Medial claviculectomy for the treatment of recalcitrant central venous stenosis of hemodialysis patients

Philip L. Auyang, MD,[a] Yusuf Chauhan, MD,[b] Thomas M. Loh, MD,[a] Matthew E. Bennett, MD,[a] *and* Eric K. Peden, MD,[a] *Houston and Bryan, Tex*

ABSTRACT

Objective: Outflow tract stenosis is the leading cause of hemodialysis access loss. Many lesions are highly resistant to endovascular treatment, necessitating open surgical intervention. We present our experience using medial claviculectomy for treatment of recalcitrant lesions at the thoracic outlet.

Methods: We retrospectively reviewed patients who underwent medial claviculectomy for dialysis-associated venous thoracic outlet syndrome at our institution between February 2013 and February 2018. Data collection included demographics, past medical history, access history, subsequent procedures, preoperative and postoperative brachial volume flows, and access use.

Results: We performed 25 medial claviculectomies in 25 patients with central venous stenosis. Four patients underwent concomitant central venous bypass and were excluded from this study. Twelve accesses were created at our institution; of these, the average access age was 41.6 months (±26.7 months). All patients previously underwent multiple angioplasty attempts to treat outflow stenosis and continued to have residual symptoms and poor fistula function. Medial claviculectomy with venolysis and angioplasty were performed to treat residual outflow stenosis at the level of the subclavian vein. Twenty-one patients had residual stenosis requiring angioplasty. Six patients had subclavian rupture requiring stent graft placement. All patients reported symptom improvement and immediate use of the fistula after medial claviculectomy. Nineteen (76%) patients reported complete resolution of symptoms after the procedure. Ultimately, eight (32%) ipsilateral arteriovenous accesses were lost, and six (24%) patients died in follow-up with patent, functional fistulas. Median length of follow-up was 17 months (interquartile range, 5-28 months). The 18-month primary patency and secondary patency with regard to subclavian vein interventions were 28% (95% confidence interval, 13.8%-56.1%) and 84% (95% confidence interval, 69.7%-100%), respectively. One patient required ligation for high-output cardiac failure. One patient had contralateral brachiocephalic jailing, which was corrected with kissing brachiocephalic stents.

Conclusions: Medial claviculectomy is an effective treatment of recalcitrant central venous stenosis of the thoracic outlet. Balloon angioplasty or stent or stent graft placement is often necessary after extrinsic compression is alleviated and demonstrates acceptable secondary patency rates. (J Vasc Surg: Venous and Lym Dis 2019;7:420-7.)

Keywords: Hemodialysis; Thoracic outlet syndrome; Subclavian vein; Claviculectomy; Central venous stenosis

Venous outflow stenosis is the leading failure mode of hemodialysis access. Fibrointimal hyperplasia, the primary culprit of outflow stenosis, can occur anywhere in the arterial-venous anastomosis to the superior vena cava in response to the supraphysiologic flow desired for a properly functioning hemodialysis access.[1] Hemodynamically significant outflow stenosis, particularly of the central veins, often results in venous hypertension, prolonged bleeding after needle cannulation, debilitating arm edema, and aneurysmal degeneration of the fistula.[2] Ultimately, as venous outflow stenosis progresses, flow becomes increasingly impaired and access failure is inevitable. Currently, the primary treatment modalities are endovascular balloon angioplasty with or without stenting[3] and, in select cases, surgical turndown or venous bypass procedures.[4] As our knowledge of venous outflow stenosis has expanded, it has become evident that multiple lesion types exist, and each type may indicate a tailored approach to treatment.[5]

Central venous stenosis is particularly challenging because of the location of the vessels in the chest and extrinsic compression of the vein by tissue and bone structures. Dialysis-associated venous thoracic outlet syndrome (TOS) is a less recognized cause of central venous outflow obstruction resulting from a narrow outlet bordered by the first rib, clavicle, and subclavius muscle and tendon.[6] Decompression with first rib resection is the current treatment reported in the literature for

From the DeBakey Heart & Vascular Center, Department of Cardiovascular Surgery, Houston Methodist Hospital, Houston[a]; and the College of Medicine, Texas A&M University, Bryan.[b]

Author conflict of interest: none.

Presented in a poster session at the 2016 Vascular Annual Meeting of the Society for Vascular Surgery, National Harbor, Md, June 8-11, 2016.

Correspondence: Philip L. Auyang, MD, Vascular Surgery, Department of Cardiovascular Surgery, Houston Methodist Hospital, 6550 Fannin St, Smith Tower, Ste 1401, Houston, TX 77030 (e-mail: plauyang@houstonmethodist.org).

The editors and reviewers of this article have no relevant financial relationships to disclose per the Journal policy that requires reviewers to decline review of any manuscript for which they may have a conflict of interest.

2213-333X

Published by Elsevier Inc. on behalf of the Society for Vascular Surgery.

https://doi.org/10.1016/j.jvsv.2018.10.024

venous lesions at the costoclavicular junction (CCJ) that persist after balloon angioplasty.[7] We propose that claviculectomy provides superior visualization of the subclavian vein and allows more complete venolysis compared with first rib resection with minimal aesthetic or functional compromise (Fig 1). The purpose of this study was to evaluate the success of decompressive surgery by an alternative surgical approach to the standard first rib resection that was originally implemented for young, active individuals. Few studies have investigated the role of thoracic outlet decompressive surgery for hemodialysis-dependent patients and report an 80% patency at 7 months in a series of 10 patients.[7] The primary end point of this study was to determine symptom relief and patency of the fistula with regard to subclavian vein interventions after claviculectomy.

ARTICLE HIGHLIGHTS

- **Type of Research:** Single-center retrospective cohort study
- **Key Findings:** Twenty-five patients underwent medial claviculectomy for venous thoracic outlet decompression ipsilateral to a dialysis access; 21 required endovascular intervention for subclavian vein stenosis. Six patients had subclavian rupture requiring stent graft placement. The 18-month primary patency was 28%; secondary patency was 84%. Symptoms resolved in 19 patients, and all accesses were used immediately postoperatively. There were eight late access losses and seven late deaths, six with patent accesses.
- **Take Home Message:** The authors propose medial claviculectomy over first rib resection for venous thoracic outlet decompression in patients with ipsilateral dialysis access because of procedural ease, 84% secondary patency, and low rate of complications.

METHODS

This is a descriptive study of patients undergoing partial medial claviculectomy at a single institution between February 2013 and February 2018. Patients' demographic and outcome data were obtained through retrospective chart review. Claviculectomy with adjuvant venolysis and stenting, stent grafting, or patch angioplasty were performed by multiple vascular surgeons. Indications included symptomatic central venous stenosis such as unilateral ipsilateral arm edema, prolonged bleeding after dialysis, aneurysmal fistula dilation, and compromised outflow as demonstrated by venous duplex ultrasound. In addition, venography was used to identify lesions at the CCJ, and all patients underwent posterior-anterior chest radiography to exclude any bone abnormalities, such as cervical ribs, before the decision was made to perform claviculectomy (Fig 2). Patients with cervical ribs were not included in this study. Study patients were identified through the use of operating room records and *Current Procedural Terminology* codes for claviculectomy. Patients' demographics, comorbid conditions, symptoms related to dialysis-associated TOS, perioperative risk factors, additional intraoperative interventions, preoperative and postoperative imaging, access patency, and additional interventions were collected. Patients were contacted with regard to additional outside interventions and continued patency to ensure completeness of follow-up data and patient-reported outcomes. Institutional Review Board approval for retrospective chart review was obtained.

Surgical technique. The patient is placed in a supine position, and the anterior chest and neck are prepared and draped in a standard surgical fashion. A transverse incision is made over the medial portion of the clavicle. Sharp dissection is carried through the soft tissues and deep fascia down to the anterior aspect of the clavicle (Fig 3, *A*). The pectoralis attachments of the medial clavicle as well as the clavicular head attachments of the sternocleidomastoid muscle are divided. The clavicle is then fully mobilized laterally and divided with a sternal, oscillating, or Gigli saw (Fig 3, *B*) per the surgeon's preference. Extraperiosteal circumferential dissection is then carried medial toward the sternoclavicular joint, where the clavicle is disarticulated (Fig 3, *C*). After this, dissection is carried deeper, and the subclavius muscle is resected. The transition from axillary vein to subclavian vein is dissected free. Dense adherent tissue is often encountered (Fig 3, *D*). The tissue can be sclerotic and inflammatory. Anterior venolysis with sharp dissection is performed to release constriction. The entire vein from the axillary vein to the brachiocephalic vein is dissected. The vein is commonly sclerotic, and fractured stent struts have protruded through the vein wall.

Once satisfactory venolysis is achieved, fistulography is performed through the fistula. Universally, the vein is stenotic (Fig 4, *A*). A stiff wire is crossed through the lesion and passed into the inferior vena cava. Angioplasty is performed, typically with a 10- to 14-mm noncompliant balloon, depending on the size of normal subclavian vein proximal and distal to the lesion (Fig 4, *B*). It is important to have a stiff wire in place and appropriately sized sheaths and stent grafts available. If there is significant residual stenosis, a bare-metal stent or covered stent is placed across the lesion. At this point, the subclavian vein is inspected for bleeding (Fig 4, *C*). In cases in which subclavian vein rupture was encountered, direct pressure on the subclavian vein provided hemostasis and covered stenting was performed promptly, fixing any bleeding. In four cases, planned prosthetic central venous bypass from the cephalic vein to the brachiocephalic vein was performed after claviculectomy for patients with

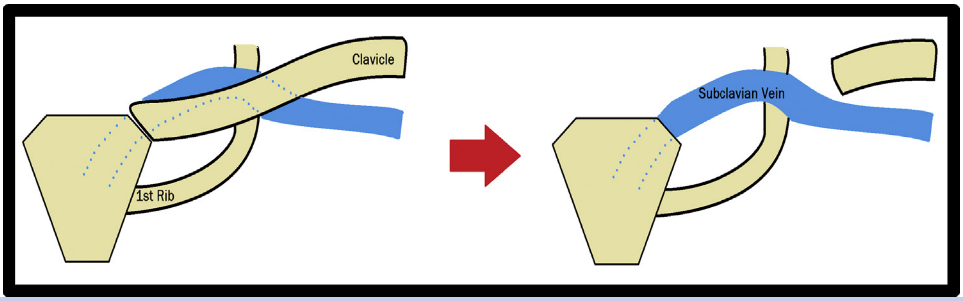

Fig 1. Diagram demonstrating that medial claviculectomy releases the extrinsic compression on the subclavian vein at the thoracic outlet and provides wide exposure of the subclavian vein.

recalcitrant stenosis of the cephalic axillary confluence and the subclavian vein. This was facilitated by the wide exposure provided after partial excision of the clavicle. These four prosthetic central venous bypass patients were excluded from the patency analysis, given that we believed the failure mode of venous bypass with prosthetic graft differs from the failure mode with stenting or angioplasty alone. Completion fistulography is performed to verify correct positioning of the stent, absence of contrast material extravasation, and absence of large collaterals that would indicate remaining outflow obstruction (Fig 4, *D*). All patients underwent chest radiography postoperatively to verify absence of hemopneumothorax.

Statistical analysis. Descriptions of patients' demographics, intraoperative variables, and postoperative complications are given in integers and percentages for categorical variables, means and standard deviations for parametric continuous variables, and median and interquartile ranges for nonparametric continuous variables. Patency rates were calculated using Kaplan-Meir analysis. All statistical analyses were performed using the R statistical package (R Foundation for Statistical Computing, Vienna, Austria).

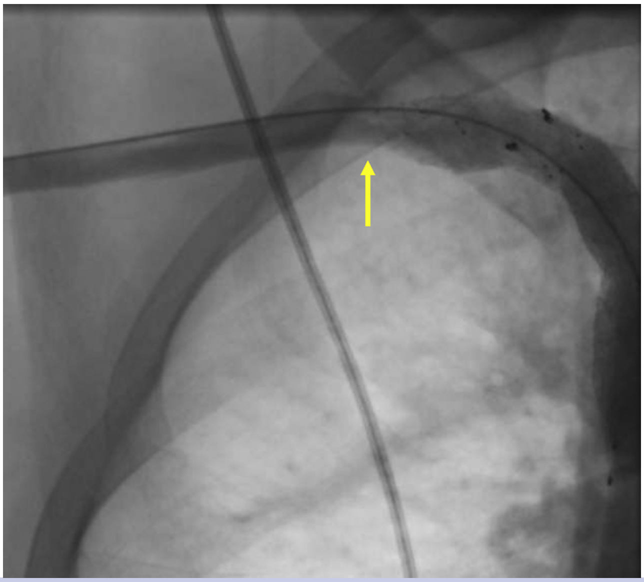

Fig 2. Preoperative fistulogram demonstrates stenosis of the previously placed subclavian vein stent at the costoclavicular junction (CCJ; *arrow*), suggestive of venous thoracic outlet syndrome (TOS).

RESULTS

Between February 2013 and February 2018, there were 25 patients who were identified to have subclavian vein lesions at the CCJ on venography and underwent medial claviculectomy. Four patients were excluded from the patency calculations as they underwent concomitant central venous bypass with prosthetic graft. The mean age was 56.7 (±14) years, and 48% were male; 40% of patients had a history of coronary artery disease, 64% had type 2 diabetes, 100% had hypertension, 32% had congestive heart failure, and 36% had hyperlipidemia. There were 44% African American, 40% Hispanic, 12% white, and 4% Asian patients (Table). Twelve (48%) patients underwent fistula creation at our institution; the remaining 13 (52%) were created at an outside hospital; 12 (48%) patients had brachial-cephalic fistulas, 4 (16%) had brachial-basilic fistulas, 5 (20%) had radial-cephalic fistulas, 2 (8%) had brachial-brachial fistulas, and 2 (8%) had an upper arm or chest wall arteriovenous graft. All patients had recurrent stenosis, and all demonstrated evidence of venous hypertension. There were 15 (60%) patients who presented with ipsilateral arm edema, 11 who (44%) had aneurysmal fistula degeneration, and 3 (12%) who had prior fistula thrombosis. All patients underwent prior angioplasty of the subclavian vein, of whom 17 (68%) also had prior stenting of the subclavian vein. Preoperative volume flows were obtained in 16 patients, which demonstrated a median flow of 947 mL/min (interquartile range, 593-1406 mL/min).

During the procedure after medial claviculectomy, ipsilateral fistulography demonstrated that all patients had residual stenosis of the subclavian vein. Intraoperative balloon angioplasty was performed in 21 (84%) cases. Seventeen (68%) patients underwent bare-metal or covered stenting indicated for either recalcitrant stenosis

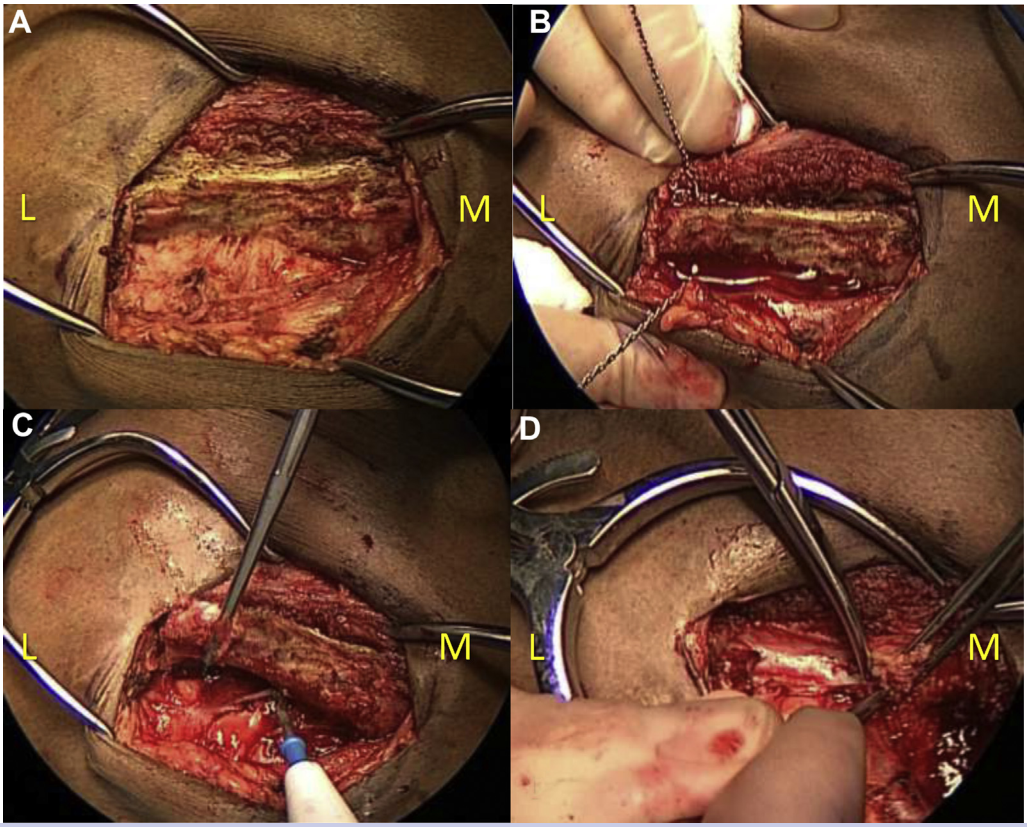

Fig 3. A, A transverse incision is made over the medial clavicle, and dissection is carried through the subcutaneous tissue and deep fascia to expose the anterior aspect of the clavicle. Muscle attachments are divided with cautery. **B,** A Gigli saw provides safe and precise transection of the clavicle; however, a variety of power saws are effective and can be chosen on the basis of the surgeon's preference and experience. **C,** The clavicle is dissected free from underlying tissue, which is performed in the lateral to medial direction. The clavicle can then be disarticulated from the sternoclavicular joint. **D,** Complete venolysis is performed using sharp dissection. The tissue is often dense and adherent because of long-standing injury and inflammation. *L,* Lateral; *M,* medial.

after angioplasty or subclavian vein rupture. Six (24%) covered stents (Viabahn; Gore Medical, Flagstaff, Ariz) were placed for subclavian vein rupture.

Eight (32%) patients had loss of fistula during follow-up. One (4%) had loss due to infection of the fistula away from the surgical site, 6 (24%) had loss of fistula secondary to thrombosis, and 1 (4%) had ligation of fistula due to high-output cardiac failure. Six (24%) patients died with patent fistulas. Seventeen (68%) patients had reintervention performed on the subclavian vein after the index procedure (median number of interventions per patient was 1.0 [interquartile range, 0-2]). Complications directly related to the operation included high flow requiring plication (8%), seroma (8%), hematoma (8%), and contralateral brachiocephalic vein jailing (4%). Seven (28%) patients died at the end of the study period; however, there were no deaths related to the procedure.

Of the patients who survived, a postoperative phone survey was conducted to determine patient-reported outcomes after medial claviculectomy for dialysis-associated TOS. Of the five patients who responded, 100% reported improvement in arm edema compared with before claviculectomy. Functionally, all patients reported that they were able to comb their hair, were able to dress themselves, and did not feel limited in their ability to lift light objects.

The 18-month primary patency of the subclavian vein was 28% (95% confidence interval, 0.138-0.561). The 18-month secondary patency of the subclavian vein was 84% (95% confidence interval, 0.697-1.000; Fig 5).

DISCUSSION

Endovascular treatment alone of the subclavian vein at the CCJ is associated with poor patency related to substantial restenosis rates. A study of 73 patients undergoing angioplasty or stenting for central venous stenosis in hemodialysis patients demonstrated 29% and 21% 1-year primary patency, respectively.[3] Although there is a paucity of literature on dialysis-associated TOS, there is extensive literature concerning management for venous TOS recommending decompressive surgery in combination with endovascular treatment.[8-12] Central venous stenosis, particularly at the CCJ, is a difficult lesion to treat because of the extrinsic compression from bone

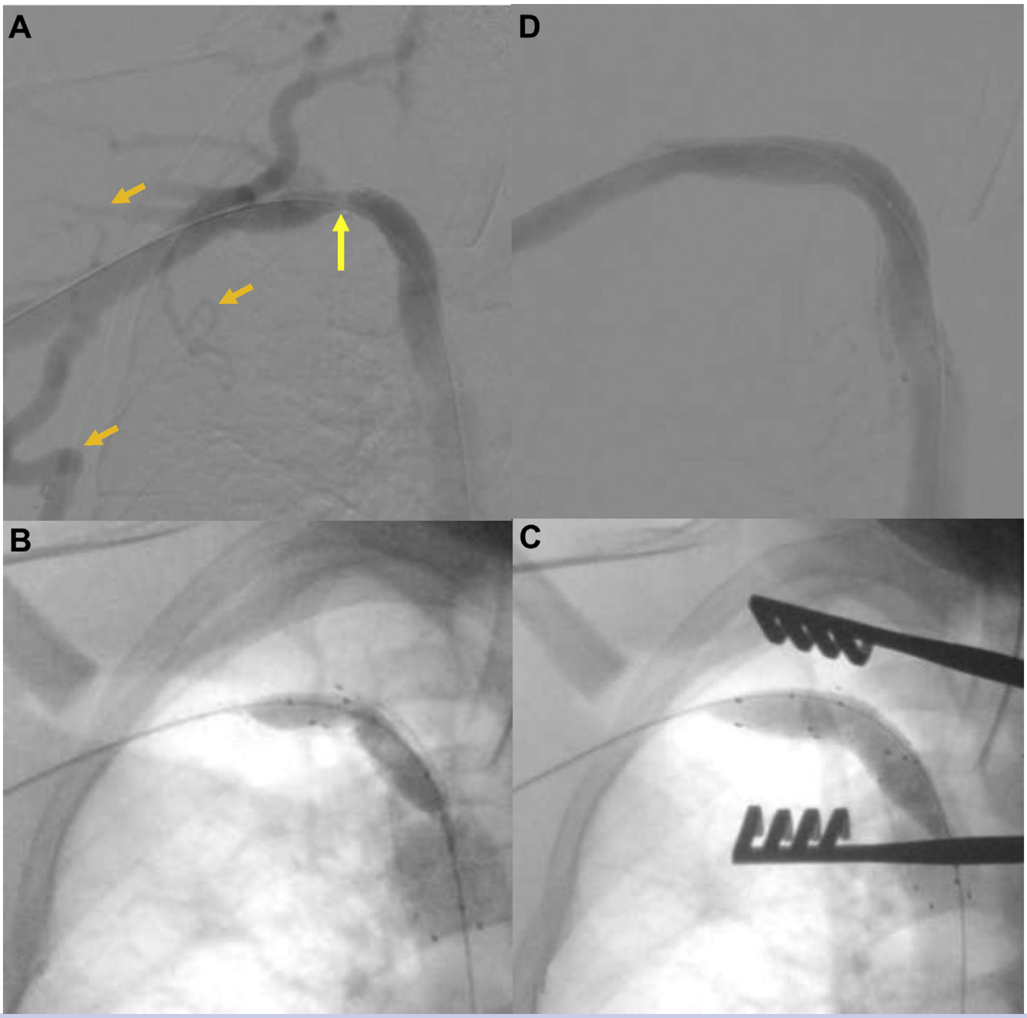

Fig 4. A, Fistulography was performed after medial claviculectomy, demonstrating recalcitrant stenosis at the costoclavicular junction (CCJ; *yellow arrow*). Large collaterals indicate hemodynamically significant stenosis (*orange arrows*). **B,** Balloon angioplasty performed with 14-mm noncompliant balloon at the CCJ demonstrates waist from significant stenosis. **C,** Balloon angioplasty is performed under direct visualization to observe bleeding, which may indicate subclavian vein rupture. **D,** Completion fistulography demonstrates complete resolution of recalcitrant stenosis and no contrast enhancement of collateral veins.

structures and muscle attachments. The subclavian vein traverses a narrow outlet between the first rib, clavicle, and subclavius muscle and tendon. This narrowing can become more pronounced and clinically significant in the setting of high flow, increased turbulence, and venous dilation generated by an arteriovenous fistula.[13] In addition, repeated angioplasty and stenting in this region may also create a hostile environment in which inflammation and further scarring can result in recalcitrant stenosis. Because of bone and soft tissue compression and repetitive vein movement at this location, stenting has demonstrated a high risk for fracture and thrombosis.[14,15]

Chronic central venous stenosis or obstruction can progress to debilitating arm edema and eventually fistula failure, most commonly from thrombosis. Another more insidious progression of the disease may result in aneurysmal degeneration of the fistula, occasionally leading to rupture and death.[16] Therefore, it is imperative to identify the cause of central venous stenosis and to treat the underlying pathophysiologic process appropriately. Given that venous TOS is a well-known phenomenon that leads to subclavian vein thrombosis in young, active individuals, it is highly likely that a significant portion of dialysis-dependent patients with central venous stenosis have underlying venous TOS and would be better served with decompressive therapy in conjunction with endovascular angioplasty, stenting, or reconstruction. First rib resection is the preferred method of decompression for TOS, and transaxillary, supraclavicular, and infraclavicular approaches have been described.[17,18] However, these invasive maneuvers do carry risk for brachial plexopathy, phrenic nerve injury, pneumothorax, and arterial injury.[10,19] The transaxillary approach may

Table. Demographic and clinical data

Variable	Total (N = 25)	
Median age, years	56.7	
	No.	**%**
Male sex	12	48
Coronary artery disease	10	40
Type 2 diabetes mellitus	16	64
Hypertension	25	100
Congestive heart failure	8	32
Hyperlipidemia	9	36
African American	11	44
Hispanic	10	40
White	3	12
Recurrent central stenosis	25	100
Venous hypertension	25	100
Ipsilateral arm edema	15	60
Fistula aneurysm	11	44
Thrombosis	3	12
Prior angioplasty	25	100
Prior stenting	17	68

provide superior cosmetic results but offers a limited operative view, leading to higher rates of incomplete decompression and potential for nerve and arterial injury. Because the subclavian vein lies in the anterior costoclavicular space, infraclavicular first rib resection has been advocated for venous TOS.[20] We have performed first rib resections for venous TOS and for dialysis access-related venous TOS. The authors think that in the dialysis population, medial claviculectomy is less complex, has less bleeding, provides excellent exposure to the subclavian vein for adequate venolysis, and is extremely well tolerated. Although first rib resection is recommended for young, active individuals, we propose that medial claviculectomy better serves the population of hemodialysis patients, consisting mostly of elderly, sedentary patients.

This study reports a single-center experience of partial claviculectomy and venolysis performed for recalcitrant stenosis at the CCJ during a 4-year period. All patients had undergone previous angioplasty or stenting that resulted in short-lived or incomplete resolution of symptoms. There was no early loss of access, early infection, or all-cause mortality directly related to the claviculectomy procedure. There were no reported neurologic injuries. This series demonstrates that claviculectomy is a safe and effective surgical approach to address central venous stenosis at the CCJ in dialysis patients. All patients experienced improvement in the presenting symptoms, such as arm edema and access site bleeding, with a majority (76%) of patients stating complete resolution. All patients had continued use of the fistula except for one patient, who had excision of an infected fistula

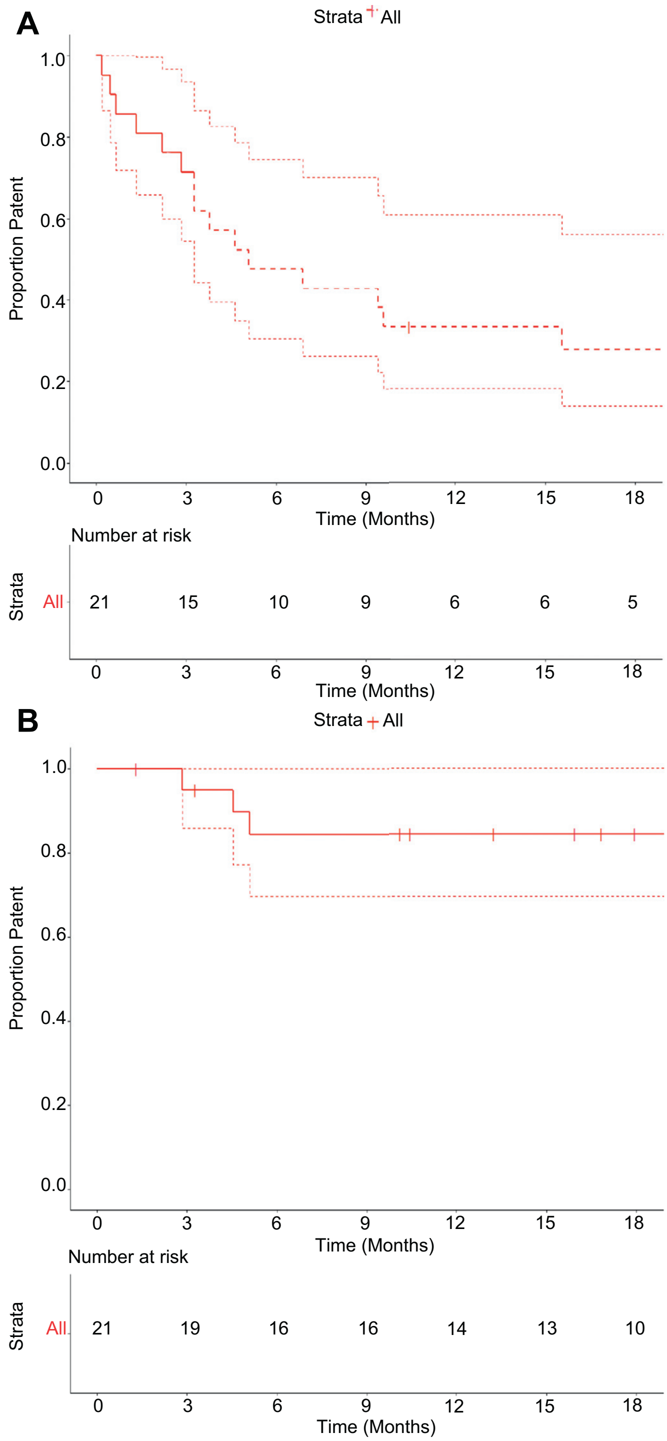

Fig 5. A, Primary patency of 28% is demonstrated at 18 months after medial claviculectomy. **B,** Secondary patency of 84% is demonstrated at 18 months after medial claviculectomy.

unrelated to the claviculectomy. Complications encountered with the procedure were limited to seroma in two (8%) patients, hematoma in two (8%) patients requiring re-exploration of the wound, and high flow requiring plication in two (8%) patients, one of whom eventually

Fig 6. Incisional scar after claviculectomy with minimal defect.

required fistula ligation because of high-flow cardiac failure and successful kidney transplantation. In one (4%) case, the subclavian stent resulted in jailing of the contralateral brachiocephalic vein, requiring kissing superior vena cava stents to relieve venous hypertension in the other arm. Operators found the procedure to be straightforward with minimal morbidity and no mortality. With adjuvant angioplasty and stenting, we found that we were able to prolong access longevity in a select group of patients.

Because of the chronic nature of these lesions, dense adherent tissue is encountered on surgical exploration. Complete venolysis is necessary for durable results, and claviculectomy provides the exposure needed to perform thorough release of the vein. In all cases, fistulography was performed immediately after surgical excision and demonstrated recalcitrant stenosis of the subclavian vein. In our series, 84% of cases required balloon angioplasty and 68% required stenting. Six cases (24%) required covered stenting because of subclavian vein rupture. Subclavian vein rupture was identified as either contrast material extravasation on venography or direct visualization of the vein. The rupture was quickly controlled by direct digital pressure or reinflation of the balloon followed by placement of a covered stent (Viabahn). In three cases (12%), the subclavian vein was found to be severely sclerotic, and patch angioplasty with bovine pericardium was performed. In our follow-up, we noted no infections related to subclavian vein stenting or patch angioplasty.

Our study had a limited investigation into the cosmetic and functional outcomes after medial claviculectomy. Only five patients responded to a survey, and all reported return to baseline functional status as well as improvement in arm edema. Functional outcomes after partial claviculectomy for effort thrombosis were investigated by Green et al,[21] who reported that the most common complaint after excision was inability to lie on the side operated on because of positional numbness of the arm. Furthermore, 10 of 11 patients returned to normal preillness activities, and only one complained of limiting arm fatigue.[21] Most notably, strength and range of motion were not affected after excision of the medial clavicle. The oncologic orthopedic literature reports that partial or total claviculectomy is rarely associated with clinically significant loss of function.[22] Krishnan et al[23] implemented the American Shoulder and Elbow Surgeons score on six individuals undergoing total claviculectomy for various indications, including tumor, infection, nonunion, and vascular compromise. Their score improved from 18 to 88 postoperatively, and pain score dropped from 9.5 to 1.5 on a scale of 10. Functional outcomes were promising in this small series. With regard to cosmesis after medial claviculectomy, there are limited data reported in this series with only five respondents, of whom none reported dissatisfaction with his or her cosmetic outcomes. The cosmetic appearance of an absent clavicle may be more acceptable in the elderly hemodialysis patient as opposed to younger patients with TOS (Fig 6).

There were four patients excluded from the patency analysis who underwent subclavian vein in situ reconstruction because of chronic central occlusion in conjunction with claviculectomy for thoracic outlet decompression. These patients were excluded because the authors believe that prosthetic reconstruction is a separate entity from endovascular angioplasty, stenting, or patch angioplasty in terms of the failure mode. Investigation into the mechanical properties of prosthetic graft for arterial revascularization identified that compliance and caliber mismatch resulted in intimal hyperplasia of the graft-vascular interface.[1] This is in contrast to the failure mode of TOS, in which extrinsic compression results in an inflammatory response, causing stenotic lesions of the affected vein. However, reconstruction is a viable option when it is anatomically necessary to maintain appropriate access function on the ipsilateral extremity.

Six fistulas were lost because of thrombosis in our follow-up period, but salvage procedures are available. If patency cannot be restored, a tunneled central dialysis catheter can be placed with ultrasound-guided puncture of the stented vein. At a later date, the catheter can be converted to a Hemodialysis Reliable Outflow (HeRO) graft (Merit Medical, South Jordan, Utah) to maintain hemodialysis access on the same extremity, which in a randomized multicenter study has patency, bacteremia rates, and adequacy of dialysis comparable to conventional arteriovenous grafts.[24]

The primary limitation of this study is that it is a retrospective descriptive study of a single center's experience. The procedures were performed by multiple surgeons, which leads to some variability secondary to the surgeon's preference. In addition, there was poor patient response to follow-up surveys and hence a poor representation of patient-reported outcomes after medial claviculectomy.

CONCLUSIONS

Medial claviculectomy is an effective treatment of recalcitrant central venous stenosis of the thoracic outlet. Balloon angioplasty or stent or stent graft placement is often necessary after extrinsic compression is alleviated and demonstrates acceptable secondary patency rates. We propose claviculectomy over first rib resection in dialysis patients for thoracic outlet decompression because of the ease of the procedure, the excellent exposure of the subclavian vein, the acceptable functional outcomes reported in the literature, and the low complication rate.

AUTHOR CONTRIBUTIONS

Conception and design: PA, TL, MB, EP
Analysis and interpretation: PA, YC, TL, MB, EP
Data collection: PA, YC, TL, MB
Writing the article: PA, YC, TL, EP
Critical revision of the article: PA, YC, TL, MB, EP
Final approval of the article: PA, YC, TL, MB, EP
Statistical analysis: PA, MB
Obtained funding: Not applicable
Overall responsibility: EP

REFERENCES

1. Roy-Chaudhury P, Sukhatme VP, Cheung AK. Hemodialysis vascular access dysfunction: a cellular and molecular viewpoint. J Am Soc Nephrol 2006;17:1112-27.
2. Padberg FT Jr, Calligaro KD, Sidawy AN. Complications of arteriovenous hemodialysis access: recognition and management. J Vasc Surg 2008;48:55S-80S.
3. Bakken AM, Protack CD, Saad WE, Lee DE, Waldman DL, Davies MG. Long-term outcomes of primary angioplasty and primary stenting of central venous stenosis in hemodialysis patients. J Vasc Surg 2007;45:776-83.
4. Chandler NM, Mistry BM, Garvin PJ. Surgical bypass for subclavian vein occlusion in hemodialysis patients. J Am Coll Surg 2002;194:416-21.
5. Yamamoto Y, Nakamura J, Nakayama Y, Hino H, Kobayashi H, Sugiura T. Relationship between the outcomes of stent placement and the properties of arteriovenous graft outflow vein stenotic lesions. J Vasc Access 2012;13:426-31.
6. Illig KA. Management of central vein stenoses and occlusions: the critical importance of the costoclavicular junction. Semin Vasc Surg 2011;24:113-8.
7. Glass C, Dugan M, Gillespie D, Doyle A, Illig K. Costoclavicular venous decompression in patients with threatened arteriovenous hemodialysis access. Ann Vasc Surg 2011;25:640-5.
8. Chandra V, Little C, Lee JT. Thoracic outlet syndrome in high-performance athletes. J Vasc Surg 2014;60:1012-7; discussion: 1017-8.
9. Hussain MA, Aljabri B, Al-Omran M. Vascular thoracic outlet syndrome. Semin Thorac Cardiovasc Surg 2016;28:151-7.
10. Lee JT, Karwowski JK, Harris EJ, Haukoos JS, Olcott Ct. Long-term thrombotic recurrence after nonoperative management of Paget-Schroetter syndrome. J Vasc Surg 2006;43:1236-43.
11. Thompson JF, Winterborn RJ, Bays S, White H, Kinsella DC, Watkinson AF. Venous thoracic outlet compression and the Paget-Schroetter syndrome: a review and recommendations for management. Cardiovasc Intervent Radiol 2011;34:903-10.
12. Vemuri C, Salehi P, Benarroch-Gampel J, McLaughlin LN, Thompson RW. Diagnosis and treatment of effort-induced thrombosis of the axillary subclavian vein due to venous thoracic outlet syndrome. J Vasc Surg Venous Lymphat Disord 2016;4:485-500.
13. Dethlefsen SM, Shepro D, D'Amore PA. Comparison of the effects of mechanical stimulation on venous and arterial smooth muscle cells in vitro. J Vasc Res 1996;33:405-13.
14. Phipp LH, Scott DJ, Kessel D, Robertson I. Subclavian stents and stent-grafts: cause for concern? J Endovasc Surg 1999;6:223-6.
15. Mallios A, Taubman K, Claiborne P, Blebea J. Subclavian vein stent fracture and venous motion. Ann Vasc Surg 2015;29:1451.e1-4.
16. Patel MS, Street T, Davies MG, Peden EK, Naoum JJ. Evaluating and treating venous outflow stenoses is necessary for the successful open surgical treatment of arteriovenous fistula aneurysms. J Vasc Surg 2015;61:444-8.
17. Urschel HC Jr. The transaxillary approach for treatment of thoracic outlet syndromes. Semin Thorac Cardiovasc Surg 1996;8:214-20.
18. de Leon RA, Chang DC, Hassoun HT, Black JH, Roseborough GS, Perler BA, et al. Multiple treatment algorithms for successful outcomes in venous thoracic outlet syndrome. Surgery 2009;145:500-7.
19. Hosseinian MA, Loron AG, Soleimanifard Y. Evaluation of complications after surgical treatment of thoracic outlet syndrome. Korean J Thorac Cardiovasc Surg 2017;50:36-40.
20. Siracuse JJ, Johnston PC, Jones DW, Gill HL, Connolly PH, Meltzer AJ, et al. Infraclavicular first rib resection for the treatment of acute venous thoracic outlet syndrome. J Vasc Surg Venous Lymphat Disord 2015;3:397-400.
21. Green RM, Waldman D, Ouriel K, Riggs P, Deweese JA. Claviculectomy for subclavian venous repair: long-term functional results. J Vasc Surg 2000;32:315-21.
22. Kapoor S, Tiwari A, Kapoor S. Primary tumours and tumorous lesions of clavicle. Int Orthop 2008;32:829-34.
23. Krishnan SG, Schiffern SC, Pennington SD, Rimlawi M, Burkhead WZ Jr. Functional outcomes after total claviculectomy as a salvage procedure. A series of six cases. J Bone Joint Surg Am 2007;89:1215-9.
24. Nassar GM, Glickman MH, McLafferty RB, Croston JK, Zarge JI, Katzman HE, et al. A comparison between the HeRO graft and conventional arteriovenous grafts in hemodialysis patients. Semin Dial 2014;27:310-8.

Submitted Jun 28, 2018; accepted Oct 26, 2018.