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Surgical Outcomes After Minimally Invasive Release of Stroke-Related Equinovarus Contracture of the Foot and Ankle

Troy J. Boffeli, DPM, FACFAS[1], Rachel C. Collier, DPM, FACFAS[2], Elizabeth F. Neubauer, DPM, MSHA[3], D. Scot Malay, DPM, MSCE, FACFAS[4]

[1] Director, Foot & Ankle Surgery Residency Program, Regions Hospital/HealthPartners Institute for Education & Research, St. Paul, MN
[2] Attending, Foot & Ankle Surgery Residency Program, Regions Hospital/HealthPartners Institute for Education & Research, St. Paul, MN
[3] Resident, Foot & Ankle Surgery, Regions Hospital/HealthPartners Institute for Education and Research, St. Paul, MN
[4] Director of Podiatric Research and Staff Surgeon, Penn Presbyterian Medical Center, Philadelphia, PA

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ABSTRACT

Cerebrovascular accident frequently causes spastic equinovarus contracture of the foot and ankle, for which traditional surgical correction involves tendon transfer, osteotomy, and hindfoot fusion, which can be challenging for patients after cerebrovascular accident. We prospectively assessed the efficacy of a minimally invasive, ambulatory approach to correct this complex deformity in 12 consecutive patients. Surgery included Achilles tendon lengthening, lengthening of the posterior tibial tendon, and flexor tenotomy of all 5 digits. The 10-cm visual-analog scale and the Bristol Foot Score were used to assess pain and subjective foot-related quality of life, respectively. The mean patient age was 61.5 ± 5.68 years, and the duration of follow-up was 29.3 ± 18.5 (range 12.2 to 63.3) months. All patients had a preoperative equinovarus foot structure and all had a rectus foot in weightbearing stance at the 1-year postoperative evaluation. Nine (75.0%) patients showed no residual or recurrent deformity, whereas 3 (25.5%) displayed incomplete release of digital contractures; all patients were treated with in-office flexor tenotomy. Preoperative maximum ankle dorsiflexion was ≤90° in 12 (100%) patients and >90° in 9 (75.0%) patients postoperatively. The mean visual-analog scale score decreased in 10 (83.3%) patients, although a statistically significant decrease was not observed ($p = .0535$). The Bristol Foot Score improved from 55.17 ± 11.10 preoperatively to 36.83 ± 13.26 postoperatively, and this improvement was statistically significant ($p = .0022$). These outcomes demonstrate the effectiveness of the minimally invasive, ambulatory surgical approach to spastic equinovarus contracture without identified patient harm.

Stroke, or cerebrovascular accident (CVA), is the fifth leading cause of death for Americans and reduces mobility in more than half of stroke survivors aged ≥65 years (1). Spasticity associated with the loss of upper motor neuron inhibition is a known complication. Painful joint contractures impair function and reduce overall quality of life (QOL) (2). The most common deformity of the lower extremities after a stroke is equinovarus contracture of the foot and ankle (3,4). Although CVA is a nonprogressive neuromuscular condition, the upper motor neuron–induced flexion contracture and resultant disability frequently worsen over time as a result of spastic muscle imbalance (Fig. 1). Longstanding lower extremity contracture may progress to a nonreducible, rigid deformity that leads to altered gait, instability, and frequent falls. Further sequelae involving pressure sores, brace challenges, chronic joint pain, stress fractures, premature disability, and loss of independent living have been well documented (5–9).

Reconstructive surgery can correct deformity and improve function in cases of longstanding or advanced equinovarus deformity; however, long operative time, cessation of anticoagulation, and postoperative non-weightbearing are often impractical in this patient population. Boffeli and Collier (5) described a minimally invasive approach to equinovarus deformity correction that involves release of stroke-related tendon contractures and allows patients to be immediately weightbearing on the involved extremity. Ambulatory surgery for late-stage CVA-induced contracture of the lower extremity performed on an outpatient basis is not common practice but can provide several benefits to both the surgeon and the patient. Procedure selection was based on pathologic involvement of the entire posterior muscle group and involves lengthening the Achilles tendon (AT), posterior tibial (PT) tendon, flexor digitorum longus (FDL) tendons, flexor hallucis longus (FHL) tendon, and plantar intrinsic musculature. Sufficient lengthening of these

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Address correspondence to: Troy J. Boffeli, DPM, FACFAS, 640 Jackson Street, Mailstop 11501G, St. Paul, MN 55101.
E-mail address: Troy.J.Boffeli@HealthPartners.com (T.J. Boffeli).

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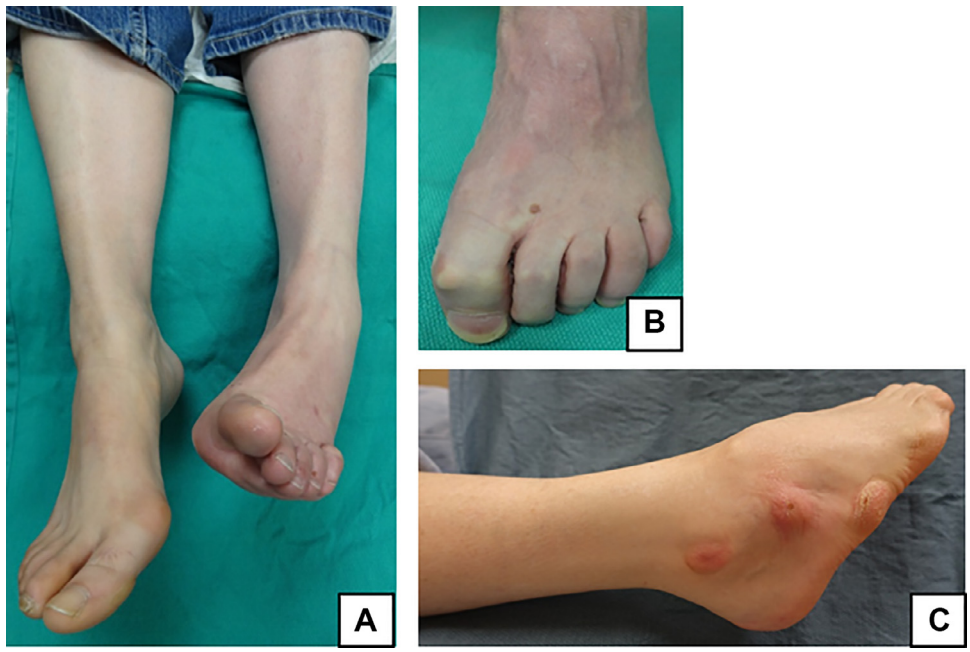

Fig. 1. Indications for soft tissue release of stroke-related contracture include pain, difficulty walking, wound breakdown, and brace-related problems associated with contracture and deformity. (*A*) Note plantarflexed and inverted left foot with (*B*) accentuation of digital contracture when weight-bearing. Pressure sores and painful pressure points are common, especially at the tips of the toes and along the lateral column of the forefoot. (*C*) Note ankle-foot orthosis brace–related pressure areas along bony prominences of the fifth metatarsal head and base, anterior process of the cuboid, and lateral malleolus.

tendons can be achieved by using a minimally invasive approach, and immediate postoperative weightbearing is encouraged. Bearing weight on the operative foot in the early postoperative period applies stretch on the local soft tissues and enables gliding movement of the tendons to reduce adhesions. The primary goal of this treatment protocol is to improve functional ability by creating a rectus, supple foot that is amenable to brace therapy.

A review of the literature indicates that there is a general lack of published reports that describe baseline pain and disability associated with stroke-related equinovarus deformity of the foot and ankle. The literature also lacks outcomes and QOL information after minimally invasive soft tissue lengthening procedures in patients with stroke-induced contracture. The present study analyzes both surgical outcomes and QOL improvements in adult patients whose foot and ankle contracture secondary to CVA was treated with a minimally invasive soft tissue release technique. Our hypothesis was that this group of patients would experience improved position of the foot and ankle after surgery, thereby rendering the foot suitable for bracing. In return, this was expected to diminish pain and improve foot-related QOL issues while avoiding overcorrection and recurrence of deformity. The primary study aim was to assess the change in foot-related QOL after our minimally invasive surgical approach. The secondary study aims were manual muscle strength testing (MMST) with active ankle dorsiflexion (DFn), passive ankle range of motion (ROM), weightbearing foot position in stance, deformity correction, and any complications associated with the operation.

Patients and Methods

After obtaining institutional review board approval (HealthPartners Institute Institutional Review Board, Bloomington, MN), we prospectively analyzed consecutive cases during the 5-year period from 2012 to 2016. Adult patients with equinovarus deformity of the foot and ankle secondary to stroke-related contracture who had not responded to conservative treatment were included. Patients with pressure sores or ulcerations in the involved foot were not excluded. Twelve patients met the inclusion criteria and were consecutively enrolled in this observational case series. Patients were excluded for the following reasons: acute phase of stroke recovery, permanently wheelchair bound and not expected to benefit from improved foot and ankle alignment, infected foot wound, <18 years of age, and not medically stable to undergo minimally invasive lower extremity surgery. Patient data on sex, age, side of involvement, activity level, body mass index, comorbid conditions, use of a brace, presence of ulceration, passive ankle joint DFn ROM, active ankle DFn strength (MMST), and foot position in stance were collected prospectively and were monitored throughout the observation period.

Preoperative Clinical Evaluation

All patients underwent a preoperative planning visit with the surgeon (coauthor T.J.B.) and a separate clinical evaluation by a board-certified foot and ankle surgeon who had no further involvement in the study (W.R.K.). The clinical evaluation included MMST with a focus on active ankle DFn ROM (defined later), maximum passive ankle DFn ROM with the knee extended, foot position in stance (valgus, rectus, varus, calcaneus, equinus, equinovarus, or equinovalgus), the presence or absence of an ulcer secondary to pressure related to skin contact with a brace, the presence of any other lower extremity deformities (i.e., hammer toes, hallux valgus, hallux limitus/rigidus, etc.), the use of a mobility device (cane, walker, or wheelchair), and activity level (defined later). Patients also reported their baseline level of pain by using a 10-cm visual-analog scale (VAS) (10–13) and completed a Bristol Foot Score (BFS) questionnaire (14) to determine their subjective preoperative functional status and foot-related QOL.

MMST was based on the standard grading scale where 0 represents no contraction, 1 represents a flicker or trace contraction, 2 represents active motion with gravity eliminated, 3 represents active motion against gravity, 4 represents some active motion against gravity and resistance, and 5 represents normal power. Patient activity level was defined by the number of hours per day a patient participated in weightbearing activity. A patient was sedentary if he or she participated in <1 hour of weightbearing activity daily, had moderate activity if he or she participated in 1 to 4 hours of weightbearing activity daily, and had constant activity if he or she participated in >4 hours of weightbearing activity daily.

Operative Technique

The specific surgical technique used to treat the series of patients in this investigation was previously described by Boffeli and Collier (5). In brief, the surgery was performed on an outpatient basis with the patient under general anesthesia or with a combination of monitored anesthesia care (MAC) and local anesthetic blockade of the target anatomic structures. The surgery was performed with the patient in the supine position in all cases. Tourniquet hemostasis was not used in any of the cases described in this report. If anticoagulated with warfarin or other anticoagulant, patients continued these medications as long as the international normalized ratio was at the low end of the designated therapeutic range (international normalized ratio <3.0 was considered safe for minimally invasive surgery). AT lengthening was performed with 1 of 2 techniques: minimally invasive triple hemisection described by Hoke (15) (Fig. 2) or open Z-lengthening with direct repair of the AT (Fig. 3). Open Z-lengthening of the PT tendon was performed through a 3- to 4-cm

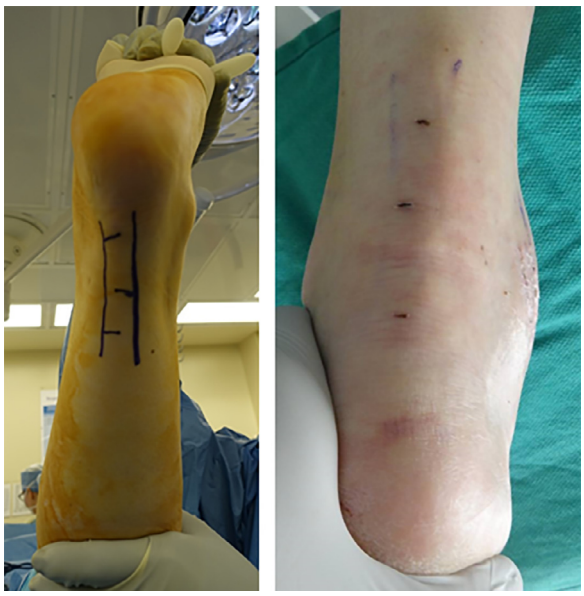

Fig. 2. Triple hemisection approach to Achilles tendon lengthening is preferred for patients with compromised skin quality, edema, or high likelihood of long-term brace therapy. There is potentially increased risk of weakness with this approach but much less concern for compromised soft tissue healing. This minimally invasive procedure is also easier to perform in the supine position compared with an open procedure.

incision extending from the tip of the medial malleolus to the navicular tuberosity (Fig. 4). The PT tendon ends were sutured in either a side-to-side or end-to-end fashion with the ankle joint dorsiflexed and subtalar joint everted to achieve a neutral, rectus position.

Follow-up Clinical Evaluations

Patients were reevaluated by the surgeon at 1 week, 2 weeks, 6 weeks, 6 months, and 1 year postoperatively. All patients were allowed to ambulate as tolerated in a below-knee fracture boot immediately after surgery. If incisions were healed and edema was well controlled by the 2-week follow-up appointment, patients were transitioned from the fracture boot to an ankle-foot orthosis (AFO). The previously fabricated solid AFO device was used postoperatively if the brace supported the foot in the corrected, neutral alignment. If the preoperative device did not adequately maintain a neutral/corrected alignment, patients were casted for a new AFO. Hinged AFOs were temporarily modified with a posterior strap (Fig. 5) to prevent dorsiflexion beyond 90°. The AFO was continued for at least 1 additional month to avoid overlengthening of the AT via excessive ankle dorsiflexion. Patients began physical therapy at 2 weeks postoperatively with a focus on gait and overall strengthening of the lower extremities. Patients were given clearance to ambulate without their AFO after the 6-week postoperative visit, and they were allowed to continue using ambulatory aids as deemed necessary for optimal gait and balance. AT strength was assessed at 6 weeks postoperatively to determine if the temporary AFO dorsiflexion stop should be removed or left in place for long-term support. At the 1-year postoperative visit, patients underwent repeat evaluation by the independent evaluator (W.R.K.). Postoperative variables were measured and recorded: MMST, foot position in stance, the presence or absence of an ulcer secondary to the brace, the presence or absence of recurrent deformity or overcorrection, any other complication, pain as measured using the 10-cm VAS, and BFS.

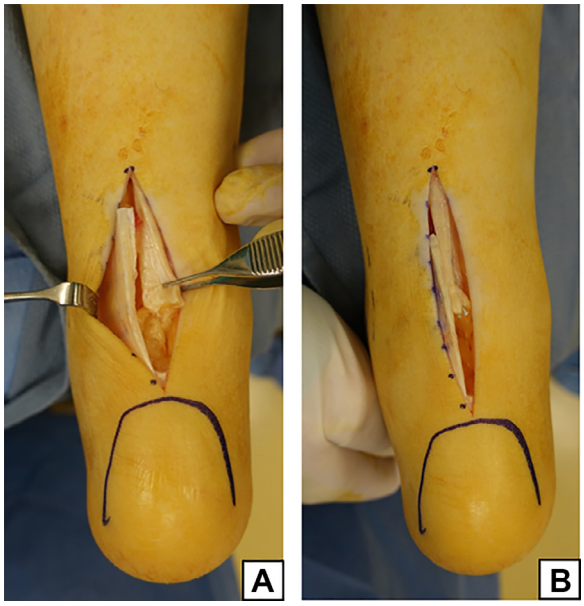

Fig. 3. Open Z-lengthening of the Achilles tendon is shown. Extensive lengthening is commonly necessary based on the severity of contracture. (*A*) This open procedure affords direct visualization for more controlled lengthening and is our preferred approach provided skin quality is adequate. (*B*) Suturing at the desired length helps to avoid overlengthening and recurrent contracture.

Outcomes of Interest

The primary outcome of interest was foot-related QOL as was measured by using the BFS, which evaluated patients' perceptions of their foot condition and its effect on their everyday life. The BFS is a validated and reliable health measure (Cronbach $\alpha = .9036$) (14). It includes 15 questions that involve the following patient-centered domains: pain, activity limitations, frustration with one's feet, gait, foot health, and footwear. Possible scores range from 15 ("best") to 73 ("worst"). Change in pain level, active ankle DFn MMST, passive ankle DFn ROM, foot position in stance, and deformity correction were secondary outcomes. Outcome parameters were previously described. MMST was used to evaluate strength of musculature in the anterior compartment to assess functional active DFn after the release of posterior contracture. MMST was graded on a 0-to-5 scale based on the examiner's subjective assessment, with 0 indicating no movement, 1 indicating trace muscle contraction, 2 indicating poor movement against gravity, 3 indicating full movement against gravity, 4 indicating fair movement against resistance, and 5 indicating normal strength against gravity and against resistance.

Statistical Analysis

Data analysis was performed with a focus on data type and distribution using descriptive statistical methods. Continuous variables were reported in terms of the mean ± standard deviation (SD), as well as the median (minimum, maximum range). Categorical variables were described in terms of frequency counts and percentages. Tests of the null hypothesis were used to compare the preoperative outcomes of interest with the postoperative outcomes of interest. Statistical significance was defined by using a 95% confidence interval ($p \leq .05$). The analyses were carried out by an unbiased statistician (coauthor D.S.M.) who did not participate in the care or clinical assessment of any of the patients described in this report.

Results

A statistical description of the cohort is given in Table 1. A total of 12 patients were analyzed in this case series: 8 (66.7%) males and 4 (33.3%) females. Their mean age was 61.5 ± 5.68 (range 54 to 73) years, and the mean duration of follow-up was 29.3 ± 18.5 (range 12.2 to 63.3) months. Stroke onset averaged 9.08 ± 6.41 (range 0.92 to 20.7) years before surgery. The mean body mass index was 31.1 ± 7.85 (range 21.5 to 46.3) kg/m^2. Surgery was performed on 5 (41.7%) right feet and 7 (58.3%) left feet. None of the patients underwent bilateral foot surgery.

All of the patients underwent the same initial intervention by a single surgeon (T.J.B.). All of the operations were performed with the patients supine, with 4 (33.4%) patients under general anesthesia and 8 (66.7%) patients under MAC combined with local anesthesia. None of the patients underwent additional procedures at the time of the operation. AT lengthening involved open Z-lengthening in 5 (41.7%) patients and triple hemisection percutaneous lengthening in 6 (50%) patients. One (8.33%) patient had neither procedure during the study but had undergone prior Achilles lengthening at an outside hospital by another surgeon. Two (16.7%) patients were admitted postoperatively, and the remaining 10 (83.3%) patients underwent outpatient surgery. Eleven (91.7%) patients resumed weightbearing immediately in a below-knee fracture boot, and 1 (8.33%) patient began weightbearing 14 days postoperatively.

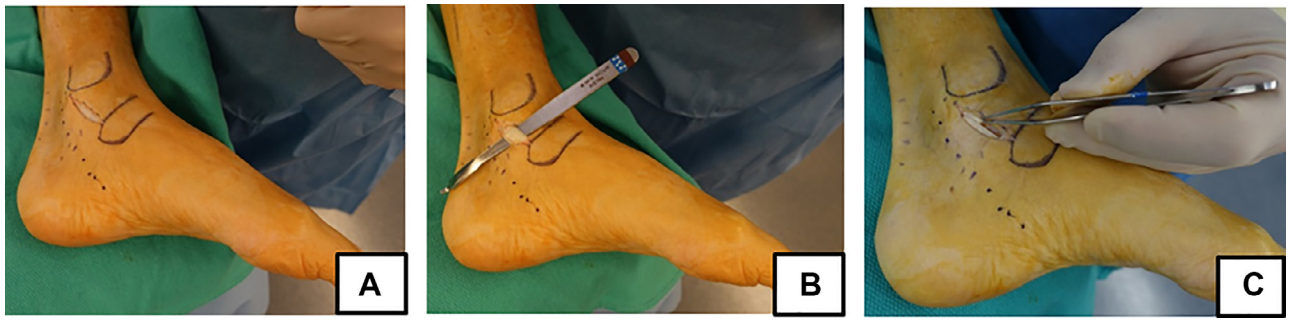

Fig. 4. Open Z-lengthening of the posterior tibial tendon is (*A*) performed through an incision from the medial malleolus to the navicular tuberosity. The dotted line represents neurovascular structures through the porta pedis, which diverges from the posterior tibial tendon at the medial malleolus. (*B*) The tendon sheath is opened and the tendon is isolated for direct lengthening. (*C*) Z-lengthening is shown here with slight overlap of tendon ends which allows suture repair at the desired length.

Three (25.0%) patients displayed incomplete release of digital contractures, and all 3 (25.0% overall, 100% of those with recurrent digital contracture) underwent a successful percutaneous flexor tenotomy procedure in the office, during a range of 6.86 to 68.1 weeks after the initial surgery. None of the patients experienced a postoperative wound complication such as infection, muscle weakness, or overcorrection within the postoperative observation period. None of the patients experienced new skin ulceration postoperatively. One (8.33%) patient had a brace-induced ulceration before surgery that resolved by 10 weeks postoperatively.

Table 2 depicts the statistical comparisons of the outcomes of interest between the preoperative and postoperative states. The BFS improved from 55.17 ± 11.10 preoperatively to 36.41 ± 12.49 postoperatively ($p = .0022$). The mean VAS pain score improved from 3.0 ± 3.22 preoperatively to 1.0 ± 1.65 postoperatively ($p = .0535$). MMST improved from an overall preoperative value of 1.66 ± 1.67 to a postoperative value of 2.83 ± 1.99 ($p = .0039$). As for the separate MMST categories, no statistically significant trend was observed when the preoperative and postoperative categories were compared ($p = .606$). Active ankle DFn strength improved by at least 1 manual muscle grade in 9 (75.0%) patients and remained the same in 3 (25.0%) patients. Strength did not decrease in any of the patients studied. Active ankle DFn improved by 1 MMST grade in 5 (41.7%) patients, by 2 grades in 3 (25.0%) patients, and by 3 grades in 1 (8.33%) patient. Three patients (25.0%) experienced no change in DFn MMST; all of these began the study with 0/5 muscle strength in the assessed muscle group.

Fig. 5. The existing hinged ankle-foot orthosis (AFO) can be modified for early postoperative rehabilitation. Temporary straps are applied to the posterior aspect to prevent excess ankle joint dorsiflexion to protect the healing Achilles tendon. This brace is used from weeks 2 to 6 routinely and for longer in patients who require ongoing brace therapy. Rigid AFOs assist with balance in patients with weak posterior muscle strength.

When the overall activity level was compared between preoperative and postoperative data of 0.5 ± 0.8 1 ± 0.9, respectively, no statistically significant difference was observed ($p = .3173$). Regarding the separate activity level categories, no statistically significant trend was observed when the preoperative and postoperative categories were compared ($p = .225$). With regard to activity level, 4 (33.3%) patients increased their activity level postoperatively, 7 (58.3%) had no change in activity level, and 1 (8.33%) experienced a decrease in activity level postoperatively. This last patient was still able to maintain a moderately active lifestyle with between 1 and 4 hours of weightbearing activity daily.

With regard to the ulceration categories, no statistically significant trend was observed when the preoperative and postoperative categories were compared ($p = .58$). In separate mobility device categories, no statistically significant trend was observed when the preoperative and postoperative categories were compared ($p = .286$).

In ankle dorsiflexion ROM categories, where patients with maximum DFn of ≤90° were considered to have equinus (unable to passively dorsiflex the ankle joint beyond 90° while seated with the knee extended) and patients who reached >90° were considered to have no equinus, a statistically significant trend was observed between preoperative and postoperative cohorts ($p < .0001$). All 12 patients displayed preoperative equinus. Postoperatively, 3 patients reached 90° of DFn and 9 reached >90°, indicating no residual eqinus in 75.0% of the patients studied. None of the patients experienced a loss of DFn ROM.

In the brace use categories, no statistically significant trend was observed when the preoperative and postoperative categories were compared ($p = .896$). However, in the weightbearing foot position categories, a statistically significant change was observed when the preoperative and postoperative categories were compared ($p < .0001$). All 12 patients in this series had a preoperative weightbearing equinovarus deformity, and all displayed a rectus stance phase foot position by 1 year postoperatively. None of the patients experienced overcorrection of their equinovarus deformity.

Attention was paid to the type of AT lengthening that was undertaken. In this series of patients, 6 (50.0%) of the patients underwent a

Table 1
A statistical description of the case series (N = 12 patients)

Age, y	61.50 ± 5.68 [60.5 (54, 73)]
Race, n (%)	
Asian	2 (16.67)
White	10 (83.33)
Ethnicity, n (%)	
Not Hispanic or Latino	12 (100)
Insurance, n (%)	
Medicare	6 (50.0)
HMO	6 (50.0)
Sex, n (%)	
Male	8 (66.67)
Female	4 (33.33)
Laterality, n (%)	
Left	7 (58.33)
Right	5 (41.67)
Height, in	63.07 ± 8.50 [62.85 (42, 77)]
Weight, lb	203.83 ± 57.11 [193.50 (130, 332)]
Body mass index, kg/m^2	31.10 ± 7.85 [29.58 (21.48, 46.33)]
Body mass index category, n (%)	
Within normal limits	3 (25.00)
Overweight	5 (41.67)
Obese	4 (33.33)
Loss of protective sensation, n (%)	0 (0.00)
Absence of ≥1 pedal pulse, n (%)	0 (0.00)
Symptom duration (time between onset of stroke and surgery), y	9.08 ± 6.41 [8.36 (0.92, 20.65)]
Actively employed preoperatively, n (%)	2 (16.67)
Comorbidities, n (%)	
Hypertension	7 (58.33)
Multiple comorbidities including DM	4 (33.33)
Multiple comorbidities excluding DM	1 (8.33)
Other	6 (50.00)
Medications, n (%)	
Aspirin	7 (58.33)
Antihypertensive	8 (66.67)
Polypharmacy	8 (66.67)
Coumadin	2 (16.7)
Smoking status, n (%)	
Never	8 (66.67)
Former	2 (16.67)
Active	1 (8.33)
Other contracture, n (%)	
Upper extremity	11 (91.67)
Knee	2 (16.67)
Other	1 (8.33)
Duration of treatment/follow-up, mo	29.3 ± 18.5 [23.4 (12.2, 63.3)]
Type of anesthesia, n (%)	
General	4 (33.33)
MAC + local	8 (66.67)
Same-day surgery, n (%)	
Yes	10 (83.33)
No	2 (16.67)
Achilles lengthening, n (%)	
Open Z	5 (41.7)
Triple hemisection	6 (50.0)
Activity level	
Baseline	0.5 ± 0.8 [0 (0, 2)]
Final	1 ± 0.9 [1 (0, 2)]
Change	0 ± 0.9 [0 (−1, 2)]
Percent change	42 ± 90.0 [−100, 200)]
BFS	
Baseline	55.17 ± 11.10 [58 (34, 70)]
Final	36.83 ± 13.26 [35 (18, 61)]
Change	−18.33 ± 11.48 [−16.5 (−34, 2)]
Percent change	31.11 ± 18.12 [27.5 (3.33, 56.67)]
VAS pain score	
Baseline	3.00 ± 3.22 [3 (0, 10)]
Final	1.00 ± 1.65 [0 (0, 4)]
Change	−2.00 ± 3.74 [−2 (−10, 0)]
Percent change	26.67 ± 32.57 [20 (0, 100)]

Abbreviations: BFS, Bristol Foot Score; DFn, dorsiflexion; DM, diabetes mellitus; MAC, monitored anesthesia care; MMST, manual muscle strength testing; VAS, visual-analog scale.
Results are reported as mean ± standard deviation [median (minimum, maximum range)] for continuous numerical variables and as frequency count (%) for categorical variables.

3-incision percutaneous Hoke lengthening and 5 (41.7%) underwent an open frontal plane lengthening. One (8.33%) patient had previously undergone tendo-AT lengthening before the intervention performed and analyzed in this study. Null hypothesis testing between the patients by type of AT lengthening revealed no statistically significant differences in terms of the outcomes of interest (Table 3).

Table 4 depicts the pairwise correlation coefficients for the final VAS pain score and the final BFS by selected baseline covariates. In regard to the final VAS pain score, inverse correlations were observed for the baseline activity level (–0.2449), BFS (–0.1983), VAS pain score (–0.0855), and MMST (–0.1319), whereas positive correlations were observed for baseline brace use (0.3358) and smoking (0.0823). As a rule of thumb, correlation coefficients between 0.00 and 0.30 are considered weak, those between 0.30 and 0.70 are considered moderate, and those between 0.70 and 1.00 are considered high. With this in mind, the correlations of baseline activity, BFS, VAS pain score, MMST, and smoking were all weak, whereas the correlation between the final VAS pain score and baseline bracing was moderately positive. As for the correlation of the final BFS by baseline covariates, moderately strong inverse correlations were observed for activity level (–0.523), MMST (–0.6861), and smoking (–0.5563), whereas moderately strong positive correlations were observed for the baseline BFS (0.5910), VAS pain score (0.3867), and preoperative bracing (0.3308).

Discussion

Nonoperative care of stroke-related spastic contracture of the foot and ankle is the mainstay of treatment and begins in the acute phase of rehabilitation. Initial treatment strategies aim to minimize resultant equinovarus contracture deformity of the foot and ankle. Physical therapy, AFO bracing, ambulatory aids, and oral drug therapy for muscle relaxation are frequently instituted with the immediate goal of maintaining or restoring ambulatory status. Maximum neurologic recovery is thought to occur during the initial 6 to 9 months after stroke onset, when surgery is not considered (3,6,16). Long-term treatment with lifetime brace therapy and muscle relaxants is effective for many patients with stroke. Phenol nerve blocks or botulinum toxin type A (Botox, Allergan, Inc., Irvine, CA) is the next line of treatment in recalcitrant cases (6,17,18). Injection therapy is painful and requires repeat treatment because botulinum toxin type A and phenol provide only temporary relief of spasticity. Surgery is not commonly considered for stroke-related equinovarus contracture because of the prevailing assumption that this patient population is too frail to undergo traditional reconstructive procedures. Many patients with stroke are therefore left with residual contracture deformity and a lifetime of disability and ongoing healthcare needs.

Despite stroke being a nonprogressive neurologic condition, long-term spasticity of the posterior muscle group results in muscle imbalance leading to a progressively plantarflexed and inverted foot with eventual digital contracture (Fig. 6). Patients are frequently diagnosed with drop foot, but this is often inaccurate because weakness of the anterior muscle group is not the primary issue. Longstanding deformity may eventually become nonreducible, which can lead to failure of brace therapy and ultimately the loss of a functional or stable gait. It is also common to examine a seemingly supple foot that then contracts into an equinovarus position when walking because of the stretch response. This creates challenges with AFO brace therapy when a neutral position brace does not control weightbearing-induced spastic contracture. The AFO brace is frequently painful to wear despite extensive modifications and may result in pressure sores along the lateral foot or ankle that are prone to infection. Uncontrolled equinovarus deformity ultimately affects QOL in regard to pain, difficult ambulation, fear of falling, loss of independent living, decreased mobility, and possible wheelchair confinement. Weightbearing examination is sometimes deferred in this

Table 2
Comparisons of outcomes of interest between the preoperative and postoperative states (N = 12 patients)

Variable	Preoperative	Postoperative	*p* value
BFS	55.17 ± 11.10	36.41 ± 12.49	.0022
VAS pain score	3.00 ± 3.22	1.00 ± 1.65	.0535
MMST			
Overall	1.66 ± 1.67 [1 (0, 4)]	2.83 ± 1.99 [3 (0, 5)]	.0039
Scale, n (%)			
0—None, no clinical evidence of muscle contraction	4 (33.33)	3 (25)	.606
1—Trace, visible or palpable contraction without gross joint motion	3 (25)	0	
2—Poor, able to move only after elimination of influence of gravity			
3—Fair, able to move against gravity only	1 (8.33)	1 (8.33)	
4—Good, mild-moderate resistance at end range of motion			
5—Normal, full resistance at end range of motion	1 (8.33)	4 (57.14)	
Activity level			
Overall	3 (25)	0	
Time spent weightbearing, n (%)	0	4 (33.33)	
Sedentary (continuous weightbearing <1 hour)			
Moderate (continuous weightbearing ≥1 hour and ≤4 hours)	0.5 ± 0.8 [0 (0, 2)]	1 ± 0.9 [0 (0, 2)	.3173
Continuous (continuous weightbearing >4 hours)			
Ulceration, n (%)	8 (66.67)	5 (41.67)	.225
No ulcer	2 (16.67)	3 (25)	
Ulcer associated with brace			
Ulcer, not associated with brace	2 (16.67)	4 (33.3)	
Mobility device, n (%)			
None	10 (83.33)	11 (91.7)	.58
Cane or walker	1 (8.33)	1 (8.33)	
Wheelchair	1 (8.33)	0	
Cane or walker plus wheelchair			
Ankle DFn, n (%)	1 (8.33)	2 (16.67)	.286
Equinus (≤90°)	7 (58.33)	8 (66.67)	
No equinus (>90°)	1 (8.33)	1 (8.33)	
Brace use, n (%)	3 (25)	1 (8.33)	
Never			
<3 times per week	12 (100)	3 (25.00)	.0001
≥3 times per week	0 (0.00)	9 (75.00)	
Always			
Weightbearing foot position, n (%)	3 (25.00)	3 (25.00)	.896
Equinovarus	0	2 (16.67)	
Rectus	2 (16.67)	0	
	7 (58.33)	7 (50)	
	12 (100)	0	<.0001
	0	12 (100)	

Abbreviations: BFS, Bristol Foot Score; DFn, dorsiflexion; MMST, manual muscle strength testing; VAS, visual-analog scale.

Table 3
Comparison of outcomes by type of Achilles tendon lengthening (N = 11 patients)

Outcome	Open (n = 5)	Percutaneous (n = 6)	*p* value
BFS	35.6 ± 4.39 [34 (32, 43)]	39.33 ± 16.75 [42 (18, 57)]	.4652
MMST DFn	2 ± 2.12 [2 (0, 5)]	3.17 ± 1.84 [3 (0, 5)]	.2947
VAS pain	0.8 ± 1.79 [0 (0. 4)]	0.83 ± 1.6 [0 (0, 4)]	.7266
Activity level	1 ± 0.71 [1 (0, 2)]	0.5 ± 0.84 [0 (0, 2)]	.2373

Abbreviations: BFS, Bristol Foot Score; DFn, dorsiflexion; MMST, manual muscle strength testing; VAS, visual-analog scale.
One patient had an Achilles tendon lengthening before the investigation.

patient population, which is unfortunate because the examiner should appreciate foot and ankle function in a state of spasm as this is a key factor influencing AFO brace tolerance and potential benefit from surgical treatment.

Various surgical treatments have been described for the correction of equinovarus contracture deformity. The primary goal of surgery is to create a plantigrade foot that is amenable to bracing. This ultimately improves ease of weightbearing transfers, reduces pressure-related sores, relieves pain, and improves ambulatory function. Traditional reconstructive approaches involve a combination of AT lengthening with or without posterior ankle joint capsular release, various tendon

Table 4
Pairwise correlation coefficients (*r*) for baseline visual-analog scal pain by baseline Bristol Foot Score and final visual-analog scale and Bristol Foot Score scores by other baseline covariates (N = 12 patients)

VAS pain score by baseline BFS: 0.47570						
Final VAS pain score by:						
Baseline	Activity level	BFS	VAS pain	Brace	MMST	Smoking
	–0.2449	–0.1983	–0.0855	0.3358	–0.1319	0.0823
Final BFS by:						
Baseline	Activity level	BFS	VAS pain	Brace	MMST	Smoking
	–0.523	0.5910	0.3867	0.3308	–0.6861	–0.5563

Abbreviations: BFS, Bristol Foot Score; MMST, manual muscle strength testing; VAS, visual-analog scale.

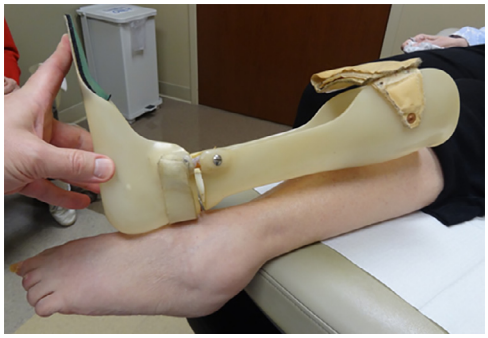

Fig. 6. Stroke is a nonprogressive neurologic disorder; however, the foot and ankle become progressively deformed due to spasticity of the posterior muscle group that overpowers the anterior and lateral muscle groups. This patient demonstrates severe plantarflexion and inversion deformity. The ankle-foot orthosis (AFO) brace shown was made 15 years earlier when the foot was still supple and reducible. Immobility and lack of constant weightbearing stress on the foot likely allow more rapid progression of deformity. AFO bracing is not practical or comfortable with nonreducible deformity.

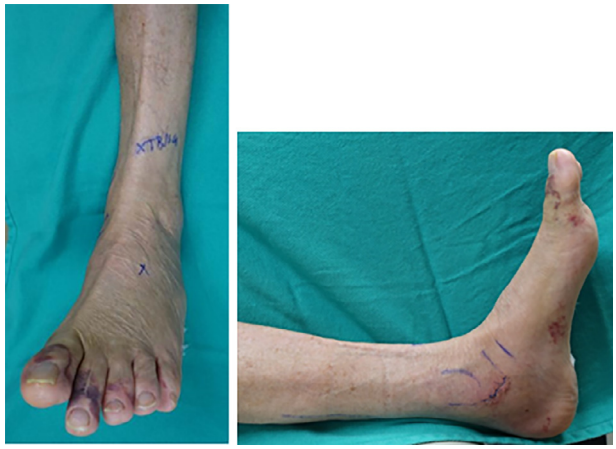

Fig. 7. Active dorsiflexion to neutral position is shown here at 2 weeks postoperatively. Note visible tension on the tibialis anterior and extensor hallucis longus. These muscles were not capable of dorsiflexion preoperatively due to spasticity and overpowering of the posterior muscle group.

transfers, tendon lengthening or release, calcaneal osteotomy, and hindfoot fusion (6,8). Patients who have experienced a stroke are not ideal candidates for major reconstructive procedures because of the combined risks associated with general anesthesia, cessation of anticoagulation medications, and long periods of postoperative non-weightbearing. Stroke survivors are commonly overlooked as surgical candidates because of the perception that surgery must be extensive to be effective. There is also fear that surgery will cause harm, leading to medical complications, overcorrection, weakness, and future gait challenges. This study demonstrates that minimally invasive soft tissue modalities are effective without any identifiable harm to the patient. Rectus rearfoot alignment was achieved in all patients without adjunctive osseous procedures or ankle joint capsulotomy.

Stroke patients are not generally referred to a foot and ankle surgeon for surgery but rather for foot pain, instability, bracing needs, infected pressure sores, or fractures related to deformity or falls. Nearly all stroke patients have had initial rehabilitation within the first 6 to 9 months after stroke but many have not had ongoing physical or medical intervention other than long-term AFO brace therapy. Consultation for medical treatment of ongoing spasticity elsewhere in the body (upper extremity, hip, and knee) is important even if foot surgery is being considered because this affects the overall function of the affected side. Despite botulinum toxin type A injections being painful and temporary, the effectiveness of deformity correction after injection can help predict the effectiveness of surgical treatment. Assessment of past and current brace therapy is important in determining if brace modifications alone will improve function and pain. Muscle inventory is also a crucial part of the preoperative assessment, but rigid equinovarus deformity does not allow full assessment of anterior muscle group function. Surgeons should be especially cautious in patients who appear to have drop foot or spastic contracture of the tibialis anterior (TA) tendon as these conditions are typically treated with more invasive procedures (muscle transfer) than what is described in the present study. In our experience, the TA tendon is not a major deforming force in stroke contracture but, rather, appears taut due to the plantarflexed and inverted position of the foot. The TA tendon is left unaltered in our surgical protocol, and the surgeon should expect some degree of functional recovery to allow active DFn after release of posterior muscle contracture (Fig. 7). We observed that 81.8% of the patients who began the study with fixed plantarflexed deformity achieved >90° of active ankle dorsiflexion at the time of their 1-year postoperative evaluation ($p < .0001$; Table 2).

There is a general lack of literature that reported the outcomes and QOL after ambulatory, minimally invasive soft tissue correction in patients with stroke-related contracture of the foot and ankle. Renzenbrink et al (19) performed a systematic review in 2012 to assess the effects of surgery on equinovarus deformity in patients after stroke or traumatic brain injury. A total of 15 studies (985 patients) including case series and case-control studies were included, with all studies reporting Level 4 evidence. Patients were treated with a variety of procedures to correct equinovarus deformity, most frequently involving tendon transfer or tendon lengthening procedures. Two patients underwent triple arthrodesis. Forty-one medical complications were reported, including 20 wound infections, 6 tendon ruptures, 5 screw pull-outs, and 3 deep vein thromboses. Toe curling was the most common, with a reported incidence of 45 of 95 residual or recurrent deformities. Additional recurrent deformities included 31 equinovarus, 8 varus, 5 equinus, and 5 valgus. Their findings demonstrated that surgical intervention can create a balanced foot position, improve walking capacity, and diminish the need for orthotic use; however; they cautioned that higher-level evidence is warranted. Redfen et al (8) retrospectively evaluated 10 patients who underwent soft tissue release to alleviate equinovarus contracture due to Parkinson disease, multiple sclerosis, or traumatic brain injury. Follow-up data for 8 of the 10 patients showed no incidence of loss of correction or overcorrection.

Our surgical approach was consistent in all patients with the exception of open Z-lengthening versus percutaneous triple hemisection lengthening of the AT. Stroke contracture generally affects the entire posterior muscle group in the lower leg. It is therefore warranted to lengthen all tendons, including the AT, PT tendon, FHL tendon, and FDL tendon. We have found that releasing the FHL and FDL tendons at the level of the digits is more effective than releasing the flexor tendons through the PT tendon incision. The PT tendon incision is intentionally made distal to the medial malleolus and proximal to the navicular because this is where the tendon is most superficial and easily palpable. The incision would allow easy access for FDL tendon lengthening, but FHL tendon access would require dissection traversing the neurovascular bundle. Lengthening the AT and PT tendon in this patient population universally causes accentuation of interphalangeal and metatarsophalangeal joint flexion contractures, requiring long flexor and plantar intrinsic lengthening. Flexor tenotomy along with interphalangeal joint capsulotomy was performed on all digits by using a minimally invasive, transverse incisional approach (Fig. 8). Release of the long flexors at the level of the interphalangeal joints is advantageous because it releases the tight joint capsule and longstanding contracture of the intrinsic musculature. (Fig. 9 demonstrates effectiveness of flexor release at the digital level.) We did identify recurrence of digital deformity in 3 (25.0%) of 12 patients, which we believe was associated with

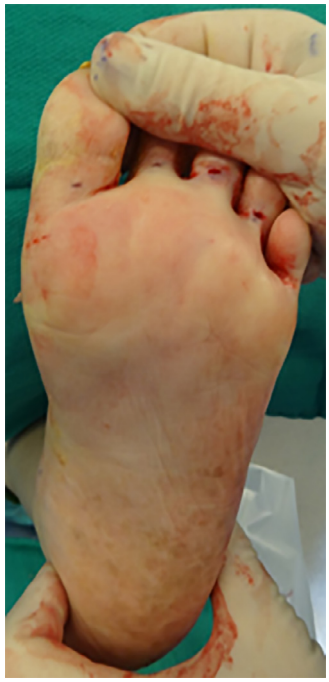

Fig. 8. Flexor tenotomy is performed at the plantar aspect of all 5 digits. This minimally invasive approach is performed with a chisel blade. Release at this location allows access for intrinsic muscle release as well as capsulotomy if needed for longstanding digital contracture.

performing the procedure under general anesthesia and MAC. This minimally invasive digital procedure is more commonly performed in the office under local anesthesia, where the patient can actively contract the toes to assess the effectiveness of the release.

The decision to perform open versus percutaneous AT lengthening for a given patient was based on the anticipated postoperative use of an AFO and quality of soft tissue at the ankle level. Open AT lengthening is especially beneficial for patients who are motivated to ambulate without the use of an AFO postoperatively because direct visualization affords the ability to lengthen gradually before suturing the tendon at the desired length. The triple hemisection percutaneous approach was preferred when the posterior skin was compromised by age-related atrophy or chronic edema. This technique was also useful in patients who were more likely to be reliant on an AFO brace for functional ambulation. Although this study presents a small patient population, we did not identify a significant difference in postoperative strength or function between these 2 methods of AT lengthening (Table 3).

Our surgical protocol was intentionally designed to allow patients to ambulate on the operative extremity in a below-knee fracture boot immediately after surgery. This made surgical intervention more practical in this patient population who also commonly struggle with ipsilateral upper extremity dysfunction, making non-weightbearing transfers more difficult (Fig. 10). Immediate postoperative weightbearing and ambulation provide stretch on the lengthened tendons and previously contracted soft tissues, which helps to ensure adequate correction of a longstanding deformity. Protected weightbearing was continued for 6 weeks—fracture boot for the first 2 weeks then AFO with dorsiflexory strap for 4 weeks. After that, the AFO and posterior strap were optional and patients were permitted to return to normal shoes and activity as tolerated. Two (16.7%) patients required a short hospital stay for low oxygen saturation after general anesthesia. Of the comorbidities that were evaluated, one of the admitted patients had the most comorbidities with 6 recorded, whereas the other patient had a similar to average number of comorbidities, with 2 recorded. Both patients were obese (body mass index 35.12 and 50.23 kg/m^2), and both had obstructive sleep apnea. The admissions for low oxygen saturation were not believed to be CVA related.

We anticipated modest improvements in BFS scores, which measured foot-related QOL preoperatively and 1 year postoperatively. Minimally invasive release of foot and ankle contracture is not anticipated to completely correct the deformity or to recreate normal lower extremity function in this challenging patient population; thus, it is prudent to establish realistic expectations with the patients preoperatively. Our overall goal of surgery was modest: release the contracture enough to provide a rectus foot that was amenable to neutral bracing in an AFO. Dysfunctions of the upper extremity, hip, and knee were not addressed and often had an ongoing negative impact on QOL assessment captured by the BFS. Despite these modest goals, BFS demonstrated a statistically significant improvement between preoperative and 1-year postoperative scores with a value of $p = .0022$ (Table 2).

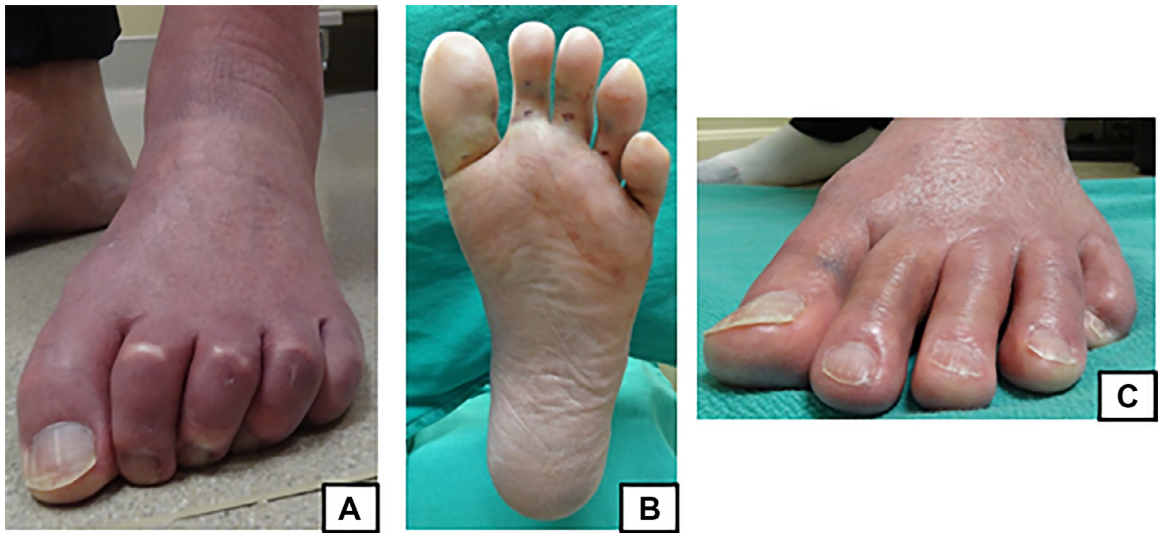

Fig. 9. (*A*) Note severe digital contracture preoperatively with blanching of the skin over the proximal interphalangeal joints and pressure at the tips of the toes. Blanched skin predisposes to ischemic sores on the dorsal prominences and at the distal tips of the toes. Release of contracture is shown 2 weeks later with healed plantar digital incisions (*B*) and straight toes when standing (*C*).

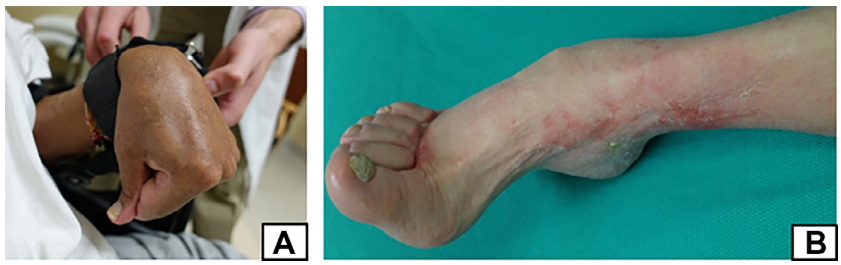

Fig. 10. Major reconstructive surgery is a challenge for patients with cerebrovascular accident–related weakness, contracture, spasticity, and gait disturbance. (*A*) Unilateral involvement typically involves the upper extremity, which frequently makes non-weightbearing recovery impractical or impossible. Note severe contracture through the elbow, wrist, and hand. (*B*) Patients often struggle with transfers, which results in facility placement if surgery requires non-weightbearing recovery and family cannot provide sufficient assistance. One goal of our minimally invasive, ambulatory approach is to allow patients to maintain residence in their home while recovering.

Patient-reported level of foot and ankle pain is not widely considered as a major component of disability in this patient population and the baseline level of pain is not often reported in the literature. This study establishes a link between pain level and functional status in this unique population. Data demonstrated a positive correlation between pain and function in the pretreatment state—as VAS score increased (worse pain), BFS also increased (worse function) ($r = 0.4757$), suggesting a possible association of decreased QOL with increased pain (Table 4). Examiners also observed this trend through preoperative discussions with patients. An increased level of foot and ankle pain was typically associated with decreased functional status because of a decreased desire and/or willingness to ambulate. Improvement in level of pain postoperatively was noted at 1-year follow-up in 10 (83.33%) patients based on VAS pain score data. One (8.33%) patient reported the same level of pain and only 1 (8.33%) other patient reported an increase in pain.

Further consideration of the correlations between the pretreatment, baseline covariates, and the final VAS and BFS scores (Table 4) was not very informative, although the results are somewhat interesting. When interpreting the results, it is important to keep in mind that, as a rule of thumb, correlation coefficients between 0.00 and 0.30 are considered weak, those between 0.30 and 0.70 are considered moderate, and those between 0.70 and 1.00 are considered strong. Also, negative or inversed correlation means that as one covariate increases in value, the other decreases in value. It is also important to note that a worse BFS has a higher score, as do the VAS pain and the bracing scores, whereas activity level and MMST are clinically better as the numbers increase. These correlations suggest that as the baseline activity level, VAS pain score, BFS, and MMST scores increased, the final VAS pain score decreased (i.e., the patient had less pain), and as pretreatment bracing and smoking increased, so, too, did the final VAS pain score (i.e., the patient had more pain). In regard to foot-related QOL, as activity level, MMST, and smoking increased, the final BFS decreased (i.e., the foot was subjectively better), whereas as pretreatment BFS, VAS pain, and bracing increased, so, too, did the final BFS.

All of the patients in this study had preoperative equinovarus deformity when standing and all achieved a rectus foot in stance that was maintained at the 1-year postoperative follow-up assessment. We anticipate that there would be no recurrence of deformity after 1 year despite a propensity for ongoing lower extremity spasticity. The best defense against recurrent contracture is to ambulate daily. We did not mandate the use of an AFO beyond 6 weeks postoperatively, but most of the patients tended to walk without the brace at home and used the AFO for community ambulation.

A secondary aim of this study was to identify if the stroke patients were at an increased risk of complications associated with minimally invasive ambulatory surgery. Despite perceived fear of surgical complication in this population, we did not identify any complications in 12 consecutive patients during the observation period of 29.3 ± 18.5 (range 12.2 to 63.3) months after the intervention. We routinely consult the primary care provider in an effort to circumvent perioperative cessation of anticoagulation. We recommend perioperative monitoring of the institutional review board to ensure that the level is within the therapeutic range (ideally <3.0). Bridging therapy can increase risk of postoperative bleeding because of to the combination of warfarin and heparin given postoperatively. Intraoperative bleeding was able to be controlled in all patients. We did find that this population was prone to lower extremity edema due to age, dependent foot position, and loss of vascular tone. However, despite the prevalence of atrophic skin and lower extremity edema, no incision-related complications were identified on close follow-up. No patients developed a deep vein thrombosis or pulmonary embolism. No patient experienced overcorrection or weakness that affected their activity level. Three (25.0%) patients had recurrence of ≥1 digital contractures, and all were rereleased in the office (Fig. 11). Recurrent digital contracture likely occurs from incomplete release related to performing the minimally invasive procedure under anesthesia. This is most commonly seen in the fifth toe, where varus digital rotation places the flexor tendons more medial than midline on the plantar aspect of the toe. The low complication rate identified in this study should increase surgeon confidence when evaluating stroke patients preoperatively, despite the long-held belief that this frail patient population is not fit for elective surgery.

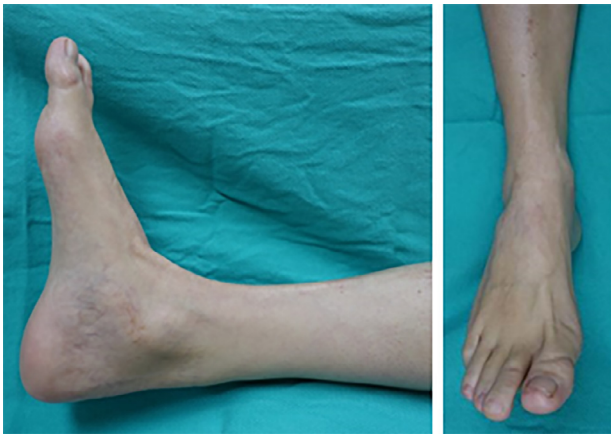

Fig. 11. One-year postoperative result in a patient with recurrence of fifth toe contracture. Note rectus foot alignment when standing, active dorsiflexion to 90°, and functional anterior muscle strength including the tibialis anterior and extensor halluces longus. Recurrent toe deformity was treated with office-based flexor tenotomy without further recurrence in this patient.

The current study was limited to the surgical release of contracture that was directly caused by CVA; however, we frequently use the same approach to treat many other neuromuscular conditions that cause spasticity and equinovarus contracture, namely cerebral palsy, traumatic brain injury, and spinal cord injury. The main difference in treating stroke-related contracture is that deformity is unilateral, whereas most other forms of spasticity affect both sides and are typically more severe. Unilateral involvement affords stroke patients an advantage regarding potential for postoperative functional improvement, despite advanced age, compared with surgical treatment of other neuromuscular conditions.

In conclusion, this prospective observational study was undertaken to assess QOL and functional outcomes 1 year after minimally invasive surgical treatment of stroke-related contracture deformity of the foot and ankle. There seems to be general skepticism among both patients and medical providers regarding the value of surgical treatment in this fragile patient population. Prospective studies that assess outcomes are therefore important in promoting more objective preoperative planning and providing realistic expectations. The main limitation of this study is the relatively small sample size; however, the patients represented a consecutive cohort and were all treated with a consistent surgical technique by 1 surgeon. Despite the small sample, we were still able to identify some statistically significant associations. We were not, however, inclined to pursue regression analyses in an attempt to identify exposures that could be associated with various outcomes of interest, because of the small sample. Thankfully, none of our patients were lost to follow-up and we attempted to limit biases by using an outcomes assessor not associated with the surgical care of the patients. We chose to report survey-based QOL data as opposed to laboratory assessment of gait, muscle strength, and objective functional capacity. This decision was made because we did not expect our patients to achieve perfect functional capacity postoperatively. A CVA can have substantial impacts on the entire lower extremity, and persistent gait problems often reflect weakness, spasticity, and contracture about the hip and knee, making postoperative physical therapy paramount. We also appreciate the fact that correlations are not always linked to causation; the findings described in Table 4 serve primarily for hypothesis generation and could potentially be used in the development of future investigations. The present study concludes that minimally invasive soft tissue correction of stroke-related contracture provides significant QOL improvement and improves weightbearing function by 1 year postoperatively. It would be beneficial to attempt to replicate this study at other institutions, reporting the outcomes of >1 surgeon.

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