

# An MRI-based Study to Investigate If the Patella is Truly Centred between the Femoral Condyles in the Coronal Plane

Nihar S Shah<sup>1</sup>, James C Kyriakedes<sup>2</sup>, Raymond W Liu<sup>3</sup> 

## ABSTRACT

**Background:** An AP knee radiograph is considered adequate if the patella is centred between the femoral condyles. Our previous studies demonstrated a tendency for lateral patellar deviation on an AP view orthogonal to the posterior femoral condyles. However, findings were based on cadaveric samples limited by the lack of soft tissue effects on patellar positioning.

**Materials and methods:** After excluding those with deformity or damage to osseous or ligamentous structures, 106 knee MRI scans were randomly selected. Patellar centring was calculated as a percentage of total distal femoral intercondylar width and represented how lateral the centre of the patella is located with respect to the midpoint of the femoral condyles. Multiple regression analysis was performed to determine the relationship between patellar centring and age, gender, anatomic lateral distal femoral angle (aLDFA), medial proximal tibial angle (MPTA) and tibial tuberosity to trochlear groove (TT-TG) distance.

**Results:** There were 35 males and 71 females included in the study with a mean age of  $29 \pm 14$  years. Mean patellar centring was  $8 \pm 4\%$ . There was a statistically significant correlation between TT-TG distance and positive (lateral) patellar centring (standardised  $\beta = 0.36$ ,  $p < 0.01$ ). There were no associations between aLDFA and MPTA with patellar centring.

**Conclusion:** This study demonstrates that the patella is rarely perfectly centred and is usually positioned slightly laterally within the femoral condyles in an AP view orthogonal to the posterior aspect of the femoral condyles. The use of supine MRI scans makes this data relevant to a patient on the operating room table.

**Keywords:** Guided growth, Hemiepiphysiodesis, Ideal knee radiograph, Lateral deviation of patella, Orthogonal imaging, Patellar centring.

*Strategies in Trauma and Limb Reconstruction* (2022): 10.5005/jp-journals-10080-1561

## INTRODUCTION

Orthogonal radiographs are routinely used when planning deformity correction and performing intraoperative assessments. An appropriate AP radiograph of the knee is classically defined by centring of the patella between the femoral condyles at the distal aspect of the femur while an appropriate lateral view is defined by when the femoral condyles are superimposed.<sup>1</sup> These two images are conventionally accepted to be orthogonal to one another. Orthogonal imaging is crucial for deformity correction as it is used to both determine the type and degree of malalignment present and surgical plans for correction.<sup>2,3</sup>

Our initial investigation into patellar centring began after repeatedly observing that a 90° rotation of the fluoroscopy unit after taking an intraoperative lateral radiograph of the knee with the posterior femoral condyles overlapped did not produce an AP image with the patella centred between the femoral condyles and instead often resulted in a laterally deviated patella. To determine if the patella was in fact laterally deviated, we performed two studies demonstrating that the patella is laterally deviated in the trochlea of cadaveric adult and paediatric skeletons as well as clinical paediatric patients with genu varum and genu valgum.<sup>2,3</sup>

While these studies found that the patella was laterally deviated for their respective sample sets, they were limited by the lack of any soft tissues and positioning of the patella in the cadaveric studies and the presence of deformity in the clinical paediatric patients. The influence of soft tissue and anatomical alignment on patellar positioning has not been well established. In an attempt to address these limitations in our previous studies, we theorised

<sup>1</sup>Division of Pediatric Orthopaedic Surgery, Case Western Reserve University School of Medicine, Cleveland, Ohio, United States of America

<sup>2</sup>Division of Pediatric Orthopaedic Surgery, University Hospitals Cleveland Medical Center, Cleveland, Ohio, United States of America

<sup>3</sup>Department of Pediatric Orthopaedics, Rainbow Babies and Children's Hospital at Case Western Reserve University, Cleveland, Ohio, United States of America

**Corresponding Author:** Nihar S Shah, Division of Pediatric Orthopaedic Surgery, Case Western Reserve University School of Medicine, Cleveland, Ohio, United States of America, Phone: +3098307469, e-mail: nss86@case.edu

**How to cite this article:** Shah NS, Kyriakedes JC, Liu RW. An MRI-based Study to Investigate If the Patella is Truly Centred between the Femoral Condyles in the Coronal Plane. *Strategies Trauma Limb Reconstr* 2022;17(2):63–67.

**Source of support:** Nil

**Conflict of interest:** None

that studying MRIs of patients without pathology would provide more precise and generalised measurements of patellar position and its determinants.

The aim of this study is to determine where the patella is positioned in MRI imaging in relation to the centre of the femur at the knee in the axis of the posterior condylar line and if this positioning varies with anatomic parameters of tibial tubercle to trochlear groove (TT-TG) distance, aLDFA, MPTA or demographic factors of gender and age.

**Table 1:** Interrelator and intrarelator for the four measured parameters are shown here

	Interrelator	Intrarelator
Patellar centring	0.83	0.86
aLDFA	0.68	0.76
MPTA	0.69	0.79
TT-TG	0.92	0.86

All parameters showed good-to-excellent reliability for interrelator testing and excellent reliability for intrarelator testing

## MATERIALS AND METHODS

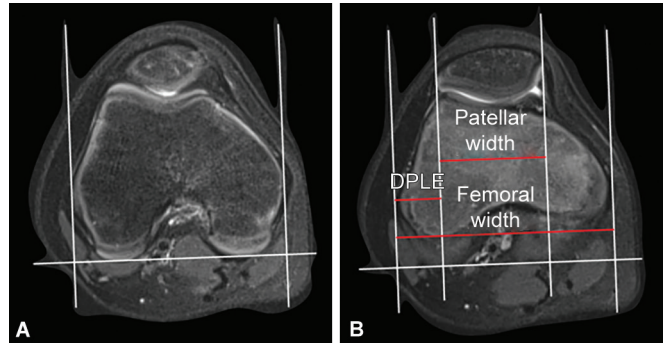
Institutional review board approval was granted for this retrospective chart review study. We queried our PACS database for MRIs of the knee for patients with images obtained between 2016 and 2018 for evaluation of pain or injury. MRIs were included if there was a lack of significant pathology. Exclusion criteria included cartilaginous or ligamentous trauma, trochlear dysplasia and obvious damage or deformity of osseous structures. In total, 106 knee MRIs were selected for the primary analysis. All measurements used for analysis were made by the primary author. Intrarelator intraclass correlation coefficient (ICC) values were calculated by having the primary author repeat measurements on a set of 20 samples for each variable. Interrelator ICC values were calculated by having two authors independently measure each variable on a set of 20 samples. Interrelator and intrarelator ICC values for each measurement were all good or excellent, as shown in Table 1. Following previously established recommendations, we considered an ICC of <0.4 to be poor, 0.4–0.75 to be fair to good, and >0.75 to be excellent.<sup>4</sup>

### Patellar Centring

All measurements were made on T2 axial images exported from PACS using ImageJ. Patellar centring was calculated as a percentage of total distal femoral intercondylar width and anatomically qualified how lateral the center of the patella is located with respect to the centre of the distal femoral condyles. A patellar centring value of zero represents a perfectly centred patella, while positive values indicate lateral deviation. The derivation of the equation used is shown below where distal patellar to lateral edge (DPLE) is the distance from the lateral patellar edge to the lateral condylar edge:

$$\begin{aligned}
 \text{Patellar Centring} &= \frac{\text{Position of Patella as Percentage of}}{\text{Width of Femur}} \\
 &= \frac{\text{Patella Centre Position}}{\text{Femoral Width}} \\
 &= \frac{\text{Centre of Femur} - \text{Centre of Patella}}{\text{Femoral Width}} \\
 &= \frac{\frac{\text{Femoral Width}}{2} - \left( \text{DPLE} - \frac{\text{Patellar Width}}{2} \right)}{\text{Femoral Width}}
 \end{aligned}$$

In order to obtain values for femoral width, DPLE and patellar width, two slices were selected from each MRI stack, one in which the distance between the condyles was perceived to be the largest and the one where the patellar width was the largest. Representative images of these two slices are demonstrated in



**Figs 1A and B:** Calculation of patellar centring. (A) The T2 axial slice in which the femoral condyles were widest is shown. A line perpendicular to the posterior aspect of the condyles was drawn. The widest portion of the condyles was then marked with lines perpendicular to this line; (B) These lines were superimposed onto the slice with the largest patellar width. Two lines marking the medial and lateral edges were drawn perpendicular to the posterior femoral condyle line. Patellar width, DPLE, and femoral width were measured as shown

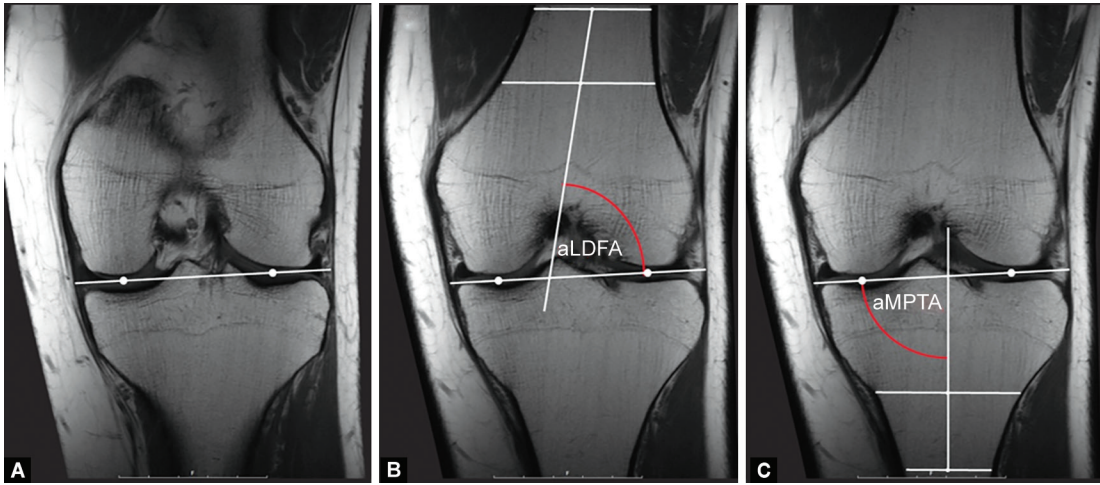
Figure 1. The orientation of all the measurements was set using a plane defined by the most posterior aspect of the condyles. This replicates our previous cadaveric studies in which a femur rested directly on a table while an AP image was taken. Two lines perpendicular to the posterior condylar line were drawn, one each at the most lateral and medial portion of each femoral condyle (Fig. 1A). These lines were then overlaid on the aforementioned patellar slice. Two lines were drawn perpendicular to the line indicating the floor to mark the lateral and medial edges of the patella (Fig. 1B). The image was then exported into ImageJ (NIH, Bethesda, Maryland). The measured femoral width, patellar width, and DPLE are shown in Figure 1B.

### Anatomical Angles

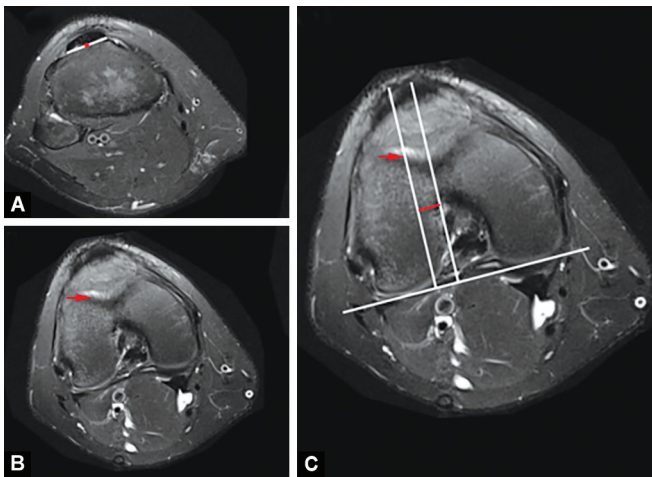
Anatomical angles of the femur and tibia were measured to determine if associations in previous studies<sup>2,3</sup> could be recreated with MRI. T1 coronal MRI slices were used for all measurements. First, the slice that best demonstrated the joint line between the femur and tibia was identified (Fig. 2A). This joint line was then superimposed onto the slices that represented the anatomy of the femoral and tibial shafts. In most cases, two different slices were used for the femur and tibia, with the cut chosen to best represent the anatomical axis. Two parallel lines were drawn across the metaphysis and the anatomical axis was drawn through the midpoint of these lines (Figs 2B and C). We then measured the aLDFA and the anatomical MPTA as demonstrated in Figures 2B and C.

### TT-TG Distance

Tibial tuberosity to trochlear groove distance was measured as described by Pandit et al., using the PACS measurement tool.<sup>5</sup> Briefly, the midpoint of the tibial insertion of the patellar tendon was identified on the most proximal axial T1 slice where the tendon could be seen in complete contact with the tibia (Fig. 3A). A cursor was placed at this point and then the axial slice where a complete cartilaginous trochlear groove was found (Fig. 3B). A reference line along the posterior femoral condyles was drawn in this image. Two perpendicular lines were then drawn; one to the midpoint of the trochlear groove and one to the cursor marking the tibial insertion. The distance between those two perpendicular lines was measured as the TT-TG distance (Fig. 3C).



**Figs 2A to C:** Calculation of the anatomical angles. (A) The T1 coronal slice is showing the cartilaginous joint line; (B) The anatomical axis of the femur was created by drawing a line through the midpoint of two parallel lines above the metaphyseal flare. The aLDFA is measured as the lateral angle between the joint line and anatomical axis; (C) Similarly, the anatomical axis of the tibia and the MPTA created by the medial angle between the joint line and anatomical axis



**Figs 3A to C:** Measurement of TT-TG distance. (A) The most proximal T1 axial MRI slice in which the patellar tendon can be seen in complete contact with the tibial tubercle was found; (B) The midpoint of the insertion was marked and superimposed onto the most distal slice in which a complete cartilaginous trochlear groove; (C) A line was drawn tangentially to the posterior aspect of the condyles. Two perpendicular lines to this line were drawn; one intersecting the midpoint of the trochlear groove and one at the cursor marking the midpoint of the patellar tendon. This distance is the TT-TG distance shown in red

**Statistical Analysis**

Comparisons between aLDFA, MPTA and TT-TG distance were assessed relative to patellar centring value using multiple regression analysis to determine the effect of anatomical alignment and soft tissue structures of the femur and tibia on the location of the patella within the femoral condyles. Age and gender were included in the statistical analysis to determine the impact of demographic factors. Prior to analysis, a Shapiro–Wilk test was performed and Q–Q plots were examined. The data were found to sufficiently meet the assumptions of normalcy, and the decision was made to proceed with the parametric analysis. A separate multiple regression analysis was performed on patients aged 17 years and under. In the regression analysis, multicollinearity was assessed as

**Table 2:** Standardised beta and significance values for the multiple regression analysis performed on all 106 patellae studied with patellar centring as the dependent variable

	Standardised $\beta$	Sig.
Gender	0.11	0.262
Age	-0.063	0.508
aLDFA	-0.1	0.304
mPTA	-0.024	0.798
TT-TG	0.359	<0.001*

Increased TT-TG showed significant association while all the other parameters were not significant. Statistical significance ( $p < 0.05$ ) is denoted with an asterisk

negative based on VIF <10 and coefficient tolerances >0.1, normal probability plots of the regression standardised residual were inspected for normality, scatterplots of the standardised residuals were inspected for homoscedasticity, and the lack of any undue influence from outliers was confirmed with a Cook’s distance <1. Multivariable regression analyses were performed using SPSS version 24 (Internal Business Machines Corporation, Armonk, New York, USA) using patellar centring as the dependent variable.

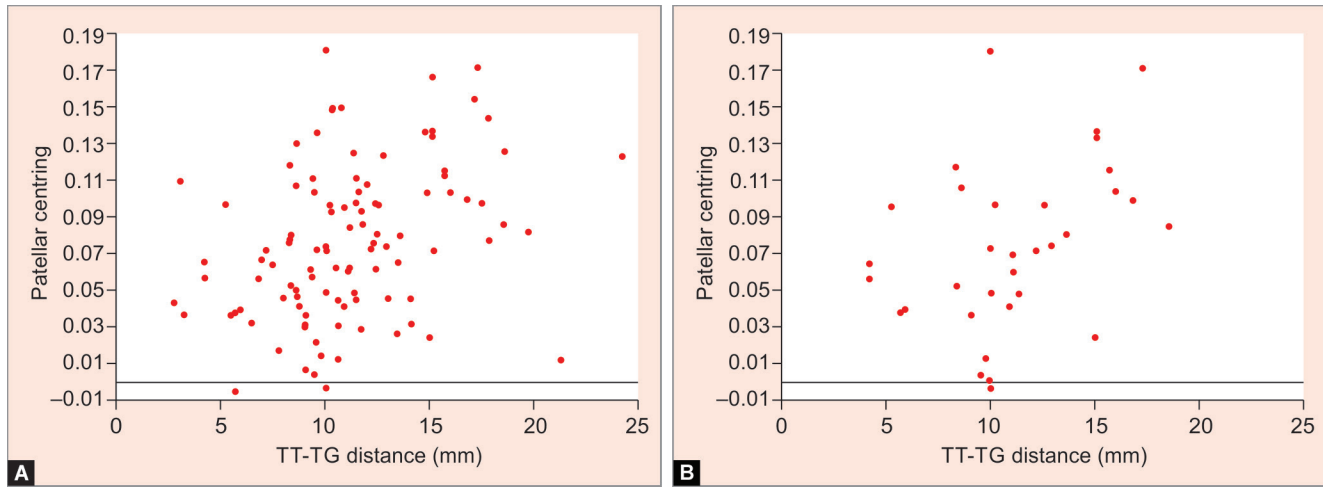
**RESULTS**

The mean age for the 106 patellae studied was  $29 \pm 10$  years, with 71 females and 35 males. Patellar centring was  $8 \pm 4\%$ , indicating that on average the patella was laterally deviated from the centre of the femoral condyles. Average aLDFA was  $81 \pm 2^\circ$  and average MPTA was  $87 \pm 2^\circ$ . Average TT-TG distance was  $11 \pm 3.9$  mm.

Table 2 shows the standardised beta values used to determine the influence of anatomic and demographic parameters on patellar centring for the entire sample set. Only TT-TG distance showed a significant  $p < 0.05$  with a standardised beta value of 0.359. Figure 4A shows the relationship between increasing TT-TG distances and the position of the patella.

A separate analysis was performed on the paediatric patellae. The mean age for these 32 patellae was  $15 \pm 2$  years. The demographic breakdown included 16 females and 16 males.





**Figs 4A and B:** Scatterplot showing relationship between TT-TG distance and patellar centring. Patellar centring is defined as the position of the midpoint of the patella relative to the total width of the femoral condyles with positive values indicating a laterally positioned patella. (A) Scatterplot for an entire sample set,  $r = 0.36$ ; (B) Scatterplot for paediatric cohort,  $r = 0.39$

**Table 3:** Standardised beta and significance values for the multiple regression analysis performed on 16 paediatric patellae with patella centring as the dependent variable

	Standardised $\beta$	Sig.
Gender	-0.014	0.945
Age	0.047	0.808
aLDFA	-0.026	0.904
mPTA	-0.134	0.468
TT-TG	0.38	0.049*

TT-TG showed significant association while all the other parameters were not significant. Statistical significance ( $p < 0.05$ ) is denoted with an asterisk

Patellar centring values were found to be  $8 \pm 4\%$ . Average aLDFA was  $81 \pm 2^\circ$  and average MPTA was  $86 \pm 2^\circ$ . Average TT-TG distance was  $11.2 \pm 3.8$  mm. Similar to the overall cohort, only TT-TG distance showed a significant association with increased lateral patellar deviation associated with increasing TT-TG distance ( $p = 0.049$ , Table 3), with a standardised beta of 0.380 (Fig. 4B).

## DISCUSSION

The purpose of this study is to determine the position of the patella when taking a radiograph of the knee that is orthogonal to a lateral view where the femoral condyles are overlapped. This MRI study of normal knees found that the patella is laterally deviated 8% on average with respect to the width of the femoral condyles. Our paediatric subgroup was also found to have a lateral deviation of 8% on average.

The values obtained correspond with results from two previous papers published by our group. The first studied 428 cadaveric specimens aged 40–79 and found a lateral deviation of 13%.<sup>2</sup> The current study found the patella to be less laterally deviated with the difference hypothesised to be due to soft tissue mitigation.

The second study investigated paediatric cadaveric samples and found an average patellar lateral deviation of 6%.<sup>3</sup> Although the lower magnitude of lateral patellar position was theorised to be incomplete ossification of the posterior aspect of the femoral

condyles leading to slight internal rotation and subsequent lower magnitude of lateral positioning during AP imaging of the cadaveric specimen, the value is similar to the current dataset.

The average values of aLDFA ( $81^\circ$ ) and MPTA ( $87^\circ$ ) were comparable to the reference ranges found in the literature.<sup>1</sup> There was no significant correlation between angular measurements of aLDFA and MPTA and patellar centring in this study. We had previously found that large amounts of distal femur valgus and varus produce lateral deviation in paediatric patients undergoing hemiepiphyseodesis.<sup>3</sup> The difference may be secondary to the younger age of 11.5 years in the previous study or to the larger amount of deformity in the previous cohort.

Average TT-TG distance was  $11.3 \pm 3.9$  mm, a value consistent with other measurements of TT-TG distance performed on MRIs.<sup>6</sup> We did see a relationship between larger TT-TG distances and more lateral patellar positioning. It has been established that larger TT-TG distances are associated with tubercle lateralisation rather than a more medial trochlear groove.<sup>7</sup> The more lateral patellar position seen with greater TT-TG could be a result of the soft tissue influence of the patellar tendon or could be from a more laterally positioned trochlear groove. Regardless, the relationship between large TT-TG distances and the lateral position of the patella should be kept in mind when correcting the deformity in these patients.

It is accepted that the frontal plane is  $3^\circ$  externally rotated to the flexion axis of the knee.<sup>1</sup> We previously used mathematical models to determine the influence of this external rotation and found that it can contribute approximately 2.6% to the patella centring value,<sup>2</sup> which is not large enough to explain the average value of 8% seen in this study.

Whether the position of the knee in normal gait is truly in line with the flexion axis of the knee has been called into question. It is known that while during normal gait there are large degrees of both external and internal rotation of the tibia relative to the femur,<sup>8,9</sup> the knee remains internally rotated during the majority of the gait cycle. One theory is that a patella-centred AP view would better approximate the position of the knee in normal gait. However, the amount of internal rotation varies throughout the gait cycle, and so choosing a patella-centred position vs any other position seems arbitrary based on this argument. In contrast, it is logical to base the

knee on the anatomical flexion axis because this plane of movement has obvious functional significance and can be approximated in the operating room.

There were a number of limitations in the methodology of this study. First, the limited coronal windows of the knee MRI made it difficult to assess femoral and tibial coronal plane angulation values. While taking measurements, we aimed to be at least the width of the femoral and tibial condyles above the joint line before the anatomic axis was established. The difficulty of measurement was demonstrated with lower but acceptable ICC values for interrelator reliability of aL DFA and MPTA of 0.68 and 0.69, respectively. However, given that our mean values and standard deviations were comparable to the literature normal values, we felt that our measurements were acceptable. There was also no way to account for the impact a femoral version would have on patellar centring values. However, a previous anatomical study did not find any relationship between the femoral version and patellar centring.<sup>2</sup>

Additionally, while the clinical utility of this study applies to patients undergoing deformity correction, patients without a knee pathology were used in this normative study. This was by necessity given a lack of knee MRI studies in deformity patients available for a study. Future studies should be performed on patients with significant knee pathology to determine how patellar centring values vary in this population. However, the overall finding that a patella-centred view is not orthogonal to a lateral based on the posterior femoral condyles overlapping in normal anatomy is still an important finding.

The degree of error that the laterally positioned patella can introduce into deformity correction is unknown. It has been shown that using the patellar forward position for AP radiographs is within 5° of neutral, and an error of up to 10° of rotation leads to little effect in alignment seen in radiographs.<sup>10</sup> Although this is within the range of rotational error found in this study, we would still caution that there are likely certain cases where this effect could be more substantial. For example, the five largest patellar centring values in this study were all 15% or higher, which would be beyond the 10° threshold.

## CONCLUSION

When conducting preoperative planning and intraoperative guidance of deformity correction, orthopaedic surgeons should be aware that a perfect lateral view with the posterior femoral condyles overlapped is not orthogonal to a patellar-centred AP

view. Surgeons should be cautious against assuming that an intraoperative patellar-centred view represents a true AP view of the knee and instead should consider obtaining a lateral view with the femoral condyles overlapped and then obtaining an orthogonal AP view. Future studies will be necessary to fully understand the clinical impact of these findings in specific regard to patients with known deformities undergoing correction and determine if these relationships hold in standing radiographs taken in the clinic.

## ORCID

Raymond W Liu  <https://orcid.org/0000-0003-3041-8312>

## REFERENCES

1. Paley D. Principles of deformity correction. New York: Springer-Verlag; 2005. p. 1–18.
2. Ajuwon AA, Desai R, Farhang K, et al. An anatomic study on whether the patella is centered in an ideal anteroposterior radiograph of the knee. *HSS J* 2015;11(2):117–122. DOI: 10.1007/s11420-014-9419-3.
3. Kyriakedes JC, Liu RW. An anatomic study on whether the immature patella is centered on an anteroposterior radiograph. *J Pediatr Orthop* 2017;37(2):138–143. DOI: 10.1097/BPO.0000000000000687.
4. Zaki R, Bulgiba A, Nordin N, et al. A systematic review of statistical methods used to test for reliability of medical instruments measuring continuous variables. *Iran J Basic Med Sci* 2013;16(6):803–807. PMID: 23997908.
5. Pandit S, Frampton C, Stoddart J, et al. Magnetic resonance imaging assessment of tibial tuberosity-trochlear groove distance: normal values for males and females. *Int Orthop* 2011;35(12):1799–1803. DOI: 10.1007/s00264-011-1240-8.
6. Hinckel BB, Gobbi RG, Filho ENK, et al. Are the osseous and tendinous-cartilaginous tibial tuberosity-trochlear groove distances the same on CT and MRI? *Skeletal Radiol* 2015;44(8):1085–1093. DOI: 10.1007/s00256-015-2118-4.
7. Prakash J, Seon JK, Ahn HW, et al. Factors affecting tibial tuberosity-trochlear groove distance in recurrent patellar dislocation. *Cios Clin Orthop Surg* 2018;10(4):420–426. DOI: 10.4055/cios.2018.10.4.420.
8. Kim HY, Kim KJ, Yang DS, et al. Screw-home movement of the tibiofemoral joint during normal gait: three-dimensional analysis. *Clin Orthop Surg* 2015;7(3):303–309. DOI: 10.4055/cios.2015.7.3.303.
9. Levens AS, Inman VT, Blosser JA. Transverse rotation of the segments of the lower extremity in locomotion. *J Bone Joint Surg Am* 1948;30A(4):859–872. PMID: 18887290.
10. Wright JG, Treble N, Feinstein AR. Measurement of lower limb alignment using long radiographs. *J Bone Joint Surg Br* 1991;73(5):721–723. DOI: 10.1302/0301-620X.73B5.1894657.