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TECHNICAL NOTE

Radiofrequency Wire Recanalization of Chronically Occluded Venous Stents: A Retrospective, Single-Center Experience in 15 Patients

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Abstract
Introduction Chronically occluded venous stents may be difficult to salvage, necessitating multiple approaches and adjunctive techniques. Radiofrequency wires have been used to cross chronic obstructions in a variety of settings. Herein, radiofrequency wire recanalization (RFWR) of chronically occluded venous stents is presented.
Materials and Methods Fifteen patients (8 males; 7 females) aged 23–74 years (median 42 years) underwent prior venous stenting in the setting of venous occlusions. Seven had an underlying coagulopathy, three had May–Thurner syndrome, three had provoked deep venous thrombosis, one had a dialysis fistula, and one had pacer leads in situ. All indwelling venous stents were chronically occluded and symptomatic. Out of 15 patients, 13 (87%) had iliocaval venous stents, while two (13%) had superior vena cava and/or upper extremity venous stents. After failing conventional and blunt recanalization techniques, RFWR was performed to traverse the chronic occlusions. Technical success and complications were recorded.
Results Fifteen patients underwent 19 procedures. Twelve patients underwent one procedure, two patients had two procedures, and one patient had three procedures. RFWR alone was used in 12/19 (63%) procedures, while 7/19 (37%) required adjunctive sharp recanalization techniques. Technical success or crossing of the occlusion with flow restoration through the occluded segments was achieved in 17/19 (89%). One major and one minor complication occurred.
Conclusion Radiofrequency wire recanalization is an effective adjunct to revise chronically occluded venous stents, potentially increasing procedural success in challenging cases.

Keywords Radiofrequency wire · Baylis · Chronic thrombosis · Stent revision · Stent occlusion · Venous · Venous recanalization · Iliocaval recanalization

Abbreviations

RF	Radiofrequency
RFW	Radiofrequency wire
RFWR	Radiofrequency wire recanalization

Introduction

Venous stenting has become widely accepted and increasingly used to relieve symptomatic venous obstructions [1]. Although primary patency rates for acute thrombotic and chronic post-thrombotic iliac venous stenting exceed 90% in the first year, the 24-month patency rates often drop below 80% [2]. If acute, recanalization of most venous occlusions can be performed with standard hydrophilic guidewire and catheter technique [3]. In contrast, chronic venous occlusions (> 30 days) or chronically occluded venous stents may be difficult to cross, particularly if the lesion consists of dense, organized fibrous tissue or extends over long segments [4]. When conventional techniques fail, more aggressive approaches including

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different needles and cannulas to facilitate crossing chronic occlusions are employed [5–7].

Radiofrequency (RF) guidewires have been used to successfully recanalize central veins, bile ducts, and arterial occlusions [8–10]. Aside from a brief report utilizing RF wires (RFW) to recanalize chronically thrombosed transjugular intrahepatic portosystemic shunts (TIPS), RFW have not been studied for use in stent recanalization [11]. Herein, the use of RF PowerWire (Baylis Medical, Montreal, QC, Canada), to recanalize chronically occluded venous stents, is reported.

Materials and Methods

Institutional review board approval was granted for this investigation, which complied with the Health Insurance Portability and Accountability Act. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Informed consent was not required for a retrospective review at our institution.

Patients were identified using retrospective review of a venous database (Excel 2017; Microsoft Corporation; Redmond, WA) in conjunction with the other electronic medical and imaging records. From May 2013 to May 2018, all patients with chronically thrombosed venous stents (> 30 days documented occlusion) who underwent RF wire recanalization (RFWR) were identified (n = 15). All patients were seen in clinic before undergoing recanalization. RFWR was offered or performed in the same session only after conventional and other sharp recanalization techniques had failed. There were no specific contraindications. Three interventional radiologists, with 4, 6, and 35 years of experience, performed the RFWR procedures. Age, gender, coagulopathy, chronicity of thrombosis, technical success, and procedural success were recorded. Complications were classified according to Society of Interventional Radiology guidelines [12].

Fifteen patients (8 males; 7 females) aged 23–74 years (median 42 years) underwent previous endovascular venous stenting and presented with symptoms of occlusion and/or imaging findings compatible with chronic in-stent thrombosis. Thirteen patients had iliocaval stents, while two had SVC and/or upper extremity venous stents. Seven had an underlying coagulopathy, three had May–Thurner syndrome, three had postsurgical or postpartum deep venous thrombosis, one had a dialysis fistula, and one had pacer leads *in situ*. Initial stenting was performed at a different institution in 10/15 (67%) patients. Imaging documentation of occlusion chronicity ranged from 2 to 36 months (mean 8.6 months; median 5 months), though possibly longer standing given that stenting was performed elsewhere in a majority of patients. A summary of patient demographics and history of venous disease is presented in Table 1.

Technical success was defined as traversing the occluded segments with the RFW and restoring anterograde flow through the occluded segments. Post-procedure, all patients were seen in clinic and were started on or continued anticoagulation with either warfarin or a direct oral anticoagulant and anti-platelet therapy with aspirin and/or clopidogrel. Follow-up was not available for all patients. Feasibility of the RFWR technique is reported without data on durability of stent patency. Repeat intervention was performed for technical failure, symptom recurrence, or stenosis/thrombosis on follow-up imaging (Patients 1 and 6).

All procedures were performed under general anesthesia. Anterograde and retrograde venous sheaths, most commonly from transfemoral/transsaphenous and transjugular approaches, ranging in size from 5 to 8 French were established and positioned adjacent to each terminus of the occluded stents (Fig. 1A, B). After failing standard recanalization, a 5-French catheter was placed through the distal sheath and the catheter tip was centered at the distal stent terminus. An exchange length of 0.035-inch flexible straight or angled tip RFW (Baylis Medical) was introduced and positioned at the distal terminus. After confirming RFW positioning with oblique images and rotational fluoroscopy, a 1–2 s pulse of 10–25 W energy was delivered from a generator while advancing the wire forward (Fig. 1C, D). This was repeated numerous times, creating a channel to support catheter advancement, frequently a few millimeters at a time. If the catheter could not follow the RFW, then a tightly tapered support catheter such as a Quick-Cross (Spectranetics, Colorado Springs, CO) or Navicross (Terumo, Somerset, NJ) was used. If necessary, the RFW would be activated while going forward, and while pulling back, to better vaporize tissue and allow for catheter crossing. If the tip of the RFW approached or contacted the edges of the stents, it would deactivate. The RFW would then be retracted, slightly redirected, or torqued, and then energy was reapplied while attempting to advance the wire in a different direction. RFW deactivation was a common occurrence, particularly in long-segment occlusions or along anatomic curves, such as the pelvis. If the problem persisted despite redirection, either the RFW or catheter was exchanged for one with a different tip angulation, to facilitate redirection away from the margins of the stent. If after these maneuvers redirection was unsuccessful, then adjunctive sharp recanalization was performed with a BRK-1 trans-septal needle (St. Jude Medical, St. Paul, MN). As the RFW traversed the stents

Table 1 Patient demographics and history of venous disease

Pt	Age	M/F	Etiology of initial venous insult	Affected segments	Occlusion chronicity
1	24	M	Behcet's variant vasculitis	REIV; RCFV	18 months
				REIV; RCFV	7 months
				IVC; LCIV	N/A
2	36	F	Postpartum deep vein thrombosis	IVC; LCIV; LEIV	17 months
3	74	M	Pacer leads	SVC; RIV; RSV; RAV	36 months
4	74	M	RUE AVF	RSV; RAV	10 months
5	42	M	Factor V Leiden mutation	IVC; RCIV; REIV; RCFV	5 months
				IVC; LCIV; LEIV	4 months
6	63	M	Hemipelvectomy; IVC filter	RCIV; REIV	2 months
				RCIV; REIV	4 months
7	38	F	May–Thurner syndrome	LCIV; LEIV; LCFV	3 months
8	37	M	Factor V Leiden mutation	LCIV; LEIV	12 months
9	33	M	Factor V Leiden mutation	IVC; LCIV; LEIV; LCFV	13 months
10	46	M	Multi-trauma deep vein thrombosis	LCIV; LEIV; LCFV	4 months
11	28	F	MTHFR/prothrombin gene mutation	LCIV; LEIV	6 months
12	48	F	Postpartum deep vein thrombosis	IVC; LCIV; LEIV; LCFV	2 months
13	58	F	May–Thurner syndrome	IVC; LCIV; LEIV	5 months
14	52	F	May–Thurner syndrome	LCIV; LEIV; LCFV	3 months
15	42	F	Lupus anticoagulant syndrome	LCIV; LEIV	4 months

Pt patient, *M/F* male/female, *IVC* inferior vena cava, *SVC* superior vena cava, *L/R CIV* left/right common iliac vein, *L/R EIV* left/right external iliac vein, *L/R CFV* left/right common femoral vein, *RIV* right innominate vein, *RSV* right subclavian vein, *RAV* right axillary vein, *RUE AVF* right upper extremity arteriovenous fistula, *N/A* not available, *MTHFR* methylenetetrahydrofolate reductase deficiency

and approached the proximal terminus, a snare, Wallstent (Boston Scientific) or Amplatzer vascular plug (St. Jude Medical), was positioned for targeting (Fig. 1E–G) [13]. After completely traversing the occluded stent, the RFW or exchange length hydrophilic guidewire (Terumo) was ensnared or entrapped in device interstices and secured in the deployment sheath before being withdrawn into the second access sheath and out of the patient to establish through-and-through access. The remainder of the recanalization technique has been described elsewhere but includes balloon venoplasty followed by placement of additional coaxial stents [14].

Results

A total of 19 RFWR procedures were performed. Twelve patients (80%) underwent one procedure, two patients (13%) had two procedures, and one patient (7%) had three procedures. The occlusion was successfully crossed with re-establishment of anterograde flow, defining technical success, in 14/15 patients (93%) and 17/19 (89%) procedures. The two procedures which were not initially technically successful were repeated by a more experienced operator. Technical success was achieved for Patient 5 with RFWR during a second procedure, whereas Patient 9 was successfully recanalized without the RFW subsequently. Details of occlusion length and technical success are noted in Table 2.

The crossing catheter in 13/19 (68%) procedures was a tightly tapered peripheral support catheter (Quick-Cross or Navicross). In the remaining 6/19 (32%) procedures, a standard catheter (vertebral tip slip-cath) traversed the occlusion. Twelve procedures (63%) were completed by RFWR alone with the length of these occlusions ranging from 4 to 23 cm (mean 13.2 cm; median 12 cm). Seven procedures (37%) required an adjunctive technique consisting of a BRK-1 trans-septal needle for sharp recanalization. In these cases, the length of stent occlusion ranged from 12–23 cm (mean 17.1 cm; median 16 cm),

Patients 1, 5, and 6 underwent multiple procedures. Patient 1 had an initial recanalization of the right external iliac and common femoral veins, but reoccluded and was subsequently recanalized again in the same segments 7 months later. The inferior vena cava and left common iliac were found to be occluded with unknown chronicity and were also recanalized in a separate procedure. Patient 5 had recanalization of each leg, with each procedure lasting greater than 8 h. Patient 6 was medically non-compliant and subsequently rethrombosed after initial recanalization,

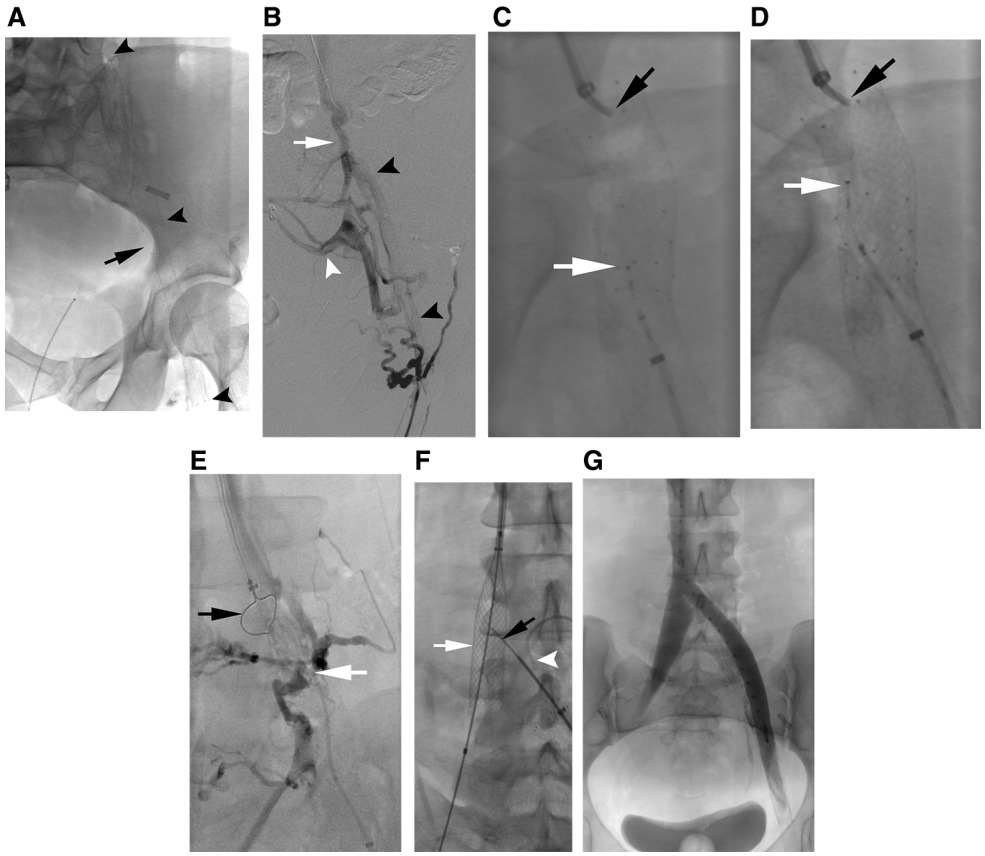

Fig. 1 38-year-old female with May–Thurner syndrome and prior stenting at an outside hospital presented with left leg swelling. **A** Multiple stents (black arrowheads) are present extending from the left common iliac vein to the left common femoral vein with an unstented gap (black arrow). **B** Digital subtraction venography reveals occlusion of the stents (black arrowheads) with cross-pelvic collateral vessels (white arrowhead) and eventual opacification of the ipsilateral common iliac vein via other collaterals (white arrow). **C** The RF wire is extended beyond the support catheter (white arrow) with a sheath and catheter present at the distal terminus (black arrow). **D** After RF energy is applied, the RF wire freely moves forward by approximately 1 cm (white arrow) and approaches the distal terminus (black arrow), which is re-evaluated in this different oblique. **E** Digital subtraction venography from the catheter (white arrow) reveals occlusion between the stent terminus and the junction of the left common iliac to inferior vena cava where a snare (black arrow) is positioned to facilitate targeting. **F** The snare was removed and from the right internal jugular vein a Wallstent (white arrow) was introduced and partially deployed. A BRK-1 needle (black arrow) was introduced from the left common iliac vein and used to cross the occlusion beyond the stent margin. A cobra-shaped catheter (white arrowhead) was placed in the right common iliac artery from a left common femoral artery access to delineate the iliac artery bifurcation during sharp recanalization. **G** Completion venography reveals prompt anterograde flow through the venous segments and collapse of the collateral veins

but subsequently after a second recanalization adhered to anticoagulation recommendations.

A single minor and a single major complication occurred. The minor complication was a consequence of extraluminal protrusion of the RFW at the junction of the left external and common iliac veins, resulting in self-limited and asymptomatic focal extravasation, requiring no treatment. The major complication was a consequence of focal transgression of the inferior vena cava, which occurred during sharp and RFW recanalization. After the patient was anticoagulated, bleeding into the retroperitoneum resulted in a decrease in blood counts and an enlarging hematoma causing back pain without deviations of hemodynamic parameters. Anticoagulation was discontinued, and the injury was managed by placement of a stent graft in the distal IVC. The patient was uneventfully discharged 2 days later and at subsequent clinic follow-ups had suffered no long-term adverse sequelae.

Discussion

Chronic venous occlusion can occur as a complication of indwelling venous devices, venous atresia or agenesis, benign and malignant venous compression, and underlying coagulopathies [1, 2, 13]. To achieve durable venous patency in those circumstances, stents are often placed to buttress the recanalized segment. Despite anticoagulation and surveillance, recurrent in-stent stenosis or thrombosis may occur, leading to multiple revascularization

Table 2 Technical approach and results of radiofrequency wire recanalization

Pt	Length of stent occlusion (cm)	Adjunctive technique	Crossing catheter	Tech. Suc.
1	12	BRK-1	Vertebral Tip	Y
	12	None	Navicross	Y
	7	None	Navicross	Y
2	12	None	Navicross	Y
3	19	None	Quick-Cross	Y
4	4	None	Quick-Cross	Y
5	12	None	N/A	N
	12	None	Quick-Cross	Y
6	15	None	Quick-Cross	Y
	15	None	Vertebral Tip	Y
7	23	BRK-1	Quick-Cross	Y
8	12	None	Vertebral Tip	Y
9	23	None	N/A	N
10	16	BRK-1	Navicross	Y
11	20	BRK-1	Quick-Cross	Y
12	19	BRK-1	Quick-Cross	Y
13	15	None	Vertebral Tip	Y
14	15	BRK-1	Vertebral Tip	Y
15	15	BRK-1	Vertebral Tip	Y

Pt patient, *Tech. Suc.* technical success, *cm* centimeter, *BRK-1* BRK-1 trans-septal needle (St. Jude's Medical, Saint Paul, MN), *Vertebral Tip* vertebral tip slip-cath (Cook Inc., Bloomington, IN), *Navicross* navicross catheter (Terumo, Somerset, NJ), *Quick-Cross* quick-cross catheter (Spectranetics, Colorado Springs, CO), *N/A* not applicable

procedures. The ability to perform angioplasty, mechanical or pharmacologic thrombectomy, and stent relining is predicated on successfully crossing a stenosis or occlusion. While conventional wire and catheter techniques can cross most acute and subacute occlusions, chronic venous occlusions are notoriously difficult necessitating advanced techniques.

A variety of advanced venous recanalization techniques have previously been described. Many of the sharp recanalization techniques rely on application of mechanical force and are most effective in crossing occlusions that are short and straight. Moreover, angulation or increasing distance from the applied force to the occlusion dampens forward pushability. In contrast, the RF PowerWire generator (Fig. 2A) delivers an electric field to the tip of its exchange length, torqueable, 0.035-inch wire, which is constructed with a nitinol core and polytetrafluoroethylene coating. A grounding pad is placed on the patient, similar to other RF systems, and cables connect the generator to the wire (Fig. 2B). Crossing occlusions is reliant on delivered electric field vaporizing adjacent tissue to allow free forward motion. Additionally, energy application may be repeated innumerable times in 1–2 s increments without decreased efficacy irrespective of distance traversed. However, it is notable that only tightly tapered crossing catheters could advance over the RFW in most cases and that the RFW was activated while going forward and pulling back to better facilitate catheter crossing. This reflects the dense, fibrous nature of the chronic occlusion, suggests the size of the channel conforms to the size of the RFW, and partially explains the difficulty in steering the wire when the wire tip is several centimeters distal to the catheter tip.

The great strength of the RF PowerWire, the ability to penetrate nearly any non-osseous structure, is also its great weakness. This aspect was of particular utility at the ends of each stent, where chronic occlusions can be organized making it difficult to establish access within the stent. Although the RF PowerWire is generally an effective tool in the recanalization of chronically occluded vessels when conventional endovascular techniques have failed, extraluminal passage is possible. Because the generator terminates the energy pulse if the RFW contacts metal, wire transgression through stent walls into adjacent structures is uncommon. Moreover, the major complication in this series occurred beyond the occluded stent margin and in conjunction with sharp recanalization techniques. Safety can be enhanced by minimizing the duration of RF energy pulse and the distance the wire is advanced during each delivery. Patience, verification of location with multiple oblique images, and advancing measured distances with each energy pulse help prevent inadvertent perforation.

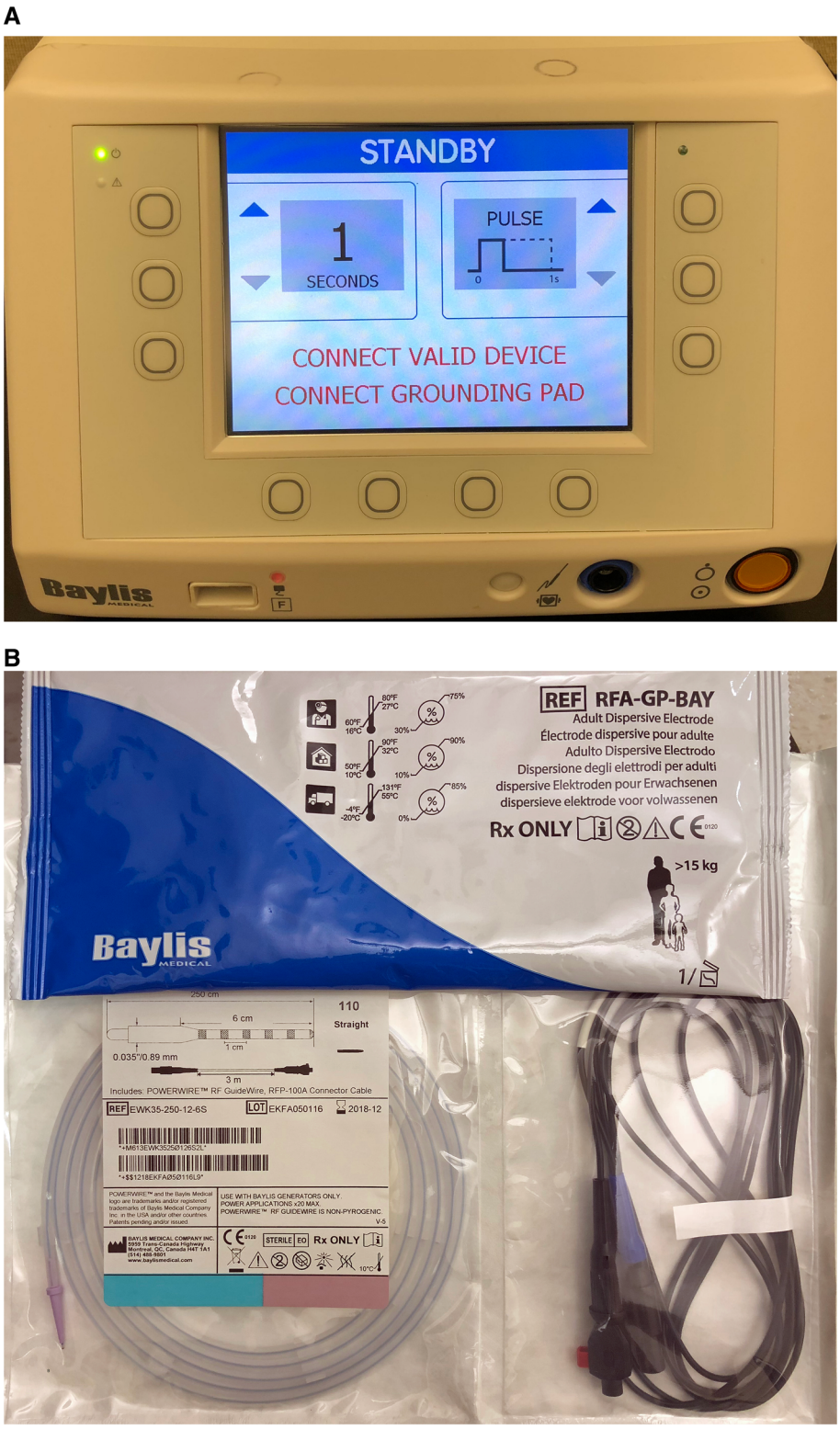

Fig. 2 Baylis RF PowerWire system. **A** The generator is able to provide energy pulses in varying increments, usually 2 s or less, and must be connected to a valid wire and grounding pad. **B** The grounding pad, in package at the top of the image, is similar to others used for radiofrequency generators. The exchange length wires (lower left) are unique for this and are available in a variety of tip strengths and shapes. Detachable cables (lower right) connect the RF wire to the generator. After crossing the occlusion, the cable connection can be removed from the wire

Study limitations include its retrospective and single-center nature. This was a modest sample size with no control arm for comparison. Additionally, selection bias was present as patients were not randomized and RFWR was not compared to other techniques. Follow-up was not consistently available on all patients to evaluate the durability of stent patency after RFWR.

Conclusion

Radiofrequency wire recanalization is an efficacious adjunct to revise chronically occluded venous stents. Its use should be considered when standard techniques are unsuccessful.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. For this type of study, formal consent is not required.

Informed Consent For this type of study, informed consent is not required.

Consent for Publication For this type of study, consent for publication is not required.

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