control	22 (C)
H Han et al. [16]	2008	KSSTA	III	Cross sectional	12 (NC)
J Hashemi et al. [17]	2008	JBJS	III	Cross sectional	23 (C)
J Ho et al. [18]	2017	J Arthroplasty	III	Cross sectional	15 (NC)
R Hudek et al. [19]	2009	Clin Orthop Relat Res	III	Cross sectional	14 (NC)
V Jaecker et al. [20]	2018	Arch Orthop Trauma Surg	III	Case-control	22 (C)
E Karimi et al. [22]	2017	ABJS	III	Cross sectional	15 (NC)
M Khan et al. [23]	2011	Int J Orthop	III	Case-control	22 (C)
A Kiapour et al. [24]	2019	Am J Sports Med	II	Cohort	15 (NC)
V Kizilgoz et al. [26]	2019	Radiography	III	Case-control	21 (C)
C Lee et al. [27]	2018	Arthroscopy	III	Case-control	20 (C)
Y Li et al. [28]	2014	Am J Sports Med	III	Cross sectional	12 (NC)
M O'Malley et al. [31]	2014	Arthroscopy	III	Case-control	22 (C)
C Pangaud et al. [32]	2020	Orthop J Sports Med	III	Cross sectional	16 (NC)
L Stijak et al. [39]	2008	KSSTA	III	Case-control	20 (C)
A Su et al. [40]	2018	J Knee Surg	III	Case-control	23 (C)
S Utzschneider et al. [42]	2011	KSSTA		Cadaveric	14 (NC)
C Wahl et al. [43]	2012	JBJS	III	Cross sectional	21 (C)
J Webb et al. [45]	2013	AM J Sports Med	III	Case-control	16 (NC)
D Weinberg et al. [46]	2016	Am J Sports Med		Cadaveric	13 (NC)
J Yoo et al. [47]	2008	J Arthroplasty	III	Cross sectional	13 (NC)
K Yoon et al. [48]	2020	Arthroscopy	III	Cross sectional	12 (NC)
C Zeng et al. [49]	2014	KSSTA	III	Case-control	23 (C)
Y Zhang et al. [50]	2018	Knee	III	Cross sectional	13 (NC)
Y Zhang et al. [51]	2014	Medicine	III	Cross sectional	15 (NC)

C Comparative study and NC Non-comparative study

Table 2 Values of PTS depending on the imaging modality studied

	Xray	CT	MRI
No. studies	14	7	14
No. patients	2172	2410	980
Min (degrees)	1	-8	-6
Max (degrees)	21	17	14.5
Mean (degrees)	8.8	6.6	4.9

Rotation

Several authors have demonstrated that rotation of the tibia increases PTS measurement on lateral radiographs;

Weinberg demonstrated an increase of 1–2° with 10° of axial rotation in either direction [8] and Utzschneider et al. showed an increase of up to 3° with both 40° internal and external rotation [31].

Ethnic Origin, Sex and Age

The geometry of the proximal tibia and subsequently degree of PTS can be influenced by a series of genetic and environmental factors, such as ethnic origin, sex and age [5, 28]. Pangaud’s CT-based study demonstrated significantly higher mean PTS and medial PTS (1.9° and 3.2° higher, respectively) in Asian patients compared to Caucasian patients. There was no difference in lateral PTS

Fig. 2 Measurement of posterior tibial slope using mechanical axis on a lateral radiograph



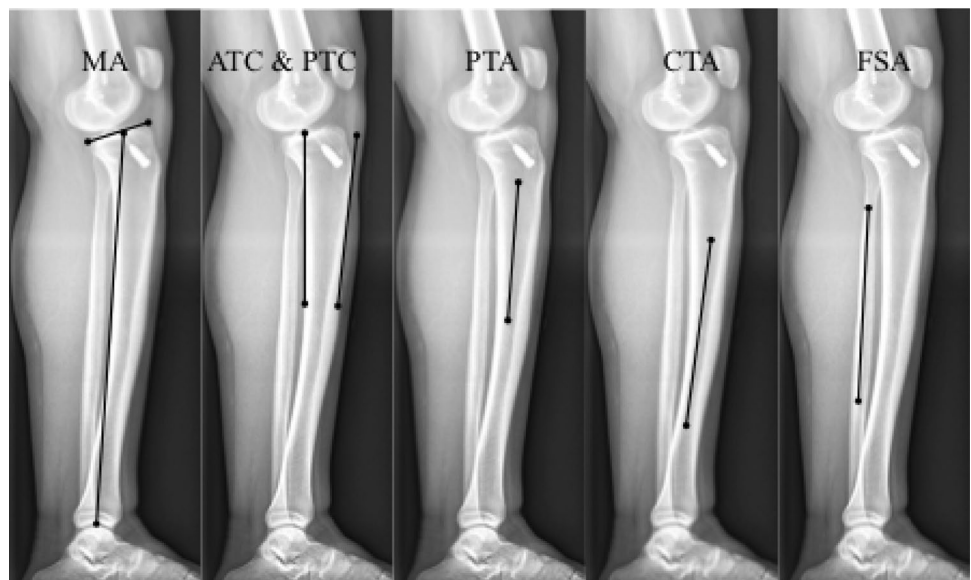
slope. Weinberg's CT study of over 1000 cadavers [8]. Demonstrated both a higher medial (2.9°) and lateral (2.1°) PTS in Black patients compared to Caucasian patients. This was repeated by Bisicchia's study demonstrating on lateral radiographs that Black patients had on average a 2.5° greater PTS compared to Caucasians [7]. However, differences in slope and ethnicity do not necessarily correspond directly to an injury, with one paper reporting six times the rate of ACL rupture in white female athletes compared to non-white [32]. This corresponds with the original statement that the pathophysiology of cruciate injury is multifactorial.

Pangaud reported a higher mean PTS in men compared to women [6]. This was contrasted by the work of Weinberg, who reported a lower mean PTS in men (6.8° compared to 7.5°) [8]. Bisicchia et al. noted in their White population there was a tendency for women to have higher PTS, as opposed to men having higher PTS amongst their Black patients [7]. This variation in the literature makes it difficult to attribute any reliable relationships between PTS, sex and ethnic origin.

Table 3 Variants used to measure longitudinal tibial axes

Variant name	Brief description of the axis
Mechanical axis	Line drawn down the mechanical axis of the tibia
Anterior tibial cortex	Line drawn down anterior tibia distal to the tibial tuberosity
Posterior tibial cortex	Line drawn down posterior tibia distal to the tibial tuberosity
Proximal tibial axis	Line drawn between mid-point of the tibia at the level of the tibial tubercle as well as point 10 cm distal to this
Central tibial axis	Line centred around the midpoint of tibial medulla extending to the midpoint of the medullary canal at approximately $\frac{1}{4}$ and $\frac{3}{4}$ of the length of the bone
Fibula shaft axis	Line drawn down the length of fibula shaft

Fig. 3 Different tibial axes, *MA* Mechanical Axis, *ATC* Anterior Tibial Axis, *PTC* Posterior Tibial Axis, *PTA* Proximal Tibial Axis, *CTA* Central Tibial Axis and *FSA* Fibular Shaft Axis



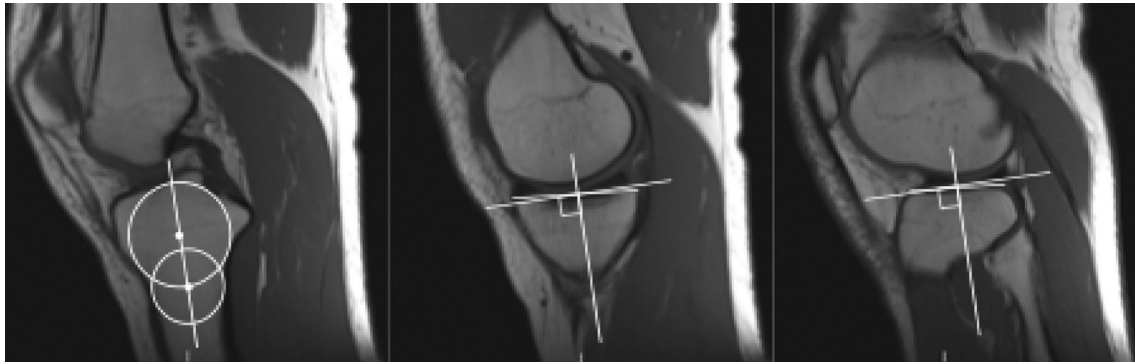


Fig. 4 Hudek's technique for axis calculation with medial and lateral PTS measurement

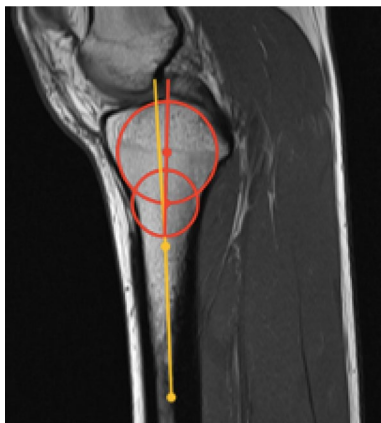


Fig. 5 Sagittal MRI comparing Hudek's technique and a method using two landmarks at approximately 5 and 15 cm distal to the joint to calculate the proximal tibial axis

The tibial slope is known to flatten as adolescents approach skeletal maturity, Dare et al. describe the PTS decreasing by between 0.3 and 0.4° per year in children [12]. In the elderly, it is universally accepted that the presence of degenerative changes increases radiological PTS [6, 33, 34]. Osteophytes formation can result in difficult interpretation of landmarks.

Medial vs Lateral

A total of sixteen papers directly compared medial and lateral PTS, shown in Table 4. Ten papers with a total of 2,924 subjects, described the medial PTS being greater than the lateral. Five papers with a total of 465 subjects described the opposite with lateral PTS being greater than medial.

PTS in Patients with Anterior Cruciate Injuries

Khan et al. [14], Stijak et al. [11] and Dare et al. [12] all showed in their MRI studies higher lateral PTS in patients

with ACL injuries compared to controls (4.6° vs 2.7°, 7.5° vs 4.4° and 5.7° vs 3.4°, respectively). DePhillipo et al. failed to demonstrate increased lateral PTS between non-contact (9.9°) and contact ACL injuries (9.1°) but both were significantly higher than controls (5.6°) [17]. Simon et al. suggested that increased lateral PTS relative to medial PTS generates an internal rotation of the tibia relative to the femur, resulting in ACL strain [35]. This theory is confirmed by Dare describing an increased ratio of lateral PTS/medial PTS in ACL injuries compared to controls [12]. Wahl described a smaller antero-posterior distance and increased convexity of the lateral plateau in patients with ACL ruptures [36]. Jaecker et al. described similar “at risk” morphological features, but almost universally seen in female patients with ACL injuries [19]. Beynnon et al. in their MRI study of 176 college athletes demonstrated a 21.7% increased risk of non-contact ACL rupture with each degree of increased lateral PTS in females but interestingly not in males [13].

Kiapour et al. demonstrated in their MRI study that patients with high lateral PTS at seven years post ACL reconstruction had increased graft laxity, poorer patient-reported outcome measures (PROMs) and a higher incidence of osteoarthritis [22].

Six papers directly compare controls and ACL rupture patients (Table 4) with a clear trend of increased PTS in patients with ACL rupture. The cumulative mean PTS for controls was 8.1°, compared to 9.9° in the ACL group. Su et al. was the only paper not to demonstrate a significant difference between ACL ruptures and control patients [37]. DePhillipo et al. used MRI with the proximal tibial axis, all other papers used lateral radiographs and the proximal tibial axis, however, there were slight variations in technique between authors.

Two papers compared PTS [2, 18] for successful ACL reconstructions to failed reconstructions (Table 5), and both demonstrated a higher PTS in those with re-injuries. The

Table 4 Comparison of Medial and Lateral PTS

Author	Country	Modality	Number of knees	Medial PTS	Lateral PTS	Medial–Lateral
Pangaud et al	France	CT	756	6.2	5.2	1
Ho et al	Malaysia	CT	100	11.3	10.9	0.4
Yang Zhang et	China	CT	160	8.4	7.6	0.8
Yijie Zhang et al	China	CT	157	8	5.6	2.4
Weinberg et al	USA	CT	1090	6.9	4.7	2.2
Han et al	South Korea	CT	133	10	8.4	1.6
Li et al	China	MRI	40	4.6	4.2	0.4
Yoon et al	South Korea	MRI	232	4.1	3.5	0.6
Karimi et al	Iran	MRI	132	7.8	6.9	0.9
Khan et al	South Korea	MRI	Controls 51	4.8	2.7	2.1
			ACLs 73	5.1	4.6	0.5
Stijak et al	Switzerland	MRI	Controls 33	6.6	4.4	2.2
			ACLs 33	5.2	7.5	-2.3
Jaecker et al	Germany	MRI	ACLR success 69	4.1	3.4	0.7
			ACLR failure 57	6.7	7.3	-0.6
Dare et al	USA	MRI	Controls 76	5.1	3.4	1.7
			ACLs 76	5.4	5.7	-0.3
Utzschneider et al	Germany	CT/MRI/X-ray	14	9.4	10	-0.6
Hudek et al	Switzerland	MRI	100	4.8	5	-0.2
Kiapour et al	USA	MRI	44	4.7	6.6	-1.9
Hashemi et al	USA	MRI	Men 22	3.7	5.4	-1.7
			Women 33	5.9	7	-1.1
Grassi et al	Italy	MRI	ACLR success 43	4.4	4.8	-0.4
			ACLR failure 43	9.4	11.4	-2

Table 5 PTS in patients with cruciate injuries

Author	Country	Modality	Number of knees	Axis	Mean PTS	PTS range
DePhillipo et al	USA	MRI	Controls 56	PTA	5.6	
			ACLs 112	PTA	9.5	
O'Malley et al	USA	X-ray	Controls 32	PTA	8.5	4.8–12.2
			ACLs 32	PTA	10.6	7.5–13.6
Kızılgöz et al	Turkey	X-ray	Controls 101	PTA	6.2	
			ACLs 92	PTA	7.6	
Brandon	USA	X-ray	Controls 100	PTA	8.5	
			ACLs 100	PTA	11.2	
Zeng et al	China	X-ray	Controls 73	PTA	9.4	
			ACLs 73	PTA	11.5	
Su et al	USA	X-ray	Controls 83	PTA	10.2	
			ACLs 123	PTA	9.7	
Lee et al	South Korea	X-ray	ACLR success 64	PTA	10.9	4.9–13.6
			ACLR failure 64	PTA	13.2	8.5–18.2
Webb et al	Australia	X-ray	ACLR success 131	PTA	8.5	
			ACLR failure 50	PTA	9.9	

failed ACL reconstructions had a cumulative mean PTS of 11.8° compared to 9.3° for successful reconstructions. Webb et al. [2] reported in their prospective study over 15 years; that 59% of patients with a PTS greater than 12° had re-injuries, compared to only 23% if under 12° [2]. Christensen et al. [3]. looked at lateral PTS on MRI for successful and failed ACL reconstructions. They found an increasing risk of re-rupture with increased lateral PTS [3] or a PTS 4° higher than the mean there was a five-fold increase of re-rupture increasing to a ten-fold risk for 6° higher than the mean [3].

Discussion

Recently there has been increased interest in the correlation between higher PTS and non-contact ACL injury as well reconstruction failure. However, there is very little consensus in the literature regarding measurement technique, normal values or an important cut-off after which osteotomy should be considered. In a recent article about managing increased PTS, Schillhammer highlighted the controversy, writing “where exactly does one draw the line...? An equally important question is how to draw the line” [38].

Very few authors have defined normal values or ranges; those that have base their figures on small studies with low levels of evidence. Lee [18] and Webb [2] both suggest 12° as the upper limit of normal when using lateral radiographs [2, 18], and Jaecker et al. suggested $> 10^\circ$ was abnormal when using MRIs [19].

Imaging Modalities

Lateral knee radiographs, whilst routinely used, make it difficult to plot a reliable line for the longitudinal tibial axis. They can also cause inaccuracy from femoral rotation as the tibia axially rotates during the “screw home” mechanism of terminal extension [39]. In addition, it is often difficult to accurately distinguish the medial and lateral compartments because of superimposition on X-ray [9, 30, 40]. We suggest a “gold standard” of a long lateral radiograph, including knee and ankle providing visualisation and allowing the true mechanical axis to be utilised.

CT has been shown to be the most accurate modality for PTS calculation [33, 41]. While the reference axes can be defined with high reproducibility and reliability [5, 28] it causes a higher exposure to ionising radiation and is not part of routine practice.

MRI scans have the limitation that very little proximal tibia is included, resulting in inadequate determination of the proximal tibial axis [42]. Hudek et al. reported a smaller PTS on MRI compared to lateral radiograph [30],

and we postulate that this is the result of the short proximal tibia segment on knee MRI scans. To reduce this error several authors advocate using a central point of the most distal tibia visible for PTA creation [12].

Due to these challenges to accuracy, our recommendation is to change scanning protocols to include at least 15 cm of the proximal tibia to allow accurate axis calculation or acquire good quality long lateral radiographs.

Tibial Longitudinal Axes

Variation in proximal tibial morphology exists, being influenced by a series of genetic and environmental factors, such as race, sex, age, and lifestyle [5, 28]. Consequently, several different axes have been suggested and compared by authors [4, 5, 27, 28, 31, 33]. The proximal tibial axis (PTA) with central reference points at 5 and 15 cm from the tibial joint line appears to correlate closest to the true mechanical axis of the leg.

Tibial Plateau Landmarks

The geometry of the articular cartilage has been shown to be significantly different from the underlying subchondral bone [12]. It is the cartilage that represents the functional part of the tibiofemoral articulation, and arguably should be included in PTS measurement [12]. For this reason, some have advocated using the meniscal-chondral junction to define the plateau angle. Jenny et al. in their cadaveric study demonstrated that the posterior meniscal horn is much thicker than anterior horn, this resulted in “meniscal” slope being 6° less than bony slope [43], effectively reducing the PTS. Feucht et al. in their systematic review suggested using the superior meniscal border measure a ‘functional slope’ [44]. However, measuring the meniscus may be unreliable given it can be highly mobile. The meniscus may also be deficient following injury or resection, particularly in revision ACL patients.

Biomechanics and Anatomy

During weight bearing the posterior inclination of the tibial plateau creates a shear force that results in anterior tibial translation. Shelbourne et al. used a computer model to demonstrate that increasing the PTS results in increased tibial shear force and anterior tibial translation [45]. The clinical paper by Dejour and Bonnin [29] reported that for every 10° increase in PTS there was a 6 mm increase in anterior tibial translation during single leg stance [29]. Consequently, an increased PTS puts higher forces through the ACL resulting in a higher chance of non-contact ACL rupture. This has been confirmed by multiple authors demonstrating a

correlation between increased PTS in ACL rupture [2, 10, 15, 42, 46], also translates to an increased risk of graft failure following ACL reconstruction [[2, 3, 18–22, 47].

Patients with ACL ruptures have been shown to have shallower medial tibial plateaus, resulting in less constraint of the femoral condyle and increased tibial translation [14, 22]. During knee flexion, there is larger anterior tibial translation laterally and the tibia internally rotates around the concave medial pivot. This tibial internal rotation further puts strain on the ACL, leading several authors to suggest the PTS of the lateral plateau is of greater importance than the medial [11–14, 22]. The pivot-shift represents subluxation of the lateral plateau and increased PTS has been associated with increased pivot-shift grades [10].

Use of Slope Changing Osteotomy

Small case series exist to support the use of slope-changing osteotomy in revision ACL surgery. Webb et al. [2] suggest osteotomy in patients with a PTS greater than 12°. This concurs with Dejour et al. [18], who report a case series of 9 patients with no re-ruptures at a minimum of 2 years follow-up after reducing mean PTS from 13.3° to 4.4° [23]. Similarly, Sonnery-Cottet et al. [24] reported a series of five ACL revision cases reducing their PTS on average from 13.6° to 9.2°, also reducing mean anterior translation by 2.8 mm [24]. When looking at PCL reconstructions Bernhardson et al. recommended slope-increasing osteotomy as an adjunct to PCL reconstruction if the slope was less than 6°[48]. There is no consensus on the absolute value of PTS to correct to when performing slope-changing osteotomy.

There were several limitations to this systematic review. The included studies were of lower-level evidence, all being apart from one being level 3. Some included studies were only of a fair score using the MINORS quality assessment tool. All studies were retrospective. Duration of follow-up differed greatly with Webb's series being the sole study with long follow-up at 15 years [45]. There was significant heterogeneity between studies, particularly relating to the methods of PTS measurement and imaging modalities. This variation prevented meta-analysis. However, the search algorithm was robust and followed the PRISMA guidelines. A large amount of data was extracted from 33 studies, allowing for useful conclusions to be made.

Conclusion

To calculate “normal” values for PTS a standardised methodology must exist. Typically short lateral radiographs and MRI scans are the most frequently used imaging modalities for cruciate surgery. Therefore, an ideal method of measuring PTS should consider this and be reliably transferable

between the two. The proximal tibial axis has been shown to be the closest surrogate to the true mechanical axis and should, therefore, be adopted for regular use, ideally with two central reference points at 5 and 15 cm from the joint line.

Based on the available literature normal ranges of 6–12° using the proximal tibia axis at 5 and 15 cms below the joint. We cautiously suggest 12° as a value to consider slope-reducing osteotomy for revision ACL reconstruction.

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Data availability Not applicable.

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Standard Statement This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed Consent For this type of study informed consent is not required.

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