Isometric Physeal-Sparing Femoral Attachment Site For Lateral Extra-articular Tenodesis in Skeletally Immature Patients: A Digitally Reconstructed Radiographic Study

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INTRODUCTION:
The incidence of anterior cruciate ligament (ACL) injuries in pediatric and adolescent patients has substantially increased over the past two decades, largely due to the growing participation in competitive sports. The management of these injuries has historically been controversial due to the risk of growth disturbances associated with physeal disruption during tunnel drilling for ACL repair or reconstruction (ACLR). The modified Lemaire lateral extra-articular tenodesis (LET) has grown in popularity as an adjunctive procedure to decrease the risk of ACLR graft rupture and recurrent anterolateral rotatory instability in high-risk populations, however, its relationship to the physis using standard operative techniques is not well understood. The purpose of this study was to define the anatomic relationship between the distal femoral physis and commonly used landmarks on the lateral femur for safe intraoperative placement of an isometric insertion point for a modified Lemaire LET using digitally reconstructed radiographs (DRRs) and 3-dimensional (3D) computed tomography (CT) models of skeletally immature patients.
METHODS: Electronic medical record systems at two tertiary care centers were queried for pediatric CT scans of knees from December 2011 to July 2021. The inclusion criteria were (1) age less than 18 years, (2) having an open or partially open distal femoral physis, (3) and having a high-resolution CT scan. The exclusion criteria were (1) presence of a distal femur fracture or deformity, (2) presence of indwelling hardware in the knee or distal femur, (3) incomplete CT rendering of the lateral aspect of the distal femur, or (4) low quality CT rendering preventing segmentation of the distal femoral physis. Patient demographic and clinical data were collected from the electronic record including patient sex, age, date of imaging, and indication for imaging. 3-Dimensional reconstructions of the knee were made using high resolution CT scans. The lateral femoral epicondyle (LFE) and distal femoral physis were marked, and a 2.4 mm diameter line was placed 4 mm posterior and 8 mm superior to the LFE, perpendicular to simulate a femoral LET tunnel. Physeal violation was recorded, and depth or closest distance to the physis was measured. Five distances from the physis were measured, including: 1) LFE to physis, 2) LFE to posterior femoral cortex line, 3) intersection point to physis, 4) point 10 mm posterior to LFE to physis, and 5) center of distal isometric attachment area (IAA) to physis. Physeal overlap with the IAA was also recorded and categorized as <50% or >50%. Two reviewers performed all measurements. ICCs and descriptive statistics were calculated using SPSS v29.0.
RESULTS:
A total of 40 knees (39 patients) were included from the 71 reviewed scans. Among the final study group, 13 (33%) were female and the mean age was 12.9 ± 2.41 years (Table 1). The most common indication for imaging was lower extremity trauma.
The ICC between reviewers for all measurements was 0.943 [95% CI 0.803 – 0.984], indicating excellent agreement. The mean distance from the LFE to the physis was 9.92 ± 3.95 mm. The mean anterior to posterior distance from the LFE to the PFCL was 5.08 ± 3.09 mm and the mean distance from the LFE and PFC line intersection to the physis was 10.9 ± 4.33 mm. The mean distance from a point 1 cm posterior from the LFE to the physis was 11.3 ± 4.32. The IAA violated the physis in 13 (33%) of the knees. Of these 13 knees, 10 had <50% of the box violate the physis and 3 of these patients had >50% violation. For the remaining patients, the IAA was located entirely proximal to the physis, with the distal aspect of the IAA being 3.2 ± 2.3 mm from the physis.
The 2.4mm diameter line simulating a drilled tunnel located 4mm posterior and 8mm proximal to the LFE as described by Dodds et al. violated the physis in 18 knees (45%). Of these 18 knees, 13 violated the physis on the lateral femoral cortex and 5 violated deep to the cortex at an average depth of 13.0 ± 5.01 mm. Of the remaining 22 knees which had a tunnel that did not violate the cortex, all were located distal to the physis, and the closest distance to the physis was on average 4.33 ± 1.67 mm.
DISCUSSION AND CONCLUSION: Using a standard LET procedure on 3D reconstructed models, the distal femoral physis would be theoretically violated in 45% of skeletally immature patients. Additionally, the isometric attachment area for a standard LET procedure would be within the physis in one third of patients. Careful consideration of the physis must be made when performing an LET procedure in skeletally immature patients.

	Value
Patients, n	39
Knees, n	40
Sex	
Female	13 (33%)
Male	26 (67%)
Age, y, mean ± SD	
Female	11.7 ± 2.63
Male	13.5 ± 2.10
Laterality	
Right	25 (63%)
Left	15 (37%)
Indication	
Trauma	23 (58%)
Knee Pain	10 (25%)
Miscellaneous	7 (17%)

Table 1: Patient demographics and characteristics.

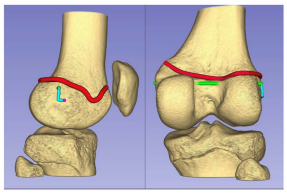

Figure 1: 3D rendered knee with physis marked out by the red line, the lateral femoral condyle marked by the magenta dot, the "classic" femoral insertion for a lemaire showing 4 mm posterior and 8 mm superior in aqua, and green line showing the directly perpendicular drill path through this spot.

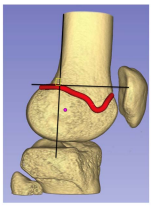

Figure 2: 3D reconstruction of the knee with physis mapped in red and the lateral femoral epicondyle marker in magenta. PFCL and PCL line shown in black with isometric attachment area described by Jakes *et al* included.

#	Distances	Mean SD (mm) or n (%); n= 40	Range [min-max]
1	**LFE to Physis**	9.92 (3.95)	3.09-19.0
2	**LFE to PFC**	5.08 (3.09)	0.50-12.9
3	**LFE + PFC Intersection to Physis**	10.9 (4.33)	3.37-19.4
4	**One Centimeter Posterior to LFE to Physis**	11.3 (4.32)	3.26-19.0
5	**Distal Aspect of IAA Box to Physis (n=27)**	3.20 (2.33)	0.67-7.89
-	**Distal IAA Within Physis Amount of Total IAA Box That Violates Physis (n=13)**	13 (33%) <50; n=10 >50; n=3	- -
-	**Rate at which Classic LET Intersects Physis**	18 (45%)	-
	Distance from Classic LET Description to Physis	N= 22; 4.33 (1.67)	1.66-7.30
	Patients With classic LET intercepts Physis (n=18)	13/18 directly hit physis 5 patients intercept during perpendicular drill – 13.0 (5.01)	8.87-20.8

Table 2: Measurements characterizing various relevant points in relation to the physis and lateral femoral epicondyle (LFE), as well as the isometric attachment area (IAA).