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Results of Lower Extremity Physeal Bar Resection

Abstract

Background: We sought to determine the incidence, extent, and prognostic factors for physeal growth resumption after partial physeal bar resection.

Methods: We performed a retrospective chart review of all patients treated between 1981-2017 by lower extremity physeal bar resection. All radiographic images were reviewed from preoperatively until cessation of affected physeal growth, subsequent surgery, or skeletal maturity.

Results: Eighty-nine patients met inclusion criteria (26 distal femora, 49 proximal tibiae -including 40 infantile Blount patients- 14 distal tibiae). Thirty-seven (42%) had at least two years' normal growth (defined as "successful"), 13 (15%) showed less than two years' growth ("partial"), and 39 (44%) had no growth ("failure") after resection surgery. 56% of the "successful" and "partial" groups required subsequent surgery compared to 100% of the "failure" group. The use of methylmethacrylate (Cranioplastic™) as interpositional material was superior to autologous fat ($p < 0.01$). Anatomic type of bar (peripheral, central, linear), physis affected, patient age, and etiology were not prognostic.

Conclusions: Approximately 40% of patients demonstrated useful resumption of growth after partial physeal bar resection. With the exception of interpositional material, other demographic variables were not prognostic. These results should be considered when determining whether physeal bar resection surgery is warranted in individual patients.

Advanced 3-D imaging reconstruction preoperatively, imaging confirmation of complete bar resection, markers to detect and monitor growth, and periodic radiographic follow up until cessation of growth or maturity should be incorporated in a standardized treatment regimen. LEVEL OF EVIDENCE: Level 3

Key Words: Physeal Arrest, Physeal Bar, Bony Bridge, Physiolysis, Epiphysiolysis

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Introduction

Partial physeal arrests (also called bony"bars") are bony bridges that form across an otherwise healthy physis and connect the osseous epiphysis and metaphysis. These arrests disturb normal physeal growth, resulting in variable shortening, angular deformity, and/or epiphyseal distortion. The extent and nature of the resultant distortion is dependent on the location and size of the arrest, the specific physis affected, and the duration of disturbed normal growth. Bony arrests most frequently result from physeal fractures, but can also occur as consequence of infection, thermal injury, irradiation, tumor and tumor-like conditions (osteochondromas, enchondromas, or unicameral bone cysts), or infantile Blount disease. Occasionally, physeal bars can present with no clearly identifiable etiology. While bony arrests may occur in any physis, the most clinically significant ones occur in the proximal humerus, distal radius, distal femur, proximal tibia, distal tibia, and distal fibula. Anatomically, partial physeal bars are characterized by their relationship to the residual healthy physis as peripheral, central, or linear[1].

Langenskiöld[2] described a surgical procedure he termed "epiphysiolysis" in 1967, consisting of the removal of the bony bar while preserving the residual healthy physis, with interposition of autogenous fat into the surgically-created cavity to prevent reformation of the bar. The expectation was that the residual healthy physis would resume normal growth. Langenskiöld[3,4] and others substantiated this concept with clinical series[1,5-9]and experimental animal studies[10-12], using fat[2-4,6-9], silicone rubber[11], methylmethacrylate[1,5], or cartilage[10,12] as the interposition material. Various techniques to expose and resect bony bars have been described, including via osteotomy or metaphyseal windows[13], cannulated drills, and with CT[14], fluoroscopic or arthroscopic guidance[15,16].Epiphysiolysis can be performed independently, in conjunction with osteotomies to correct co-existing bony deformity, or growth modulation[16].

Langenskiöld[4], Peterson[1] and more recently Yuan et al[5] reported a high likelihood of resumption of growth after physeal arrest resection surgery and recommended that the procedure be considered in patients with more than two years of growth remaining and less than 50% physeal surface area affected. Others report more modest results[6,8,9]. The purpose of this study was to review the results of physeal bar resection surgery at our institution, with specific reference to the likelihood and extent of normal growth resumption, and to identify prognostic characteristics.

Method

We performed an IRB-approved retrospective chart review of patients who underwent physeal bar resection from 1981 to 2017. Inclusion criteria were clear descriptions of the surgical procedures; bars affecting the distal femur, proximal tibia, or distal tibia; adequate preoperative imaging to allow identification of location and approximate size of the arrest; and postoperative radiographic follow-up of at least six months to document resumption of growth (if any). Exclusion criteria were inadequate clinical or radiographic records, and resections involving other physes. We also excluded three patients in whom bone wax only was used to retard reformation of the bar (none of these grew postoperatively). 89/148 physeal bar resection surgeries met inclusion criteria.

We collected pre-operative data including patient age, gender, height, weight, ethnicity, pertinent medical history and co-morbidities, previous surgeries and etiology of arrest. We recorded the surgical technique, interposition material used (autologous fat or methylmethacrylate (Cranioplastic^{TM} -Codman & Shurtleff, Inc., Raynham MA-), postoperative complications, and subsequent surgery.

All available radiographs and advanced imaging were analyzed. Bar size, location, anatomic type (peripheral, central, or linear) were determined from analysis of all pertinent preoperative radiographic imaging, including orthogonal plain films, tomograms, CT scans, and MRI, including 3-D reconstructions, as available.To estimate bar size (as a percentage of total affected physeal surface) and location, we made several assumptions. When only orthogonal plain films were available, bar size was calculated based on greatest diameter in each film, and the total physeal surface as a rectangle based on the same images. Linear bars were assumed to be continuous from anterior to posterior, unless advanced 3-D constructions documented to the contrary. For infantile Blount disease, we used 3-D CT or MRI reconstructions, delineating all disrupted physis as the bar area (Figure 1). When advanced imaging was not avail able in infantile Blount disease cases, we estimated bar size from orthogonal plain films, based on their appearance compared to cases in which both advanced 3-D reconstructions and plain films were available to estimate percent involvement.

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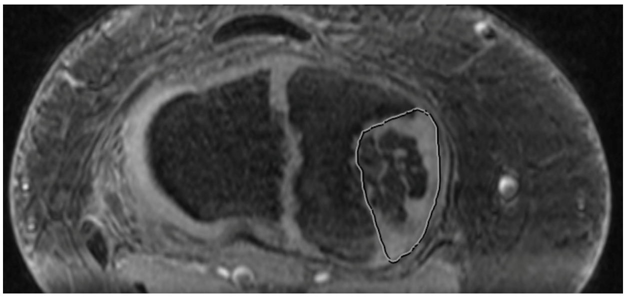

Figure 1. Orthogonal axial MRI 3-D reconstruction of disrupted proximal tibial physis in a patient with infantile Blount disease. For the purposes of this study, bar size was calculated as percentage surface area of the entire affected physis (white outline).

Postoperative radiographs were reviewed to document residual angular deformity and the extent and duration of subsequent growth (if any). For the purposes of this study, we qualified resumption of growth as "successful" if there was radiographically-documented growth of at least two years of normal growth; "partially successful" for growth of six months but less than two years; and "failure" if there was less than six months' or no growth after surgery.

Statistical Methods

We evaluated demographic factors including age, gender, bar size, type of bar, etiology of bar, location of bar, and presence of interposition material to determine prognostic significance for resumption of growth. Statistical analysis was performed to see if any significant difference was seen ($p < 0.05$). For continuous variables, ANOVA test were used. For categorical variables, Fisher's exact test or Chi-Square test was used. Lastly, for each group, return to the operating room and complications were also analyzed.

Results

Eighty-nine patients comprised the study population, including 26 distal femoral, 49 proximal tibial (40 due to infantile Blount disease), and 14 distal tibial bars. The demographic characteristics of the 89 patients are summarized in Table 1.

Thirty-seven patients (42%) were classified "successful," 13 patients (15%) as "partially successful," and 39 patients (44%) as "failures." There was no significant difference in the rate of success based on physis affected by Chi-Square analysis (Table 2), nor based on patient age, bar size, gender, location, bar morphology, or etiology (Table 3).Local or harvested autologous fat was used more frequently in this cohort (77 cases) than Cranioplastic™ (12 cases). There was a statistically significant increase in successful bar resections using Cranioplastic™ compared to either locally- or remotely-harvested autologous fat ($p < 0.01$).

There were seven complications associated with the 89 index surgical procedures of arrest resection, including two deep infections, two compartment syndromes, one fracture, one wound dehiscence and one metaphyseal marker revision. Table 4 summarizes the rate of further reconstructive surgery in the three treatment outcome groups. Overall, 67 patients (75%) required a second reconstructive procedure, 10 (11%) grew to maturity without requiring a second procedure, while 12 (14%) were either still growing at the time of this study or growing when lost to follow up. Initial resumption of growth followed by premature cessation of growth in patients characterized as either "successful" or "partially successful" occurred in 28/51 patients who resumed affected physeal growth, at an average 18 months postoperatively.

Table 1. Demographics of Study Population (89 lower extremity bar excisions)

Location	Distal Femur	Proximal Tibia, non-Blount	Infantile Blount	Distal Tibia
Number	26	9	40	14
Male	15	5	14	6
Female	11	4	26	8
Mean Male age at surgery (years)	8.8 ± 2.6	11 ± 3.4	7.9 ± 1.3	8.7 ± 2.1
Mean Female age at surgery (years)	7.8 ± 2.4	6.9 ± 0.5	7.2 ± 1.1	7.5 ± 2.2

* Chi-Square test to compare proportion of males and females: p= 0.29 (not significant)

Table 2. Incidence of Resumption of Growth in the Study Population

Bar Location	Number	Success*¶ (number/%)	Partial*¶ (number/%)	Failure¶ (number/%)	Grew to Maturity
Distal Femur	26	11 (42.3%)	3 (11.5%)	12 (46.2%)	2
Infantile Blount	40	14 (35%)	5 (12.5%)	21 (52.5%)	1
Proximal Tibia (non-Blount)	9	3 (33.3%)	3 (33.3%)	3 (33.3%)	2
Distal Tibia	14	9 (64.3%)	2 (14.3%)	3 (21.4%)	5
Total	89	37 (41.6%)	13 (14.6%)	39 (43.8%)	10

*Includes 13 still growing or growing when lost to follow up.
¶ "Success" defined as ≥ 2 years of normal growth, "partial" as 6-24 months of normal growth, and "failure" as no or less than 6 months of normal growth.
Chi-Square Test to compare Proportion of Successes between groups: p = 0.29. There is no significant difference.

There was a statistically significant higher need for reconstructive surgery in the "failure' group, compared to the "successful" group (Table 4), and these procedures tended to be more extensive. The "successful" group underwent procedures ranging from epiphysiodesis (ipsilateral or contralateral) to subsequent osteotomy. One patient requiredrevision of a symptomatic distal tibial metaphyseal pin and another required arthroscopy with lysis of adhesions to treat postoperative flexion contracture. The "partially successful" and "failure" groups underwent more frequent, and generally more extensive surgical reconstruction sincluding repeat bar resections (two patients, one "failure" and one "partial success"), epiphysiodesis, growth modulation, osteotomies, compartment releases with flap reconstruction, and leg lengthening by external fixation.

Patients with infantile Blount disease were the single largest group by location and etiology (40/49 proximal tibial growth arrests). Within the infantile Blount disease group there were 14 successful resections (35%), 5 partial successes (13%) and 21 failures (53%). Table 5 highlights the secondary procedures in the infantile Blount population. In the infantile Blount group, patients characterized as "partial success" or "failure" also underwent more frequent and generally more extensive subsequent reconstructive procedures compared to the "successful" patients. Thirty-six patients with infantile Blount disease (90%) required a second reconstructive procedure, compared to 75% in the entire cohort.

Discussion

Langenskiöld drew attention to the effect and treatment of partial physeal arrests[2]. Enthusiasm waxed for this technique, based on reports of a relatively high rate of success (in excess of 90%) by Langenskiöld[4], Peterson[1], and more recently, Yuan et al[5]. Other reports[6,8,9] have suggested more modest results, including both failure of resumption of growth, or premature cessation of growth[1,4,9,10]. Many studies are limited by a relatively small number of cases, a vague or variable definition of "success," and often incomplete follow up to maturity. We sought to document the effectiveness of this surgical procedure with a relatively large patient cohort, a clear definition of success, and rate and nature of subsequent surgery in these patients.

Table 3. Prognostic Factors in Study Population (Total = 89)					
Prognostic Factor		Success (n = 37)	Partial Success (n = 13)	Failure (n = 39)	p-value
Interposition*	Fat (77)	26	13	38	<0.01
	Cranioplastic™ (12)	11	0	1	
Age¶	(Years ± SD)	7.6 ± 1.8	8.1 ± 2.7	8.3 ± 2.2	0.29
Bar Size¶	(% surface area)	13.2 ± 6.2	11.8 ± 6.0	12.6 ± 5.9	0.42
Gender*	Male (40)	17	4	19	0.52
	Female (49)	20	9	20	
Bar Location*	Distal Femur (26)	11	3	12	0.35
	Proximal Tibia (49)	17	8	24	
	Distal Tibia (14)	9	2	3	
Type of Bar*	Peripheral (73)	26	11	36	0.08
	Central (12)	7	2	3	
	Linear (4)	4	0	0	
Etiology*	Trauma (35)	19	3	13	0.16
	Infection (7)	2	3	2	
	Blount (40)	14	5	21	
	Other (7)	2	2	3	

¶ For continuous variables, ANOVA was used.
*For categorical variables, Fisher's exact test was used.

Using a threshold of at least two years' worth of normal growth of the affected physis, we found that approximately 40%of patients demonstrated useful resumption of growth. It should be noted that "useful" is meant to imply either a significant impact on anticipated shortening due to impaired longitudinal growth, and/or an opportunity to influence existing angular deformity by a combination of successful resumption of growth and growth modulation. By the same token, approximately 40% of our patient cohort demonstrated little or no useful resumption of growth. Only 10 cases (11%) grew to maturity without requiring any reconstructive surgery, although a further 12 patients were either still growing at the time of evaluation or when lost to follow up. Premature cessation of growth has been noted by others[14-16], and is an important outcome to be monitored by continuous clinical and radiographic assessment.

We did not identify any significant association between successful resumption of growth and patient age at the time of surgery, bar size, type of bar, gender, etiology or physis affected.

While Langenskiöld used autologous fat, others have recommended slow-setting non-barium impregnated methylmethacrylate (Cranioplastic™)[1,5] or silicone rubber[11], although the latter is no longer commercially available. Eleven of 12 patients in our cohort

Table 4. Incidence of Subsequent Surgery in the Study Population

	Success (n = 37)	Partial Success (n = 13)	Failure (n = 39)	p-value
Subsequent surgery	21 (57%)	7 (54%)	39 (100%)	<0.01*
No further surgery	16 (43%)	6 (46%)	0 (0%)	
Total secondary procedures	42 (1.1/patient)	17 (1.3/patient)	114 (2.9/patient)	
Types of secondary procedures	Hemiepiphysiodesis Epiphysiodesis (ipsilateral/contralateral) Osteotomy Growth modulation Implant removal Marker revision	Hemiepiphysiodesis Epiphysiodesis (ipsilateral/contralateral) Osteotomy Growth modulation Leg lengthening	Hemiepiphysiodesis Epiphysiodesis (ipsilateral/contralateral) Osteotomy Growth modulation Repeat bar resection Leg lengthening	

***Fisher's Exact Test to compare Return to OR between groups: $p = 9 \times 10^{-6}$. There is a significant difference.**

Table 5. Secondary Procedures in Infantile Blount Patients (Total = 40)

	Success (n = 14)	Partial Success (n = 5)	Failure (n = 21)	p-value
Subsequent surgery	11 (79%)	4 (80%)	21 (100%)	0.04*
No further surgery	3 (21%)	1 (20%)	0 (0%)	
Total secondary procedures	21 (1.5/patient)	11 (2.2/patient)	51 (2.4/patient)	
Types of secondary procedures	Lateral hemiepiphysiodesis Osteotomy Growth modulation Implant removal	Lateral hemiepiphysiodesis Osteotomy	Lateral hemiepiphysiodesis Epiphysiodesis (ipsilateral/contralateral) Osteotomy Repeat bar resection Leg lengthening	

***Fisher's Exact Test to compare Return to OR between groups: p = 0.04. There is a significant difference.**

who had Cranioplastic™ used as interposition material were classified as "successful," which was statistically-significantly better than autologous fat. However, methylmethacrylate can be difficult to remove at subsequent surgery and the resultant cavity may complicate reconstructive procedures. Since repeat surgery was so frequent even after successful resumption of growth in our patients, we believe that careful consideration must be given in determining whether to use methylmethacrylate as the interposition material.

The need for further reconstructive procedures in the “failure” group was significantly higher than in the “successful” group. Even the cases qualified as successful in our patient population required surgery 57% of the time. However, the subsequent procedures performed in the successful group were typically less extensive than those required in the failure group. Patients with infantile Blount disease had a higher rate of subsequent surgery compared to the group as a whole, even when bar resection was categorized as “successful.”

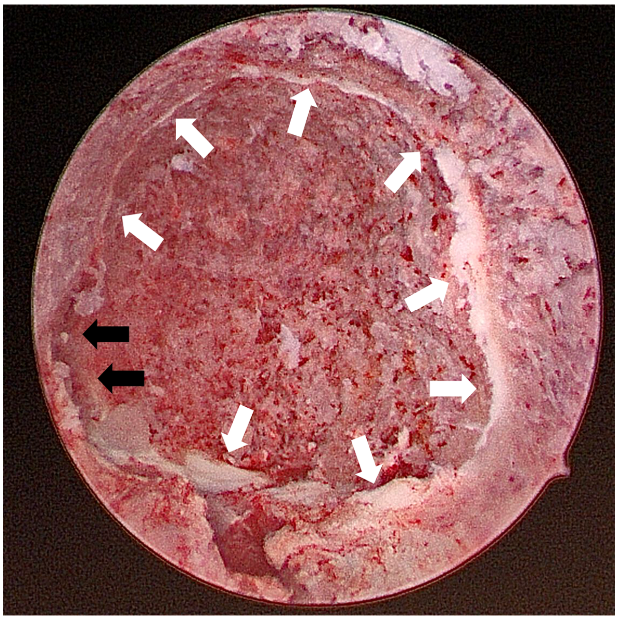

Figure 2. Intra operative arthroscopic photograph documenting near-complete central bar excision (viewed from the meta physeal side). Healthy physis is visible around the entire circumference of the cavity (white arrows), except from the approximately 7-9 o’clock position (black arrows), where further resection is required.

The primary limitation of this study is its retrospective nature. Many cases had to be excluded from analysis because of inadequate pre- or post-operative imaging, the inability to reliably document subsequent growth in the absence of a metaphyseal marker, or inadequate follow-up. In addition, most patients did not have intra operative photographs or advanced postoperative imaging to unequivocally confirm complete resection of the original bar. Hasler and Foster[9] in an evaluation of failures of physeal bar resection found that a portion were due to incomplete resection of the bar. We cannot discount the possibility that some failures in our series were due to incomplete resection of the bar.

In reviewing all of the clinical material in this cohort, several things became apparent to us. First, this is an easy operation to make technically difficult. Careful three-dimensional analysis of the bar and its orientation relative to the residual healthy physis is important to preoperative preparation. The surgical procedure should be kept as simple as possible by using image-guided cannulated drills, without excessive concern for preserving every square millimeter of healthy physis. Photographic, arthroscopic or postoperative advanced 3-D imaging by CT or MRI[17,18] to document complete bar resection should also be standard (Figure 2). Secondly, failure of resumption of growth despite technically adequate bar resection, or premature cessation of growth after initial success are common outcomes (Figure 3). Therefore, metaphyseal markers of some nature to enable objective evaluation of (continued) growth and absence of angular deformity development, and regular radiographic postoperative assessments until skeletal maturity are essential to proper patient management. Finally, at the best of times, in our hands, physeal bar resection was effectively a “50-50” proposition with respect to resumption of growth, so that its indication must be weighed carefully in each patient. On the one hand, physeal bar resection in the hopes of restoring two years of longitudinal growth of the proximal tibia (for a presumed gain of approximately 12 millimetres) is likely not indicated. On the other hand, correction of angular deformity requiring less than two years’ of growth by combining bar resection with growth modulation, thus preventing both progressive leg length discrepancy and the need for high tibial osteotomy, may well be worth the procedure (Figure 4), as long as both the patient and surgeon recognize that the procedure may not be successful.

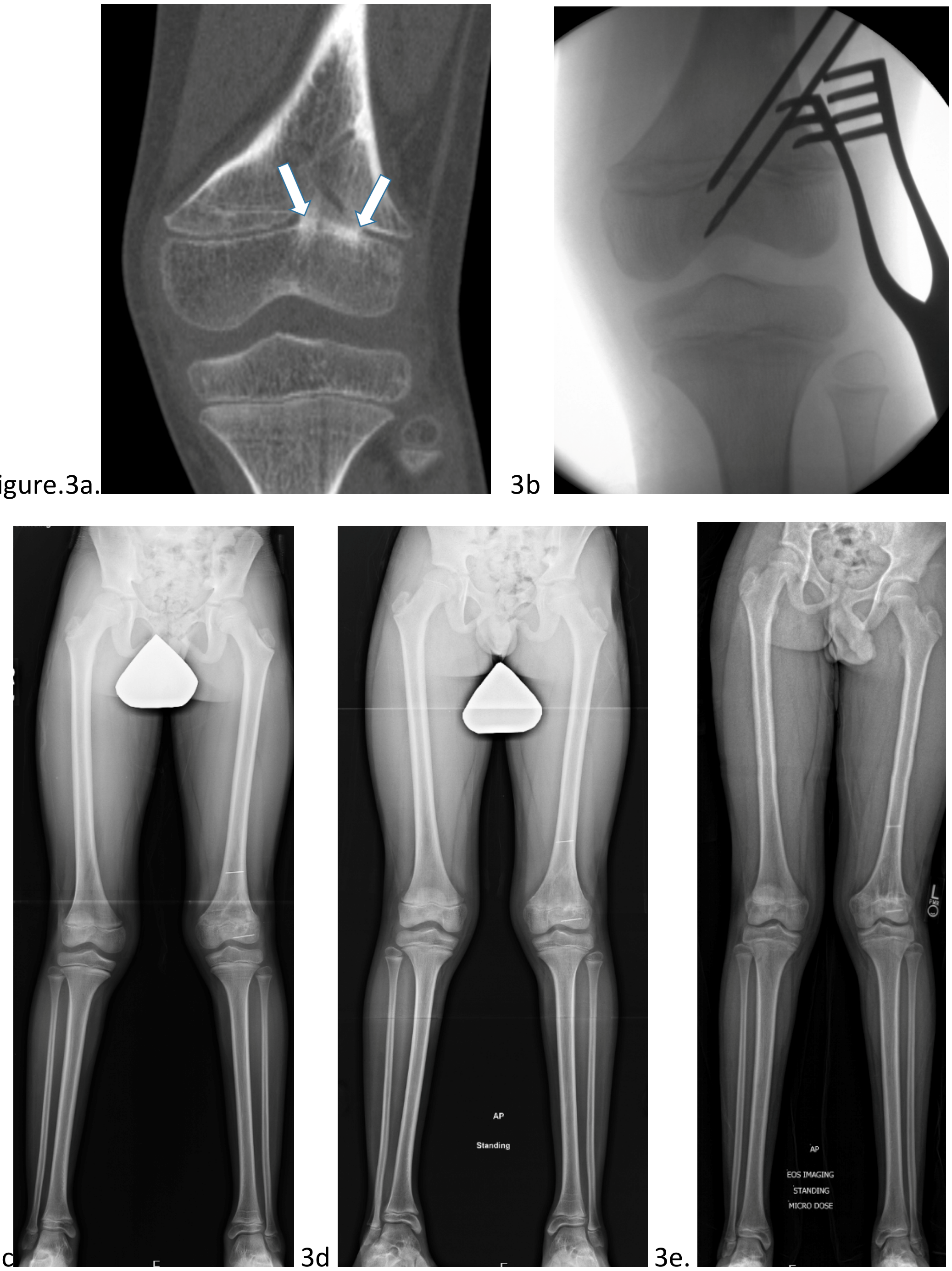

Figure.3a. 3b 3c 3d 3e.

Figure 3a-e. Clinical course of a 7+5 male presenting one year after closed reduction and percutaneous pining of a right lateral distal femoral physeal fracture.

Figure 3a. 3-D CT coronal plane reconstructions confirmed the presence of an eccentrically located central bar of the distal femoral physis (arrows).

Figure 3b. Intraoperative fluoroscopic image of the right distal femur. A metaphyseal window has been made to access the bar, guide wires placed into the physis, and proper location confirmed with 3D fluoroscopy. Graduated cannulated drills were then used to remove the bar.

Figure 3c.Standing anteroposterior (AP) radiograph of the lower extremities 9 months after surgery. The separation of the markers document 16 mm. of growth across the left distal femoral physis since surgery.

Figure 3d. Standing AP radiographs 29 months after surgery, documenting 38 mm of growth of the distal femur since surgery, with no evidence of angular deformity.

Figure 3e. The patient failed to return until 4 ½ years later (83 months after surgery). During that interval, only 20mm of further growth has occurred in the distal femur, indicating premature cessation of the growth after the initial success.

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In conclusion, our study affirms a modest rate of resumption of growth after physeal bar resection surgery, and frequent occurrence of subsequent deceleration of growth after initial restoration of growth. The latter led to the need for secondary procedures including epiphysiodeses, growth modulation, or osteotomies in over half of our "successful" group. Therefore, counselling families regarding these outcomes, and evaluating these patients sequentially until skeletal maturity is important.

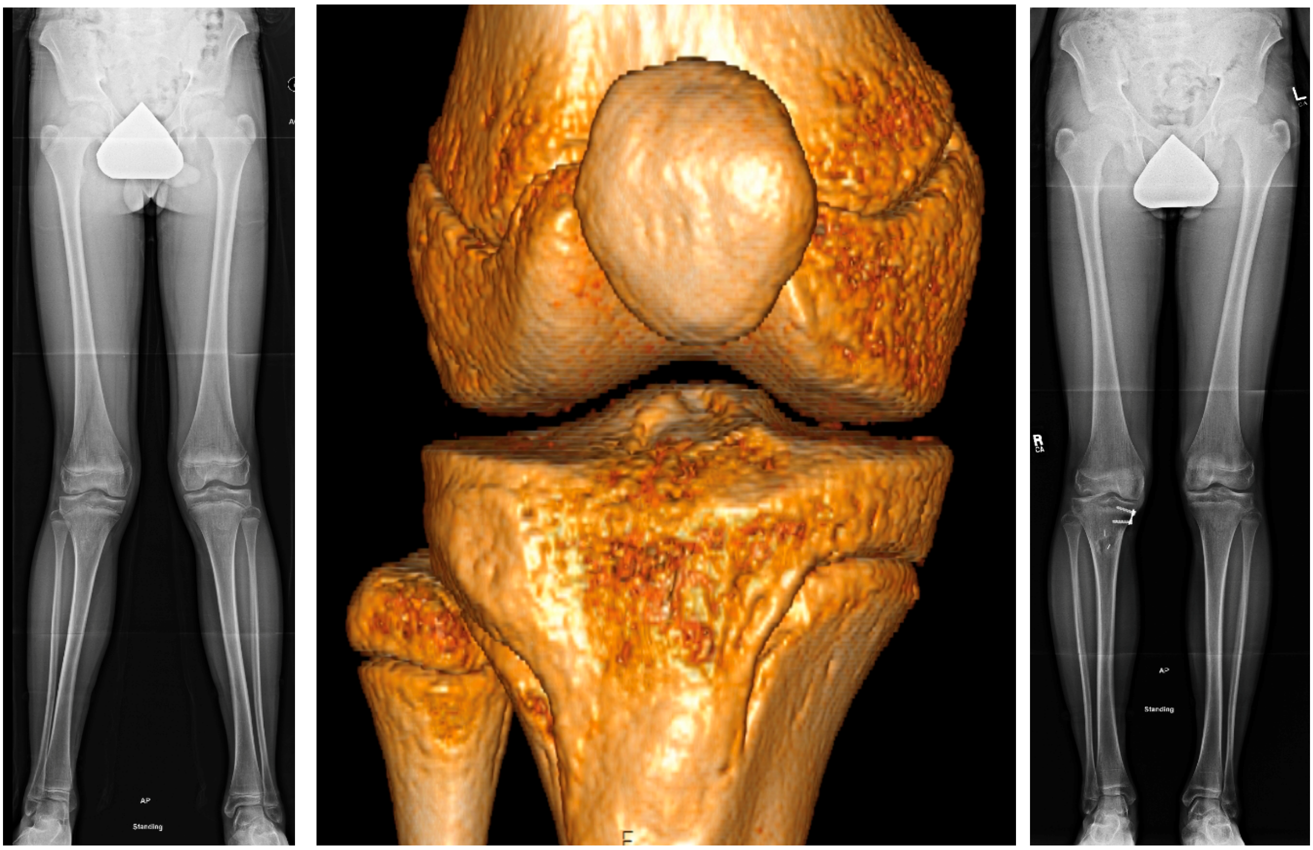

Figure 4 a. 4 b. 4c.

Figure 4a-c. A 15-year-old male (skeletal age 14) with a peripheral anterolateral bar of the proximal tibial physis after multiple trans-metaphyseal drilling of an osteochondral lesion of the lateral tibial plateau. The exact cause of the bar was uncertain.

Figure 4a. Standing antero-posterior radiograph of the lower extremities 15 months after transmetaphyseal drilling demonstrates valgus deformity of the right leg.

Figure 4b. 3-D CT reconstruction documents the location of the bar.

Figure 4c. Radiographic appearance 13 months after physeal bar resection, demonstrating divergence of the markers and correction of the valgus deformity.

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