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What Risk Factors Predict Usage of Gastrocsoleus Recession During Tibial Lengthening?

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Abstract

Background Tibial lengthening is frequently associated with gastrocsoleus contracture and some patients are treated surgically. However, the risk factors associated with gastrocsoleus contracture severe enough to warrant surgery during tibial lengthening and the consistency with which gastrocsoleus recession (GSR) results in a plantigrade foot in this setting have not been well defined.

Questions/purposes We compared patients treated with or without GSR during tibial lengthening with respect to (1) clinical risk factors triggering GSR use, (2) ROM gains and patient-reported outcomes, and (3) complications after GSR.

Methods Between 2002 and 2011, 95 patients underwent tibial lengthenings excluding those associated with bone loss; 82 (83%) were available for a minimum followup of 1 year. According to our clinical algorithm, we performed GSR when patients had equinus contractures of greater than 10° while lengthening or greater than 0° before or after lengthening. Forty-one patients underwent GSR and 41 did not. Univariate analysis was performed to assess independent associations between surgical characteristics and likelihood of undergoing GSR. A multivariate regression model and receiver operating characteristic curves were generated to adjust for confounders and to establish risk factors and any threshold for undergoing GSR. Chart review determined ROM, patient-reported outcomes, and complications.

Results Amount and percentage of lengthening, age, and etiology were risk factors for GSR. Patients with lengthening of greater than 42 mm (odds ratio [OR]: 4.13; 95% CI: 1.82, 9.40; $p = 0.001$), lengthening of greater than 13% of lengthening (OR: 3.88; 95% CI: 1.66, 9.11; $p = 0.001$), and congenital etiology (OR: 1.90; 95% CI: 0.86, 4.15; $p = 0.109$) were more likely to undergo GSR. Adjusting for all other variables, increased amount lengthened (adjusted OR: 1.05; 95% CI: 1.02, 1.07; $p < 0.001$) and age (adjusted OR: 1.02; 95% CI: 0.99, 1.05; $p = 0.131$) were associated with undergoing GSR. Patients gained 24° of ankle dorsiflexion after GSR. Self-reported functional outcomes were similar between patients with or without GSR. Complications included stretch injury to the posterior tibial nerve leading to temporary and partial loss of plantar sensation in two patients.

One of the authors certifies that he (SRR, ATF), or a member of his or her immediate family, has received or may receive payments or benefits, during the study period, an amount of USD 10,000 to USD 100,000 from Smith and Nephew, Inc (Memphis, TN, USA).
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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.
This work was performed at the Hospital for Special Surgery, New York, NY, USA.

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Conclusions Dorsiflexion was maintained and/or restored similarly among patients with or without GSR when treated under our algorithm. Functional compromise was not seen after GSR. Identification of patients at risk will help surgeons indicate patients for surgery. Acute dorsiflexion should be avoided to minimize risk of injury to the posterior tibial nerve.
Level of Evidence Level IV, therapeutic study. See Instructions for Authors for a complete description of levels of evidence.

Introduction

Tibial lengthening is a well-established surgical procedure that results in predictable bony union without functional impairment, but additional procedures are often needed [1]. It is performed for various reasons, such as congenital and developmental leg length discrepancy (LLD), bone loss due to trauma, osteomyelitis, infected arthroplasties, and tumors. Tibial lengthening can be done as a simple lengthening of the tibia or as part of a bone transport in segmental bone loss [1]. Complications may arise from the bone or soft tissues during tibial lengthening. An important soft tissue complication is joint contracture involving the ankle and knee [18, 21]. The ankle is more often involved than the knee and most commonly results in ankle equinus [21].

There are various treatment approaches available to prevent, decrease the severity of, and treat gastrocsoleus contracture. The approaches include walking, use of an orthosis to maintain the ankle in the neutral position [20], night splinting, employment of a neutral foot plate, plaster casts, physiotherapy (passive stretching exercises), exercises with a stretch strap, injection of botulinum toxin A, NSAIDs, temporary fixation of the ankle with K-wires, prophylactic addition of foot ring, various forms of Achilles tenotomies [20], and ankle fusion [14, 20]. While nonsurgical treatment is commonly effective, there are situations where surgical treatment is needed. One of the surgical approaches is a gastrocsoleus recession (GSR) [6].

GSR is an effective and safe procedure for dealing with equinus contractures [7, 13, 14, 16]. A literature search revealed a wide range of reported frequencies of ankle equinus with tibial lengthening. Studies report an incidence range from 10% to 50% depending on the etiology of shortening [1, 19]. The resulting equinus contracture can lead to a disruption in ankle, foot, and gait function [7]. Maskill et al. [12] reported that patients with equinus contractures can also develop plantar fasciitis, metatarsalgia, posterior tibial tendon insufficiency, osteoarthritis, and foot ulcers. However, the risk factors associated with gastrocsoleus contracture severe enough to warrant surgery during tibial lengthening and the consistency with which GSR results in a plantigrade foot in this setting have not been well defined.

We therefore evaluated a clinical algorithm used by one experienced limb-lengthening surgeon that defined when patients would or would not receive a GSR in the course of a tibial lengthening. Specifically, we studied patients treated under this algorithm with respect to (1) clinical risk factors that triggered the use of GSR, (2) the ROM gains and patient-reported outcomes among patients, and (3) the complications associated with GSR.

Patients and Methods

Institutional review board approval was obtained for this study, but our treatment protocol was not altered for this study.

Study Period and Algorithm

This is a retrospective review of the experience of a single surgeon (SRR). Between 2002 and 2011, 206 patients underwent consecutive tibial lengthening procedures. We excluded patients who had tibial lengthening related to bone transport, bone defect, or adjacent knee or ankle fusion. The exclusions left 95 patients, of whom 82 patients (83%) with 105 tibia lengthenings were available for followup at a minimum of 1 year. During the study period, we performed GSR for these patients during four time frames: (1) in patients who had a preoperative contracture of greater than 0° (mean, 2.5°) done to prevent increased equinus; (2) in patients while in the frame who had a recalcitrant contracture of greater than 10° (mean, 20°); (3) in patients at frame removal who had a recalcitrant contracture of greater than 0° (mean, 15°); and (4) in patients after frame removal who had a persistent contracture of greater than 0° (mean, 9°). The patients who underwent GSR at time of frame application had a preexisting equinus contracture before tibial lengthening and the surgery was performed to prevent severe contracture during tibial lengthening. In those cases, the frame spanned the ankle. In all other cases, the frame did not span the ankle. No patients received botulinum toxin A injections. No other soft tissue releases were done at this time.

During followup, the ankle and knee ROMs were carefully examined for development of gastrocsoleus tightness and ankle equinus. In those patients who developed equinus contracture, the Silverskiold's test was used to confirm contracture of the gastrocnemius-soleus complex. The maximal dorsiflexion of the ankle with the knee fully extended was measured with a goniometer. Ankle dorsiflexion of less than 0° was considered as equinus.

Table 1. Demographic data for the patients who did and did not undergo GSR

Variable	No GSR		GSR		p value
	Number of legs evaluated	Value	Number of legs evaluated	Value	
Number of patients/legs	41/50		41/55		
Sex (number of legs)					> 0.999
Male	49	36 (74%)	55	41 (75%)	
Female	49	13 (27%)	55	14 (26%)	
Age (years)*	50	28.04 (15.10)	55	32.11 (15.56)	0.178
Preoperative tibial length (mm)*	45	341.84 (51.81)	52	333.15 (52.14)	0.414
Time in frame (months)*	50	4.43 (2.26)	54	4.12 (2.53)	0.508

*Values are expressed as mean, with SD in parentheses; GSR = gastrocsoleus recession.

At a minimum followup of 12 months, we had complete followup on 41 of 82 patients (55 legs) who underwent GSR (50%) and 41 patients (50 legs) who did not undergo GSR (50%). The two groups of patients were similar for age, sex, LLD, preoperative tibial length, time in frame, and followup (Table 1). Followup was at a median of 64 months (range, 12–145 months) for the patients who received a GSR and 68 months (range, 12–160 months) for those who did not.

Surgical Technique

The tibial lengthenings were performed using a multiple drill hole osteotomy technique and the Taylor Spatial Frame™ (Smith & Nephew, Inc, Memphis, TN, USA). After tibial lengthening surgery, patients were encouraged to bear weight as tolerated and were encouraged to participate in a physiotherapy exercise program. Active and passive ROM of the knee and ankle was prescribed four times per day, 15 repetitions of each exercise (Fig. 1). Exercise instruction sheets, exercise videos, and referral to a physical therapist were all routinely given. While the patients were in bed, in those patients who had no foot ring, a foot splint was attached to the distal ring using straps to maintain the ankle in neutral position.

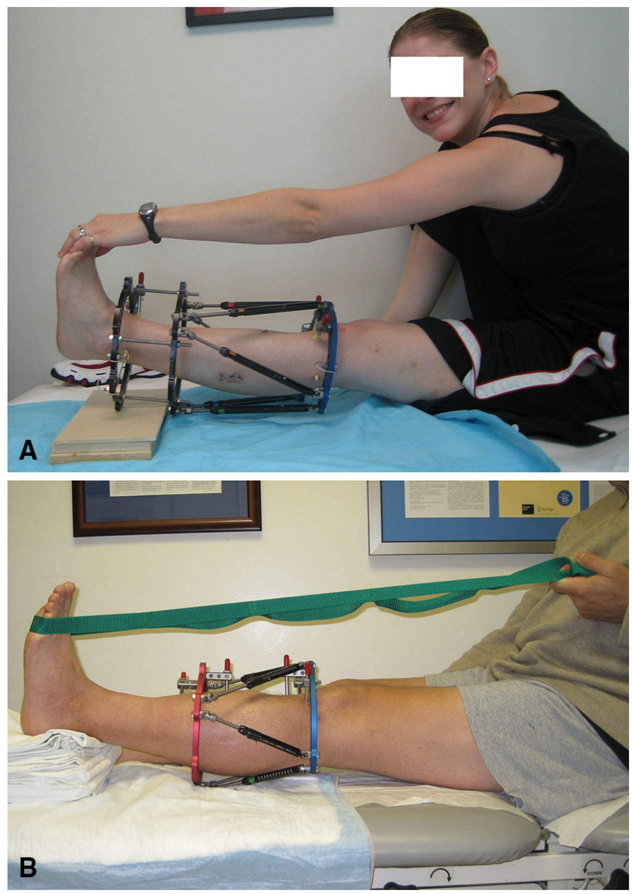


Fig. 1A–B A photograph demonstrates dorsiflexion stretching of the ankle with (A) a hand and (B) a strap. Note that the knee is maintained in extension with (A) a block or (B) sheets under the distal ring or foot.

For GSR surgery (Fig. 2), the patients were positioned supine on the operative table. An assistant held the extremity elevated by flexing the hip to 70° to 80° while the knee was kept fully extended. A midline 2-cm posterior incision was marked at the junction of middle and distal ⅓ of the leg. Skin and subcutaneous fascia were incised with a knife and the fascia overlying the gastrocsoleus complex was exposed. Care was taken to avoid injury to the sural nerve and the lesser saphenous vein. The fascia was incised longitudinally exposing the white gastrocsoleus fascia. Retractors were placed on either side but pulling only on one side at a time. The gastrocsoleus fascia was cut transversely using a knife without cutting the muscle fibers. This exposed the median raphe, which was then isolated and transversely cut with scissors. Forcible dorsiflexion of the ankle was avoided to prevent double-crush stretch

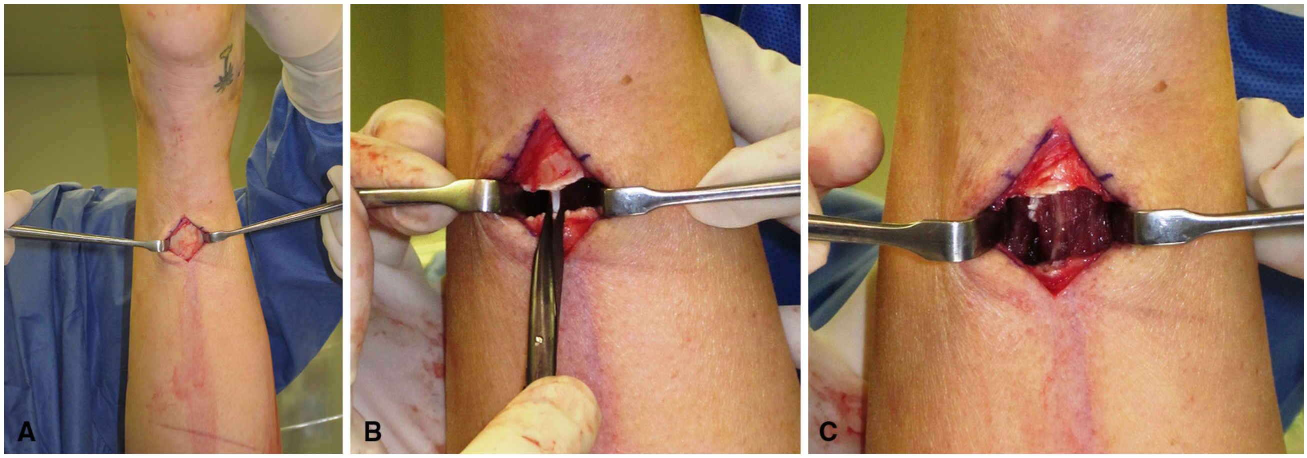


Fig. 2A–C The GSR surgical technique is illustrated. (A) An incision is made at the middistal 1/3 of the posterior leg. The leg is elevated and the heel is at the top of the photograph. Note the white gastrocnemius fascia. (B) After incision of the gastrocsoleus fascia, the medial raphe is seen. The raphe is about to be cut with scissor. (C) Note separation of fascia and underlying muscle.

injury to the posterior tibial nerve and vessel, which had already been stretched by the tibial lengthening. After irrigating the wound with sterile saline, the wound was closed in a single layer using 3.0 nylon sutures. Care was taken to avoid injury to the sural nerve and the lesser saphenous vein during closure. Also, we did not cast patients in maximal dorsiflexion to avoid double-crush nerve injury as mentioned before. When performing this procedure in patients wearing a frame, the external fixator was prepared into the field and the pin sites were covered with Betadine®-soaked sponges. While the procedure was the same, it was more technically challenging when operating around the frame.

Analysis

Three of the authors who were not the operating surgeons (SZ, SM, EWB) performed a chart review to determine ROM at latest followup and complications. We recorded the following data: age, sex, past medical history, past surgical history, side, etiology, years after trauma, soft tissue scarring, preoperative plantar flexion strength, preoperative dorsiflexion strength, preoperative tibial length, change in tibial length, date of index surgery, osteotomy site, osteotomy type (traditional, lengthening and then nailing, lengthening and then plating), length of followup, time in frame, external fixation index, amount lengthened, percentage of bone lengthened as compared to the initial bone length, date and time frame of GSR, complications, ROM of ankle and knee before and after tibial lengthening and before and after GSR, and answers to a self-reported outcome questionnaire. This questionnaire used a series of seven relevant questions determined by the senior author (SRR) and answered by the patient as yes or no: (1) ability to toe off on both feet, (2) ability to toe off on one foot, (3) ability to run, (4) presence of limp, (5) necessity for assistance to walk, (6) weakness of ankle compared to before tibial lengthening surgery, and (7) stiffness of ankle compared to before the tibial lengthening surgery. This questionnaire has not been validated but is obtained as part of longitudinal tracking on all patients who undergo tibial lengthening at our center.

Overall, summary statistics were calculated in terms of means and SDs for continuous variables and frequencies and percentages for categorical variables. Group differences among continuous variables were evaluated using independent-samples t-tests (or their nonparametric equivalents if the assumption of normality was not met). Group differences for discrete variables were evaluated using the chi-square test or Fisher's exact test. Unadjusted odds ratios (OR) and their respective 95% CIs were calculated to assess the magnitude of the association.

These univariate analyses determined what risk factors were more likely to have resulted in a patient undergoing GSR. Factors we considered as possible risk factors in this analysis were amount of lengthening, percentage of lengthening, etiology, and osteotomy location. These variables were then considered candidates for inclusion in the formation of a multivariate binary logistic regression model. Age and sex were also included as additional variables to evaluate. Using a forward stepwise procedure, characteristics that failed to achieve a p value of 0.15 or below were removed from the final model. Because of the exploratory nature of the analyses, a p value of 0.15 was chosen as the critical threshold for retention. Characteristics that achieved a p value of 0.05 or below were called statistically significant factors. For all regression models, adjusted ORs and their respective 95% CIs were reported.

Two receiver operating characteristic (ROC) curves were created to determine the amount and percentage of lengthening that were most predictive of GSR (excluding patients who had their release done at the time of frame application since the recession was performed prophylactically before the tibial lengthening). We then calculated sensitivity, specificity, positive predictive values, and negative predictive values for the threshold. All analyses were performed using SPSS® (Version 20.0; IBM Corp, Armonk, NY, USA).

Results

Risk Factors

The risk factors for equinus contracture development and GSR indication included lengthening amount, percentage of lengthening, age, and etiology. Amount (49 mm versus 35 mm; $p < 0.001$) and percentage (16% versus 11%; $p = 0.003$) of lengthening were higher in those who had GSR (Table 2). Patients with greater than 42 mm and greater than 13% of lengthening were four times more likely to undergo GSR (OR: 4.13; 95% CI: 1.82, 9.40; $p = 0.001$; and OR: 3.88; 95% CI: 1.66, 9.11; $p = 0.001$, respectively). Patients with congenital etiology were almost twice more likely to undergo GSR than patients with other etiologies (odds ratio: 1.90; 95% CI: 0.86, 4.15; $p = 0.109$). Conversely, traumatic patients were 56% less likely to undergo GSR (OR: 0.44; 95% CI: 0.19, 0.99; $p = 0.046$). Age, sex, previous surgery history on the same limb, preoperative soft tissue scarring of the leg, preoperative knee and ankle strength, distal tibial osteotomy, and time in frame were not associated with the development of gastrocnemius contracture.

In the multivariate logistic regression model (Table 3), the following variables were included as candidates for evaluation: age, sex preoperative tibial length, time in frame, amount of tibial lengthening, percentage of tibial lengthening, and congenital etiology. Adjusting for all other variables in the model, age and amount of tibial

Table 2. Risk factors for GSR

Variable	No GSR (n = 41 patients/50 legs)		GSR (n = 41 patients/55 legs)		Odds ratio	95% CI		p value
	Number of legs evaluated	Value	Number of legs evaluated	Value		Lower	Upper	
Amount of lengthening (mm)*	50	35.08 (18.73)	53	48.94 (16.48)				< 0.001
Lengthening > 42 mm (number of legs)	50	16 (32.0%)	53	35 (66.0%)	4.13	1.82	9.40	0.001
Lengthening as percentage of preoperative tibial length*	45	10.83 (7.08)	50	15.80 (8.65)				0.003
Lengthening > 13% (number of legs)	45	15 (33.3%)	50	33 (66.0%)	3.88	1.66	9.11	0.001
Etiology (number of legs)								
Congenital	50	25 (50.0%)	55	36 (65.5%)	1.90	0.86	4.15	0.109
Developmental	50	1 (2.0%)	55	5 (9.1%)	4.90	0.55	43.47	0.208
Traumatic	50	22 (44.0%)	55	14 (25.5%)	0.44	0.19	0.99	0.046
Unclassified	50	2 (4.0%)	55	0 (0.0%)	NA	NA	NA	NA

*Values are expressed as mean, with SD in parentheses; GSR = gastrocsoleus recession; NA = not applicable.

Table 3. Results from the multivariate regression model

Variable	Crude odds ratio	95% CI		Adjusted odds ratio	95% CI		p value
		Lower	Upper		Lower	Upper	
Female sex	0.49	0.17	1.35				
Age	1.02	0.99	1.04	1.02	0.99	1.05	0.131
Preoperative tibial length (mm)	1.00	0.99	1.01				
Time in frame (months)	0.95	0.80	1.11				
Amount of lengthening (mm)	1.05	1.02	1.07	1.05	1.02	1.07	< 0.001
Lengthening as percentage of preoperative tibial length	1.11	1.04	1.18				
Congenital etiology	1.90	0.86	4.15				

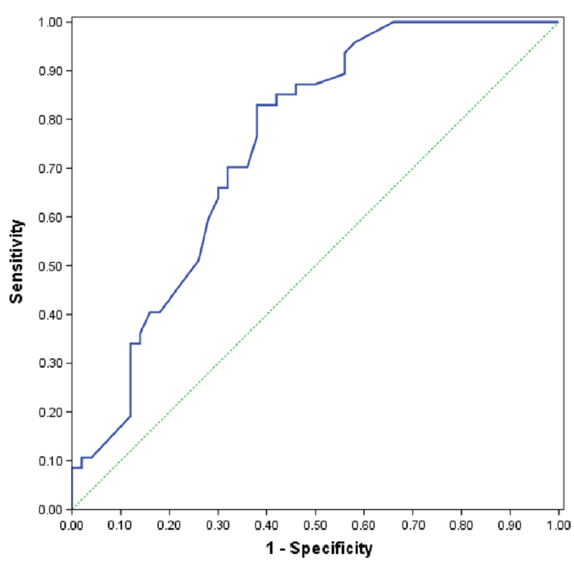
Blank values under the adjusted odds ratio column indicate variables that were not retained in the final model.

lengthening were found to be predictors for undergoing GSR. Yearly increases in age increased the risk of recession by an adjusted rate of 2% (adjusted OR: 1.02, 95% CI: 0.99, 1.05; $p = 0.131$). Although age was not statistically significant, it met the criteria for being maintained in the final model. Increased lengthening was found to increase the risk of GSR by 5% after controlling for all other variables in the model (adjusted OR: 1.05; 95% CI: 1.02, 1.07; $p < 0.001$).

According to ROC curve analysis, an amount of lengthening threshold of greater than 42 mm was the best predictor for undergoing GSR (Fig. 3A). An area under the curve value of 0.747 (95% CI: 0.649, 0.844) indicated that this was a good diagnostic indicator for GSR ($p < 0.001$). Diagnostic statistics of sensitivity (0.702), specificity (0.680), and positive (0.674) and negative (0.708) predictive values also confirmed this finding. Although univariate analysis showed a significant difference in percentage of tibial lengthening between patients who underwent GSR and those who did not (Table 2), this variable was not retained in the final multivariate model. We did however establish a threshold. Based on ROC curve analysis, a percentage of lengthening threshold of greater than 13% was found to be a predictor for undergoing GSR (Fig. 3B). When we ran the multivariate regression analysis, the amount of lengthening threshold of 42 mm was superior to the percentage of lengthening threshold of 13%.

ROM and Patient-reported Outcomes

Dorsiflexion was maintained and/or restored similarly among patients who did or did not undergo GSR when treated under our algorithm. In patients who underwent GSR, 8° of dorsiflexion was present before and after tibial lengthening. In patients who did not undergo GSR, the mean dorsiflexion dropped from 14° to 10° ($p = 0.002$). After GSR, patients gained a mean 24° of ankle dorsiflexion. The ankle dorsiflexion gained in each of the subgroups was 11° at frame application, 26° while in the frame, 26° at frame removal, and 14° after frame removal. The biggest changes in ankle dorsiflexion were in the patients who underwent GSR for recalcitrant contracture while in the frame or at frame removal (Table 4). There were no differences in the seven functional outcome parameters between groups based on the self-reported



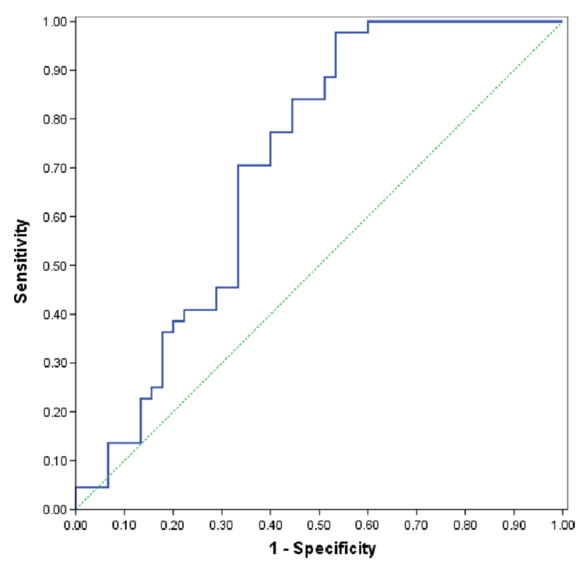
Area under the curve for ROC curve

Area under the curve	Standard error	p value	95% CI Lower bound	95% CI Upper bound
0.747	0.050	< 0.001	0.649	0.844

Diagnostic statistics for tibial lengthening cutoff of 42 mm

Lengthening measure	Sensitivity	Specificity	Positive predictive value	Negative predictive value
42 mm	0.702 (0.549, 0.822)	0.680 (0.532, 0.801)	0.674 (0.523, 0.794)	0.708 (0.557, 0.826)

A



Area under the curve for ROC curve

Area under the curve	Standard error	p value	95% CI Lower bound	95% CI Upper bound
0.709	0.056	0.001	0.599	0.820

Diagnostic statistics for tibial lengthening cutoff of 13% of preoperative tibial length

Lengthening measure	Sensitivity	Specificity	Positive predictive value	Negative predictive value
13%	0.705 (0.546, 0.828)	0.667 (0.509, 0.796)	0.674 (0.519, 0.800)	0.698 (0.537, 0.823)

B

Fig. 3A–B ROC curves depict cutoff values for (A) numerical tibial lengthening and (B) percentage of lengthening above which a patient is at an increased risk for equinus contracture.

Table 4. Ankle dorsiflexion gained after GSR in the four subgroups (determined by time and indication) of patients who underwent GSR

Timing	Indication	Number of patients/legs	Pre-GSR equinus contracture (°)*	Final ankle dorsiflexion (°)*	Ankle dorsiflexion gained (°)*	p value
At frame application	Preoperative contracture	8/8	2.5 (0–15)	3.5 (0–10)	11 (10–15)	0.082
While in frame	Recalcitrant contracture	7/9	20 (10–30)	6 (0–15)	26 (15–35)	< 0.001
At frame removal	Recalcitrant contracture	22/34	15 (0–30)	12 (0–50)	26 (10–45)	< 0.001
After frame removal	Recalcitrant contracture	4/4	9 (0–20)	5 (0–15)	14 (10– 0)	0.005
All		41/55	13 (0–30)	8 (0–20)	24 (10–45)	< 0.001

*Values are expressed as mean, with range in parentheses; GSR = gastrocsoleus recession.

Table 5. Results of a self-administered outcome questionnaire

Question	Number of affirmative responses/number of responses			p value
	GSR	No GSR	All patients	
Ability to toe off on both feet	29/30 (96.7%)	22/24 (91.7%)	51/54 (94.4%)	0.579
Ability to toe off on one feet	24/29 (82.8%)	21/24 (87.5%)	45/53 (84.9%)	0.715
Ability to run	23/27 (85.2%)	23/27 (85.2%)	46/54 (85.1%)	0.999
Presence of limp	6/28 (21.4%)	6/25 (24%)	12/53 (22.64%)	0.823
Necessity for assistance to walk	1/28 (3.6%)	4/25 (16%)	5/53 (9.4%)	0.176
Weakness of ankle compared to before tibial lengthening	8/28 (28.6%)	4/24 (16.7%)	12/52 (23%)	0.346
Stiffness of ankle compared to before tibial lengthening	9/26 (34.6%)	8/24 (33.3%)	17/50 (34%)	0.924

GSR = gastrocsoleus recession.

outcome questionnaire (Table 5). There was no difference in ankle strength, mobility, gait, and need for assistance when walking in patients after tibial lengthening whether or not they underwent GSR. The self-reported outcomes were negatively affected by preoperative weakness, neuromuscular disorders, tibial fracture or surgery especially if multiple and in the ankle/supramalleolar region, distal tibial osteotomy, and preexisting equinus contracture, but there were no differences in these parameters among all of the patients with tibial lengthening.

Complications

Two patients developed posterior tibial nerve neuropraxia after GSR. Both of these patients were early in our experience and underwent forced dorsiflexion after the soft tissue release, which is no longer our practice. Both patients underwent tarsal tunnel release and posterior tibial nerve decompression within 24 hours. The first patient had partial plantar sensation recovery, and the second patient completely recovered. There were no sural nerve or lesser saphenous vein injuries, wound complications, inadequate equinus correction, equinus recurrence, gastrocsoleus overlengthening, plantar flexion weakness, Achilles tendon rupture, and gait changes.

Discussion

Numerous nonoperative methods are used to try to prevent development of equinus contracture [14, 20]. During tibial lengthening, these are not always successful, and in that setting, GSR is commonly performed before, during, or after a tibial lengthening to prevent or relieve equinus contracture [6, 21]. However, the risk factors associated with gastrocsoleus contracture severe enough to warrant surgery during tibial lengthening and the consistency with which GSR results in a plantigrade foot in this setting have not been well defined. We therefore evaluated a clinical algorithm that defined when patients would or would not receive a GSR in the course of a tibial lengthening to identify (1) clinical risk factors triggering the use of GSR under the algorithm, (2) the ROM gains and patient-reported outcomes among patients treated under this algorithm, and (3) the complications associated with GSR.

Limitations of our study include a relatively small sample size (55 tibial lengthenings with a GSR and 50 tibial lengthenings without a GSR), loss of some patients to longer-term followup, and the partial reliance on nonvalidated self-reported outcomes in patients after GSR. A prospective study evaluating gait and ankle ROM and strength would better determine gait derangements and ankle dynamics after tibial lengthening and GSR. Some

Table 6. Comparison of our study with other studies from the literature

Study	Reported risk factors for joint contractures*			Outcomes
	% of lengthening	Mean lengthening (mm)	Etiology	Mean gain in ankle dorsiflexion after GSR (°)
Current study	13	42	Congenital	23.5
Antoci et al. [2]	15 (lower limb)		Acquired (lower limb)	
Belthur et al. [3]	> 20		Multiple	
Schroeder [17]				15.7
Saxena and Widtfeldt [16]			Multiple	12.6
Lehman et al. [10]		40–60	Multiple	
DiDomenico et al. [5]				18
Kim et al. [9]				10

*We could not identify studies that precisely established numerical risk factors for equinus contracture after tibial lengthening; blank values mean that these data were not available in the study listed; GSR = gastrocsoleus recession.

confounding variables, eg, congenital etiology and amount of lengthening, probably overlapped some, and we could not completely tease them apart even with multivariate analysis. There was transfer bias (loss to followup) and selection bias (retrospective study analyzing a general approach, but it probably was not followed perfectly). All of these limitations are unidirectional biases; that is, they would tend to make the surgical intervention appear better than it might be in a properly controlled, prospective study.

We found a mean tibial lengthening of greater than 42 mm, a tibial lengthening of greater than 13% of original bone length, increased age, and a congenital etiology to be risk factors for equinus contracture and a consequent GSR. This is consistent with previous studies (Table 6), which found that equinus contracture is related to lengthening rate, etiology, amount of lengthening, and the condition of the gastrocsoleus-Achilles tendon complex [3, 10]. Antoci et al. [2] found that, in children, a percentage of limb lengthening of greater than 15% places the patient at an increased risk for joint contracture. Dahl et al. [4] also reported that a lower-extremity lengthening of greater than 15% led to joint contractures. A study by Maffulli et al. [11] found an even greater threshold of 18% bone lengthening for joint contracture. The slightly higher threshold in these studies can be attributed to a pediatric population whose muscle fibers may have a greater ability to stretch and grow [6, 15, 21]. In a case series of 80 tibial lengthenings over an intramedullary nail, Kim et al. [9] reported a 72% equinus contracture rate. Tibial lengthening of greater than 20% preceded 95% of those cases that went on to develop equinus contracture [9]; however, this does not indicate that a lower degree of lengthening may not be a risk factor for contracture development.

The measured outcomes after GSR included ankle dorsiflexion and functional outcome. There was a gain of 24° in dorsiflexion with GSR (Fig. 4). All patients had a gain in dorsiflexion after GSR except for the subgroup that had release done at frame application (Table 4). This however was expected because the GSR was performed prophylactically in those patients with a preexisting contracture to prevent even more loss of dorsiflexion. Our GSR most closely resembled the Vulpius approach, allowing for a balance of both increased lengthening and stability of the muscle-tendon unit [6]. Ultimately, there were no differences in the seven self-reported outcomes or loss of ankle dorsiflexion between patients undergoing tibial lengthening who received a GSR to correct equinus contracture versus those who had no equinus contracture to correct. This may dispel the common criticism of GSR that it leads to permanent weakness and nerve damage [13]. Our ROM values after GSR were better than those reported in other studies (Table 6). Schroeder [17] only had a 16° increase in ankle dorsiflexion after endoscopic GSR while another study reported a 13° increase in dorsiflexion [19]. Additionally, DiDomenico et al. [5] accomplished an 18° gain in dorsiflexion after endoscopic GSR. These studies however did not examine patients undergoing tibial lengthening [5, 16, 17], and so the difference in etiology and timing of onset of gastrocsoleus contracture may have played a role in the different outcomes. The patients in the study of Saxena and Widtfeldt [16] received an endoscopic GSR for preexisting contractures secondary to multiple etiologies, while the studies of Schroeder [17] and DiDomenico et al. [5] did not define the etiology of the contracture in their patient populations. In their evaluation of tibial lengthening over an intramedullary nail for short stature, Kim et al. [9] reduced equinus contracture by a mean of 10° in those patients who had developed the contracture during the course of lengthening with a GSR after distraction but before removal of the frame. Finally, a difference in surgical approach to GSR may play a role in outcome as well.

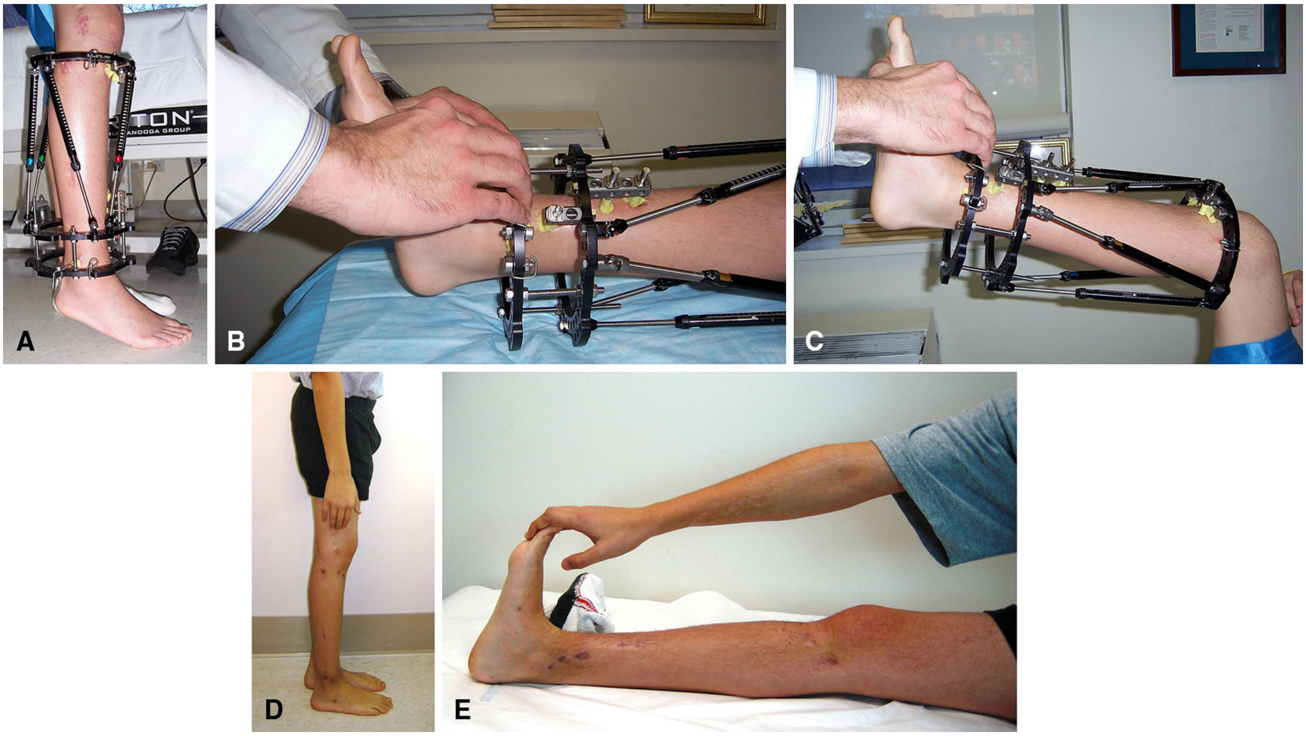


Fig. 4A–E Images illustrate the case of a 14-year-old boy with congenital LLD who underwent an 8-cm tibial lengthening. (A) Equinus contracture makes it difficult for the heel to reach the floor. (B, C) Demonstration of Silverskiold's test shows that the ankle can be passively dorsiflexed when the knee is flexed. After GSR, the patient (D) stands with plantigrade foot and (E) can dorsiflex ankle when the knee is in extension.

The complications that we encountered were posterior tibial nerve neuropraxias in two patients. Both of these patients had forceful dorsiflexion, as it was early in our experience. At the time of posterior tibial nerve decompression, the nerve was noted to be bruised and we learned from this experience the importance of avoiding acute dorsiflexion as this likely leads to a double-crush effect on the nerve already compromised from bone lengthening. One patient completely recovered, while the other patient had partial recovery of plantar sensation. Ippolito et al. [8] demonstrated in an animal model that moderate degenerative change was present in the myelin sheath after 8% lengthening, but normal structure was recovered after 2 months, supporting our impression of a double-crush phenomenon. Our complication rate after GSR was better than that found by Saxena and Widtfeldt [16] who reported a 15% incidence of lateral foot dysesthesia in the sural nerve distribution. This complication may be related to their use of endoscopic technique.

In conclusion, we found, consistent with other studies, that the amount of tibial lengthening, percentage of bone lengthened, and congenital etiology predicted the development of an equinus contracture with tibial lengthening. Being able to predict which patients are more likely to develop severe enough equinus to warrant a GSR after tibial lengthening can help clinicians emphasize the importance of nonsurgical techniques to prevent the development of equinus contractures, which may decrease the need for additional surgery, though this premise will need to be tested by prospective trials. We further found a substantial gain in ankle dorsiflexion after GSR and that the procedure did not impair function compared to patients managed without GSR.

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