ORIGINAL ARTICLE

Sagittal Plane Assessment in Deformity Correction Planning: The Sagittal Joint Line Angle

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Abstract

Aim: Evaluate the validity of a recent approach to calculate the knee flexion or extension contracture contributing to the overall sagittal deformity using the sagittal mechanical axis angle (SMAA) for the overall alignment assessment and sagittal joint line angle (SJLA) for soft tissue contribution. The methods of evaluating these angles and their clinical applications are discussed.

Materials and methods: In total, 107 normal limbs met the criteria and were divided into two groups: skeletally mature and immature. Sagittal alignment was evaluated using the Bone Ninja iPad application, and the posterior distal femoral angle (PDFA), posterior proximal tibial angle (PPTA), SMAA and SJLA were recorded.

Results: In skeletally immature patients, mean SJLA was 13.46° [standard deviation (SD), 4.55°], and in mature patients, it was 16.91° (SD, 2.948°). The PDFA and PPTA were consistent with previously published measurements.

Conclusion: The SJLA method is a practical way to quantify the soft tissue contribution and degree of contracture. It can also be used for monitoring deterioration or improvement of knee range of motion during lengthening or physical therapy.

Clinical significance: All patients in this study presented to our clinic with symptoms on the contralateral side. This, in addition to the retrospective nature, was a limitation in our study.

We recommend a validity study to compare our SJLA method to the classic anterior cortical line angle (ACL) method in addition to an inter-observer and intra-observer reliability study for the SJLA. We also recommend a study on completely normal asymptomatic subjects to better standardise the angle measurements in skeletally immature patients at different ages.

Keywords: Deformity correction, Deformity planning, Knee, Range of motion, Sagittal mechanical axis, Soft tissue contractures.

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Introduction

Preoperative planning is essential before any successful orthopaedic surgical intervention. Failing to plan is planning to fail.[1,2] Many studies have demonstrated not just the importance but also the methods of preoperative planning in several fields, including (but not limited to) fracture, arthroplasty and deformity surgeries.[2–6] The significance of this step in surgical treatment is also supported by the development of several computer software programmes for preoperative templating and planning.[7,8]

It is crucial to evaluate sagittal plane deformities and correct them when necessary, as they may cause harm to knee joint dynamics.[9–12] Deformities in this plane are more likely to go unnoticed and uncorrected, largely a result of two reasons. First, they tend to be more tolerable to patients because they occur within the plane of motion. Second, surgeons who do not routinely deal with deformity cases may only look at the frontal plane view. It may be true that sagittal plane deformities are less common than their frontal plane counterparts, but due diligence should lead the surgeon to look at both planes. It is worth noting that the remodelling potential in the sagittal plane is relatively better, particularly in the paediatric population.[13] Although it has been suggested that sagittal deformity is both more well-tolerated and remodels more readily, this has not been strictly evaluated or proven. Some long-term follow-up studies demonstrate significant risk of arthritis secondary to sagittal deformity.[11,12,14] It is possible that sagittal deformity is quite significant but remains silent until early degenerative disease occurs.

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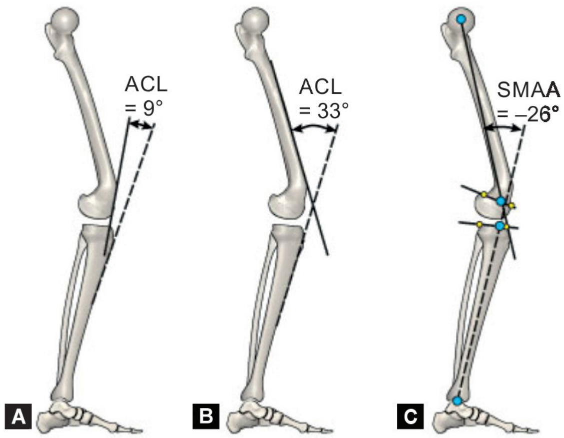
Standard joint-orientation angles of a well-aligned limb in the frontal plane have been well-studied and are widely accepted.[15,16] However, little published data exist about the standard angles in a sagittal plane.[17] Historically, the ACL was used in conjunction with PDFA and PPTA as a proxy to ascertain the knee soft tissue



Figs 1A to C: (A and B): A consistent ACL measurement can be difficult to define. Even though each panel shows the same deformity, the ACL measurement may vary depending on how one draws each anterior cortical line. This is particularly evident in metabolic bone disease. (C) SMAA uses anatomic landmarks so that it can be drawn consistently. © 2021, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore. Used with permission

contribution—either flexion or extension contracture—to the overall sagittal malalignment. We have found inconsistency when drawing the lines in our experience with this method, making it unreliable (Fig. 1). We evaluate the validity of a recent approach by McClure et al.[18] to calculate the knee flexion or extension contracture contributing to the overall sagittal deformity, using what is called SMAA for the overall alignment assessment and SJLA for soft tissue contribution.

The SJLA is formed between the sagittal distal femur and proximal tibia joint lines of a maximally extended knee. This is similar to the frontal plane's joint line convergence angle (JLCA), which occurs between the frontal plane's distal femur and proximal tibia joint lines and is used to evaluate the laxity in the knee collateral ligaments.[15,16] Normal PDFA range is 79–87°, and normal PPTA range is 77–84°; we hypothesize that a normal SJLA would range between 9° and 24°, with 16° being the median. In this study, we test this hypothesis, assess if 16° is the mean SJLA and demonstrate how this angle can be utilised in sagittal plane evaluation and deformity correction planning.

Materials and Methods

Institutional review board approval was obtained prior to conducting this observational, retrospective study occurring at a single centre. Clinical data were reviewed from >300 patients' electronic medical records and long-leg lateral X-rays from 2012 to 2019. The study included either limbs from patients with no lower limb abnormalities or otherwise the contralateral normal side of patients who presented with various unilateral pathologies. The exclusion criteria were the presence of any deformity in any plane, previous surgeries, or improperly rotated X-rays that precluded accurate angle measurements. If none of these exclusions were present, and if the condyles superimposed perfectly, the X-rays were granted inclusion. In total, 107 limb X-rays met our criteria.

X-rays were obtained from our picture archiving and communication system, converted to JPEG, and evaluated using the Bone Ninja application (International Center for Limb Lengthening, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore, Baltimore, MD) for iPad (Apple, Cupertino, CA). Statistical analysis was conducted with SPSS v17.0 (IBM, Armonk, NY). A p-value <0.05 was considered statistically significant.

Subjects were divided into two groups: skeletally mature and immature, with group assignment based on physis closure. We evaluated the long leg lateral X-rays, including measuring the SMAA, PDFA, PPTA, and SJLA. All angles were measured by the senior author PKM. Some X-rays were taken with slight knee flexion and not the ideal maximum knee extension, or had a normal variant of slight knee hyperextension. For these, we would note an adjusted SJLA which we determined by subtracting the SMAA from the SJLA. For example, a patient with an SJLA of 16° and an SMAA of 2° (2° of hyperextension) will have an adjusted SJLA of 14°.

Measuring the Angles

A lateral hip-to-ankle standing X-ray with the knee in maximum extension is required to begin. To ensure accurate measurements of the PDFA, PPTA and SJLA, the X-ray beam should be centred on the knee with the planted limb 10° externally rotated for a perfect lateral view.

The sagittal plane-modified femoral mechanical axis can be drawn from the centre of the femoral head to the 1/3 point on the length of the distal femoral joint line from the anterior cortex. The PDFA is the angle formed between this line and the distal femoral joint line (Fig. 2). The PDFA quantifies the femur's contribution to overall alignment.

The sagittal plane-modified tibial mechanical axis can be drawn from a point 1/5 of the proximal tibial joint line from the anterior cortex to the centre of the distal tibial joint line. The PPTA is the angle formed between this line and the proximal tibial joint line (Fig. 2). The PPTA quantifies the tibia's contribution to overall alignment.

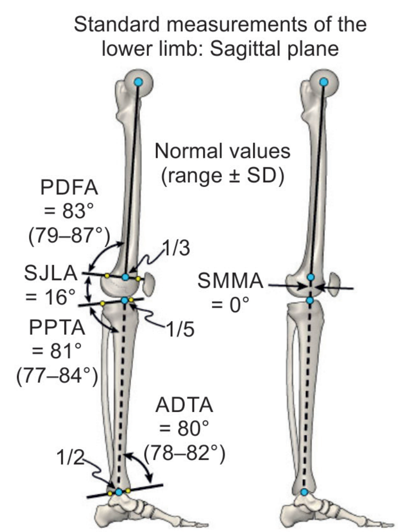


Fig. 2: Posterior distal femoral angle is the angle between the femur mechanical axis and distal femur joint orientation line. Posterior proximal tibial angle is the angle between the tibia mechanical axis and proximal tibia joint orientation line. Sagittal mechanical axes angle is the angle between the femur mechanical axis and tibia mechanical axis. Sagittal joint line angle is the angle between the distal femur joint orientation line and proximal tibia joint orientation line. © 2021, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore. Used with permission

The sagittal distal femoral joint line is drawn from the most anterior point of the physeal scar line (open physis in skeletally immature patients) to the most posterior. Next, the sagittal proximal tibial joint line is drawn from a point on the anterior part of the tibia plateau to a point on the posterior part of the plateau. The SJLA is the angle formed by these two lines (Fig. 2). The SJLA quantifies the soft tissue contribution to overall alignment.

The SMAA is the angle formed between the tibial and femoral mechanical axes (Fig. 2). The SMAA represents the overall position of the knee joint (neutral, flexion or hyperextended).

Analyzing the Sagittal Plane

An overall flexion contracture deformity could be attributed to a soft tissue knee flexion contracture, bony procurvatum deformity or both. In fact, there could be a compensatory extension contracture of the knee that is not enough to overcome the bony procurvatum deformity and neutralise the sagittal axis. To be accurate and consistent, systematic analysis is needed.

A sagittal mechanical axis line is drawn from the centre of the femoral head to the centre of the ankle. This line should be anterior to the knee centre of rotation and within the confines of the distal femur. This allows the knee to lock and avoid quadriceps fatigue. A line that is posterior and outside the confines denotes a flexion deformity. A line that is anterior and outside the confines of the distal femur indicates an extension deformity or hyperextended knee.

A PDFA >83°, a PPTA >81° and an SJLA >16° can each cause an extension deformity. A (+) sign is added for extension deformities. A PDFA <83°, a PPTA <81° and an SJLA <16° can all cause a flexion deformity. A (–) sign is added for flexion deformities (Fig. 3).

If a limb's sagittal axis is neutral, the SMAA should be 0° (± 2°). If the limb is not neutral and a deformity is present, the SMAA will be apparent in an angle formed by the femoral and tibial mechanical axes. This angle is given the sign (–) in flexion contracture and (+) in extension contracture.

The next essential phase is to analyse from where this deformity originates. An following equation can be used:

SMAA = Soft tissue contribution + total bony deformity

If the amount of bony contribution is equal to the overall deformity SMAA, then there is no soft tissue contribution. If the bony contribution is not equal to the overall deformity SMAA, then there is a soft tissue contribution to the overall deformity.

Soft tissue contribution = SMAA – total bony deformity

Sagittal Joint Line Angle Clinical Applications

The SJLA can be used to check the calculation: SMAA = Soft tissue contribution + total bony deformity. An example follows and is shown in Figure 4.

A patient has an overall 26° of flexion contracture (SMAA= –26°), a PDFA of 63° (femur procurvatum 20°, normal PDFA = 83°) and a PPTA of 81° (normal PPTA = 81°).

SMAA (–26) = Soft tissue contribution + total bony deformity (–20 + 0)

Soft tissue contribution = –26 – (–20) = –26 + 20 = –6°

This means that the soft tissue contribution is –6° (6° flexion contracture in the knee). Thus, when checking the SJLA in this patient (normal SJLA 16°), it should measure 16 – 6 = 10°.

Another useful way to utilise the SJLA clinically is by measuring it on the normal contralateral limb from a lateral knee X-ray in maximum extension. This can be compared to the SJLA on the affected side with the same lateral knee X-ray in maximum extension. For example, a patient with an SJLA of 14° on the unaffected normal side and 8° on the affected side means they have 14 – 8 = 6° of soft tissue flexion contracture.

An additional clinical application is monitoring worsening or improvement in knee motion after a recorded baseline. For example, a patient with a 6° soft tissue knee contracture is undergoing physical therapy. Serial SJLA measurements in maximum knee extension during the course of therapy can be an accurate assessment tool. Similarly, if a patient is undergoing

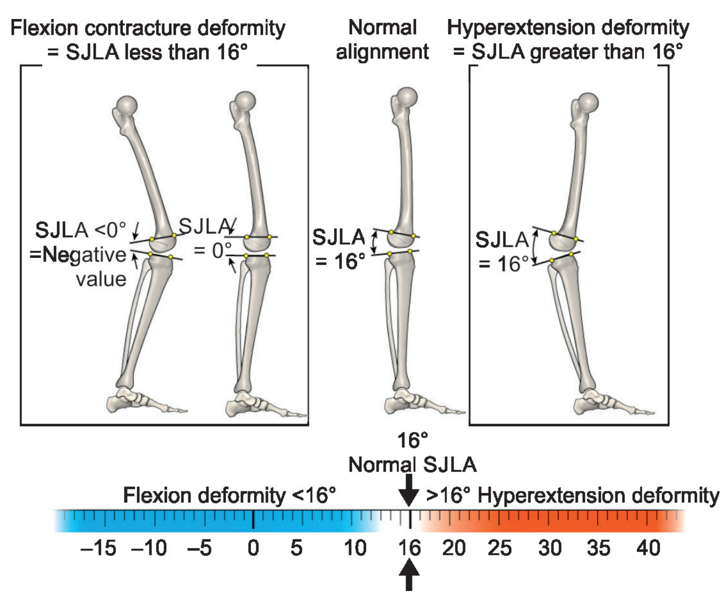
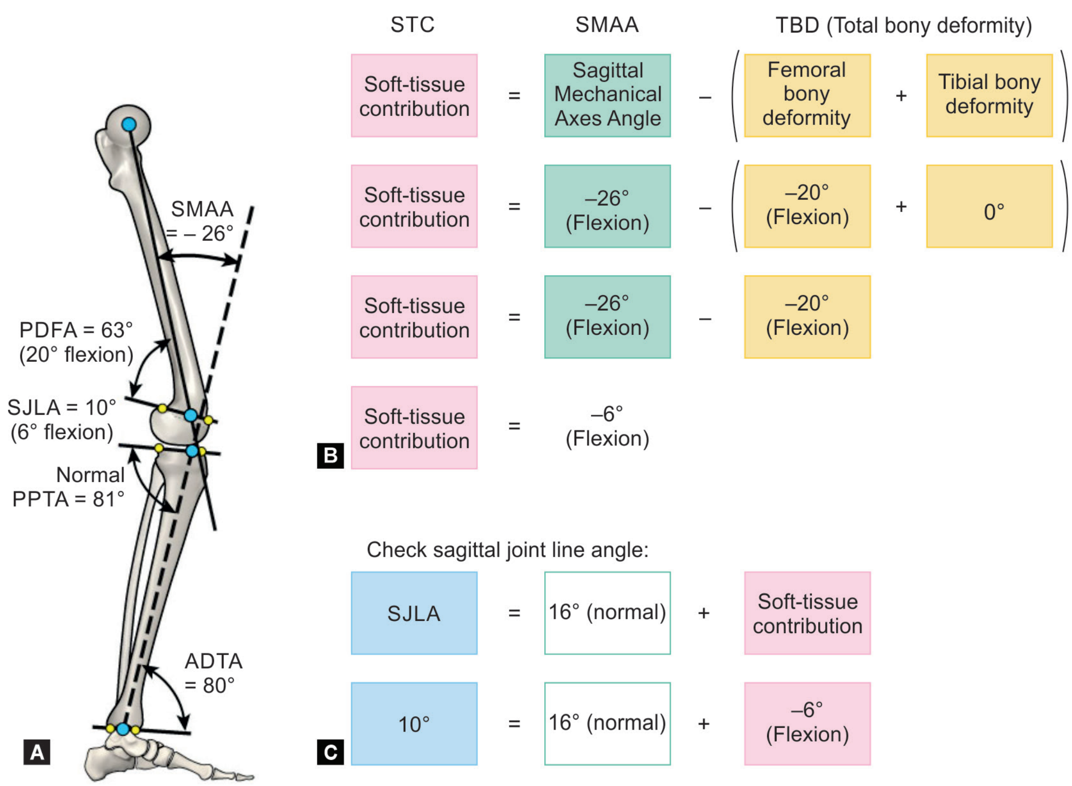
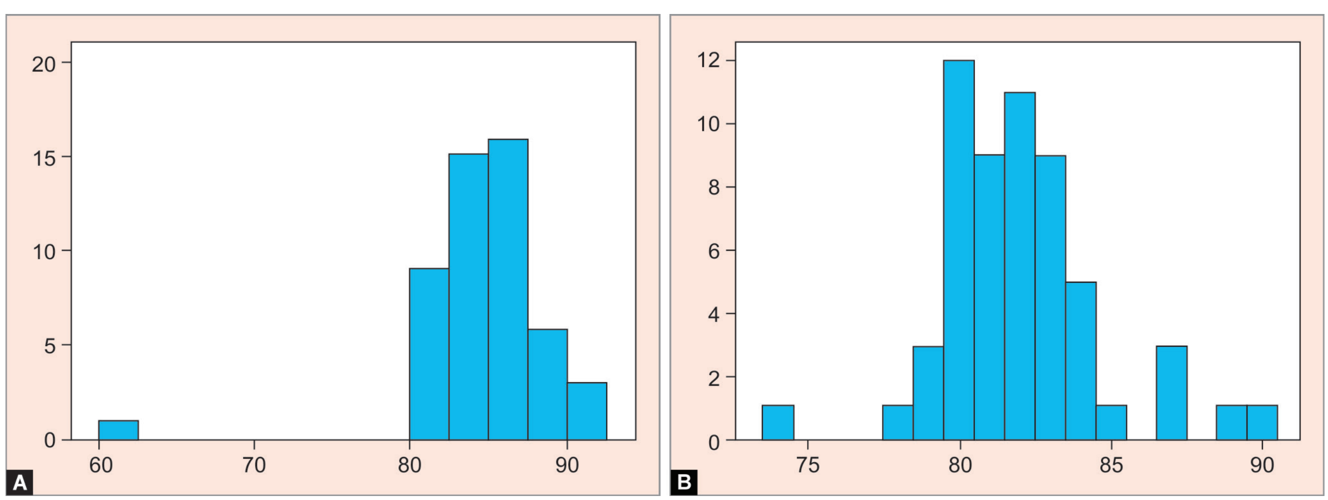


Fig. 3: A sagittal joint line angle less than 16° indicates flexion deformity while an SJLA greater than 16° indicates hyperextension deformity.



Figs 4A to C: Example of sagittal plane bony and soft tissue deformities. The measurement of the SMAA shows that there is a flexion deformity of 26° that is caused by a distal femoral deformity of 20° flexion with an additional soft tissue contribution. The tibia is normal [PPTA = 81° and anterior distal tibial angle (ADTA) = 80°], and the patient does not have any ankle complaints. © 2021, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore. Used with permission



Figs 5A and B: Posterior distal femoral angle among (A) immature and (B) mature patients

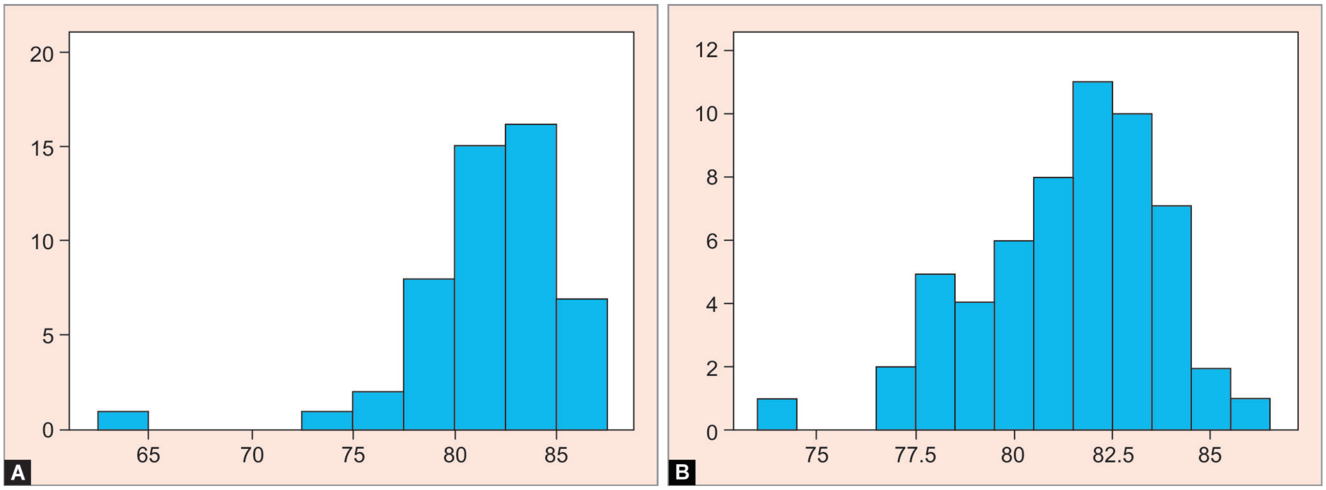
lengthening, we can detect early radiographic signs of developing a flexion contracture (decreasing SJLA from baseline).

Results

In total, 107 limbs were reviewed, 50 of which were skeletally immature (47.7%) and 57 of which were mature (53.3%). Overall mean PDFA was 83.07° (SD, 3.75°). In skeletally immature patients, mean PDFA was 84.32° (SD, 4.41°), whereas, in mature patients, it was 81.96° (SD, 2.639°) (Fig. 5). Overall mean PPTA was 81.4° (SD, 3.189°). In skeletally immature patients, mean PPTA was 81.44° (SD, 3.955°), and in mature patients, it was 81.37° (SD, 2.358°) (Fig. 6). The mean-adjusted SJLA in all 107 patients was 15.3° (SD, 4.142°) (Fig. 7). In skeletally immature patients, mean SJLA was 13.46° (SD, 4.55°), and in mature patients, it was 16.91° (SD, 2.948°) (Fig. 8).

Discussion

In our study, the PDFA and PPTA overall means were 83.07° and 81.4°, respectively. These findings are consistent with previously



Figs 6A and B: Posterior proximal tibial angle among (A) immature and (B) mature patients

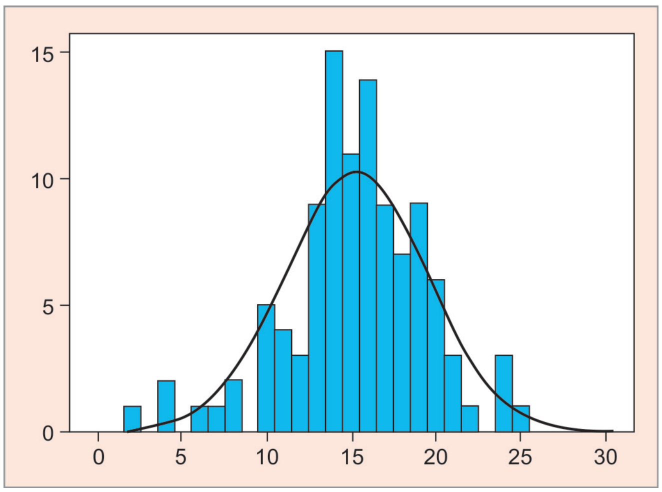


Fig. 7: Distribution of the adjusted SJLA among all patients. (X axis: adjusted SJLA, Y axis: frequency)

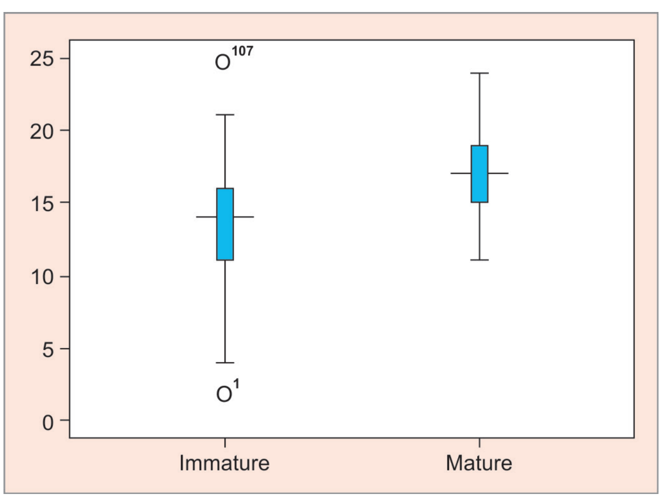


Fig. 8: Adjusted SJLA mean comparison between mature and immature patients

published measurements.[15] These standard measurements were based on a study on completely asymptomatic adult patients. In our study, the subjects were a combination of skeletally mature and immature patients with pathology on the contralateral side.

Solomin et al.[17] studied 23 individuals with no deformities in any plane and, based on computed tomography (CT), found that the lower limb mechanical axis in the sagittal plane intersects and divides the joint line of the distal femur to a 43.8 ± 7.9% segment anteriorly and 56.2 ± 7.9% posteriorly (i.e., 2/5 anteriorly and 3/5 posteriorly). This differs from the research by Standard et al.[15] wherein the anatomical axis of the distal femur divides the joint line to 1/3 anteriorly and 2/3 posteriorly. They found that the mechanical axis line extends to divide the proximal joint line of the proximal tibia and divides it into a 23.3 ± 8.8% segment anteriorly and 76.7 ± 8.8% posteriorly (1/5 anteriorly and 4/5 posteriorly). Standard et al.[15] also recorded the PDFA as 81.1 ± 3.95° and the PPTA as 81.6 ± 2.8°.

When focusing on the skeletally immature patients, the mean PDFA was 84.32° and the mean PPTA was 81.44°, indicating that standard measurements for skeletally immature patients need to be customised. The mean SJLA in skeletally immature patients was 13.46° (SD, 4.55°). This could be attributed to the differences in angles measured between different ages in the skeletally immature group. We experienced some difficulty drawing the lines in the immature group, which may have created inconsistency when measuring the PDFA, PPTA and SJLA. We recommend an inter-observer and intra-observer reliability study to confirm this.

The ACL method is commonly used to quantify the overall alignment in the sagittal plane.[16] In our opinion, this method is unreliable because there are different ways a surgeon might draw the ACL, and moreover, it can only be used in a portion of sagittal deformities (Fig. 1). Additionally, the ACL does not take into consideration the proximal femur and distal tibia.[15] By moving the points that define a line further apart (femoral head and 1/3 instead of best fit of anterior rule of distal 1/3), the variability in line selection decreases.

Vilenskiy et al.[19] reviewed CTs in 23 adult patients with nondeformed femurs and demonstrated that the angle between the proximal femoral anatomical and mechanical axes on the sagittal plane is 10.2° ± 2.4°, and the angle between the femoral neck and the mechanical axis of femur in the sagittal plane is 16.0° ± 7.6°. This is a practical way of drawing the proximal mechanical axis of a deformed femur in the sagittal plane when planning correction. This study focused on femur planning rather than the overall sagittal plane assessment, particularly the joint contribution. The absence of a torsional deformity on the femur was a prerequisite in this study.

Jud et al.[20] found that a rotational osteotomy of the femur closer to the knee, as opposed to the hip, exerts more overall sagittal axis deviation. It was noted in our study that the anteversion and retroversion in the femur could affect the sagittal alignment. This observation needs to be studied to determine the effect of the femur neck version on the sagittal alignment, if any.

Conclusion

In contrast with the frontal plane, understanding the soft tissue contribution to the sagittal mechanical axis is more commonly relevant, and careful evaluation is essential when analysing and correcting a sagittal plane deformity.

The SJLA method we describe is useful when analysing sagittal plane deformities. Sagittal joint line angle analysis is a practical way to quantify the soft tissue contribution and degree of contracture. The SJLA can also be used for monitoring improvement or deterioration of knee range of motion during lengthening or physical therapy.

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