Venous and Arterial Thrombus Removal With the Indigo System: Pulmonary Embolism Indication

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The acute pulmonary embolism (PE) treatment paradigm is evolving to treat patients who have emergent symptoms and are unable to tolerate long thromboaspiration procedures. Now, the goal with thrombus removal in PE is to safely and effectively remove thrombus and potentially reduce treatment time. Thrombolysis is not a universal option for all patient groups, especially if the patient has an absolute or relative contraindication to a fibrinolytic agent. Large-bore embolectomy, when paired with a syringe, has led to variable results, with questions regarding the ideal technique to achieve a uniform state of vacuum aspiration.[1] The catheters used to aspirate should ideally be atraumatic and easily deliverable to be able to access and establish flow through the lobar branches of the pulmonary artery (PA), reducing right heart strain and PA pressure (PAP). Sustained aspiration from the Indigo System provides physicians with an alternative option for patients who are not ideal candidates for lytics or open embolectomy and provides a frontline therapy option that still preserves the use of any adjunctive therapy.

The Indigo Aspiration System provides a treatment option that is CE Marked. The sustained aspiration from the Penumbra ENGINE provides constant uninterrupted full-vacuum aspiration throughout the procedure, addressing the constraints of syringe-based large-bore embolectomy, which include vacuum dropoff from the syringe filling with fluid. The CAT8's large lumen can allow for efficient clot removal, which can be enhanced when paired with mechanical separation from the SEP8. Engineered to be trackable, deliverable, and torqueable, the CAT8's atraumatic tip can navigate the lobar anatomy of the PA to help establish inflow and outflow, helping to restore patient vitals to normal.

The EXTRACT-PE study completed in 2019 evaluated the safety and efficacy of the Indigo Aspiration System in the management of submassive PE. The Indigo System Catheter CAT8 was used across 22 sites in the United States in patients with submassive PE who did not receive thrombolytics (98.3%), with a right ventricular/left ventricular (RV/LV) ratio reduction of 27.3% at 48 hours. The on-table PA pressures were statistically reduced, and the median device time was 37 minutes. This procedure time has been embraced by countless interventionalists concerned about prolonged case times with other thromboaspiration technologies. The major adverse event rate in EXTRACT-PE was 1.7%, and patients had a median intensive care unit stay of < 1 day. The EXTRACT-PE trial demonstrated that the Indigo System can provide immediate mechanical relief using sustained aspiration. As PE treatment options continue to grow, the EXTRACT-PE results with the Indigo System serve as a promising data set in helping move the PE landscape forward.

This new thromboaspiration technology allows for clot removal and potential reduction in right heart and PA pressure. It is low-profile and deliverable to all vascular territories in the pulmonary circulation. It is a welcome addition to our existing endovascular technologies for the treatment of acute PE.

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HIGH-RISK PULMONARY EMBOLISM CONTRAINDICATED FOR FIBRINOLYSIS TREATED WITH INDIGO SYSTEM

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PATIENT PRESENTATION

A 73-year-old woman developed swelling of both legs as well as difficulty breathing. She was admitted to the emergency department with a pulse oximetry of 85%, a FiO_2 of 21%, and a blood pressure of 90/60 mm Hg. She had a history of head injury with intraparenchymal cerebral, subdural, and subarachnoid hemorrhage 30 days prior to the hospital consultation.

CTA was performed and showed thrombus in the right and left main PAs with a Qanadli score of 70% to 80%, RV/LV ratio > 0.9, and moderate pericardial effusion (Figure 1). She also had elevated high-sensitivity troponin T and a transthoracic echocardiogram showed RV dysfunction with a tricuspid annular plane systolic excursion (TAPSE) < 16 mm. Compression ultrasound demonstrated a proximal vein thrombosis in the left and right femoral veins.

Catheter-directed thrombolysis and systemic fibrinolysis were contraindicated. A nearby center with a specialized team for surgical thrombectomy was not available. Mechanical thrombectomy using the Indigo System (Penumbra, Inc.) was established as the treatment of choice.

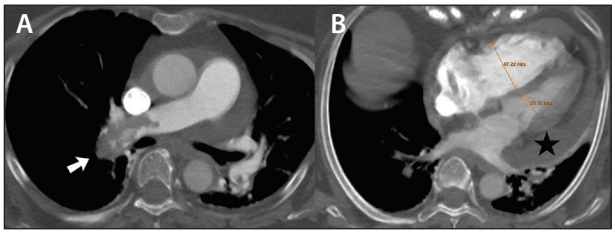

Figure 1. Thrombus in the main right PA (white arrow) (A). RV/LV ratio > 0.9; moderate pericardial effusion (black star) (B).

INTERVENTION

The patient was monitored by an anesthesiologist without performing tracheal intubation or the administration of intravenous sedation. Right jugular access with a 10-F Super Sheath XL (Boston Scientific Corporation) was used, and a Günther Tulip inferior vena cava (IVC) filter (Cook Medical) was placed infrarenal before the pulmonary procedure to prevent additional thrombotic embolization. A 6-F angled-pigtail catheter (Cordis, a Cardinal Health company) was introduced in the main PA, and PAP was measured at 43/16 mm Hg (mean, 27 mm Hg). A 260-cm stiff guidewire was inserted into the pigtail catheter and exchanged for the Indigo System's Aspiration Catheter CAT8 XTORQ. The CAT8 catheter was delivered into the highest thrombus burden in the patient's right PA. Power aspiration using the CAT8 and Separator 8 allowed thrombus removal and created the first channels for flow restoration. Aspiration of thrombus from distal to proximal was finalized after hemodynamic stability was achieved and the decrease in systolic PAP was > 10 mm Hg. The final PAP was 32/14 mm Hg (mean, 17 mm Hg) (Figures 2 and 3).

The patient was admitted to the intensive care unit for monitoring and remained there for 7 days because of uncontrolled atrial fibrillation and urinary infection. The patient remained hemodynamically stable and a nasal

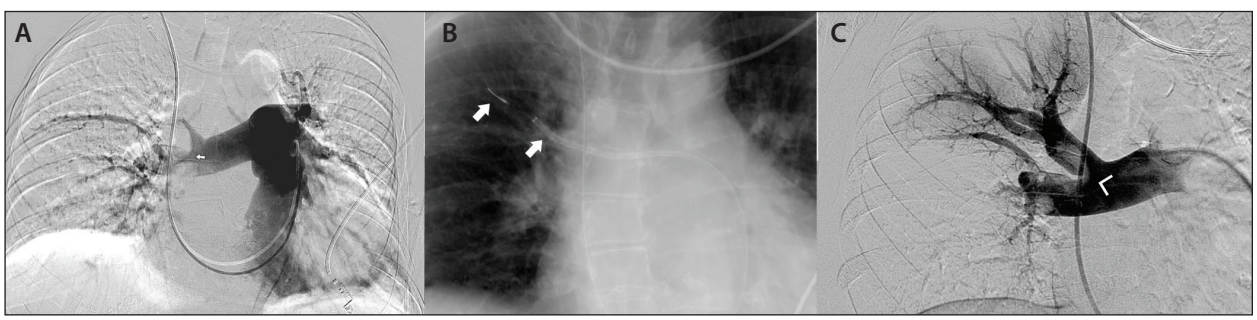

Figure 2. Thrombus in the main right PA (white arrow) (A). CAT8 and SEP8 (white arrows) in the right superior trunk artery (B). Angiography postthrombectomy shows recanalization (white arrow) of the superior trunk and inferior PA (C).

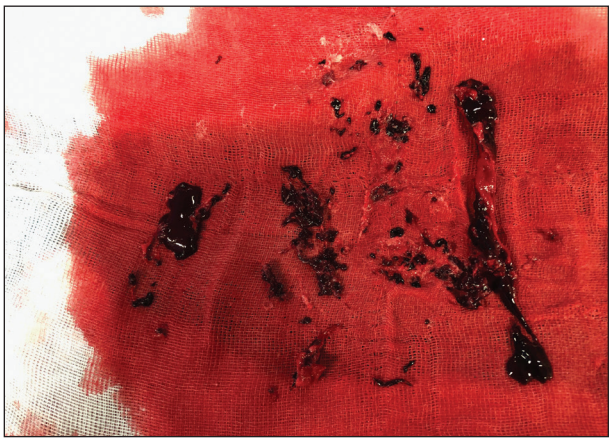

Figure 3. Partial thrombus aspirated with CAT8.

Figure 4. Pulmonary angiography control after 1 month scheduled for IVC filter retrieval.

cannula was used for oxygen therapy after thrombectomy was performed.

The patient was scheduled for IVC filter retrieval 1 month after PE thrombectomy. Final PAP was 25/4 mm Hg (mean, 14 mm Hg); pulmonary angiography showed complete recanalization of both PAs (Figure 4).

DISCUSSION

The typical treatment option for high-risk PE is systemic fibrinolysis with urokinase or recombinant tissue plasminogen activator (tPA). In this case, both fibrinolysis and anticoagulation with unfractionated heparin or low-molecular-weight heparin were contraindicated because of the history of intracerebral hemorrhage 30 days prior to presentation. The only therapeutic options for this patient were surgical thrombectomy or mechanical thrombectomy.[1,2] An IVC filter was implanted to prevent the migration of more thrombi that can worsen the patient's status. The Indigo System CAT8 is an effective, safe, and simple device that allows the aspiration of emboli and thrombi in the PAs. CAT8 paired with continuous power aspiration delivered by Penumbra ENGINE can remove thrombus, even in large-diameter vessels as demonstrated in this case. In addition, SEP8 can be utilized to aid in thrombus removal by helping clear thrombus from the catheter tip.

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2. Ciampi-Dopazo JJ, Romeu-Prieto JM, Sánchez-Casado M, et al. Aspiration thrombectomy for treatment of acute massive and submassive pulmonary embolism: initial single-center prospective experience. J Vasc Interv Radiol. 2018;29:101-106. doi: 10.1016/j.jvir.2017.08.010

INDIGO SYSTEM FOR ILIOFEMORAL POPLITEAL VENOUS THROMBOSIS

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PATIENT PRESENTATION

A 66-year-old woman presented with a 1-day history of acute-onset left leg swelling. Contrast-enhanced CT revealed thrombosis of the left common and external iliac veins extending into the left femoral veins. The distal extent of thrombus was not established. The origin of the left common iliac vein appeared compressed from the right common iliac artery, suggesting May-Thurner syndrome. The medical team referred the case to interventional radiology.

Due to the acute presentation and severity of the left leg swelling in an otherwise fit and very active patient, mechanical thrombectomy with the Indigo System was used.

INTERVENTION

An infrarenal IVC filter (Celect Platinum, Cook Medical) was placed initially accessing the right internal jugular vein with a 9-F sheath (Brite Tip; Cordis, a Cardinal Health company). A hydrophilic guidewire passed easily through the left iliac thrombus. Venography confirmed thrombosis extending to the mid femoral vein level (Figure 1).

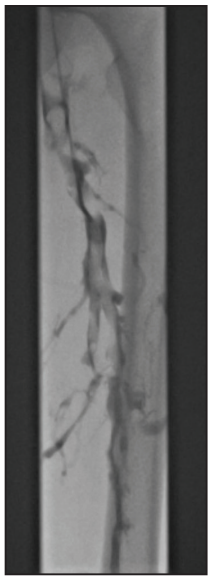

Figure 1. Venogram demonstrating an extensive iliofemoral thrombosis.

Figure 2. Parts of thrombus removed, which wrapped around the SEP8.

Figure 3. Following use of the Indigo System, a venogram showed patency of the iliofemoral segment with a small amount of residual thrombus.

Figure 4. Final venogram confirming good venous outflow.

Thrombus was laced with 10 mg of tPA administered through a multipurpose catheter (Glidecath, Terumo Interventional Systems) and left for 15 minutes. The origin of the left common iliac vein was then dilated using a 10-mm balloon (Advance, Cook Medical); a marked degree of balloon wasting was observed.

The 115-cm CAT8 XTORQ aspiration catheter easily tracked into the thrombus. Under power aspiration, the CAT8 was slowly advanced distally into the common iliac vein in combination with SEP8 allowing for thrombus removal in a single passage. By cycling the Separator back and forth under aspiration, the thrombus was removed (Figure 2).

Repeat venography revealed a good result with a very small amount of residual thrombus (Figure 3).

Venous access was then secured using a 6-F sheath (Avanti+; Cordis, a Cardinal Health company) via the left popliteal vein. Thrombolysis was continued overnight using tPA and a heparin infusion. Repeat venography the following day revealed a moderate degree of residual thrombus involving femoral and iliac veins; however, the veins were patent. A 10-F Brite Tip sheath was placed in the left common femoral vein to place an 8-cm X 16-mm sinus-Obliquus stent (optimed Medizinische Instrumente GmbH) to cover the left common iliac stenosis. A final venogram confirmed good venous flow (Figure 4).

PATIENT OUTCOME AND FOLLOW-UP

A mild degree of left leg swelling persisted the day after treatment, although this had improved. The pain had also reduced. The patient was discharged the following day without complication with continued oral rivaroxaban.

DISCUSSION

Endovascular management is currently recommended for acute presentations of thrombotic May-Thurner syndrome with moderate to severe symptoms.[1] We prefer to place a temporary IVC filter prior to intervention to protect against PE, although the British Society for Haematology guidelines state thrombolysis is not an indication for filter insertion.[2]

The Indigo System was well tolerated and allowed for restoration of flow. The Separator helped evacuate the thrombus effectively by limiting catheter clogging, which helped to reduce the procedure time. The appropriately sized venous stent was not available at the time of aspiration. Had this been available, venous stenting could have been completed immediately after clot aspiration to help avoid the risks of overnight catheter thrombolysis and a second procedure.

1. Patel NH, Stookey KR, Ketcham DB, Cragg AH. Endovascular management of acute extensive iliofemoral DVT caused by May-Thurner syndrome. J Vasc Interv Radiol. 2000;11:1297-1302. doi: 10.1016/s1051-0443(07)61304-9
2. Baglin TP, Brush J, Streiff M. Guidelines on use of vena cava filters. Br J Haematol. 2006;134:590-595. doi: 10.1111/j.1365-2141.2006.06226.x

ACUTE UPPER LIMB THROMBOSIS TREATED WITH INDIGO SYSTEM

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PATIENT PRESENTATION

A woman in her 50s with no previous diseases presented with an acute left arm and shoulder edema and purple skin coloration after sudden physical exercise. Doppler ultrasound was performed, identifying a complete thrombosis of the left axillary and subclavian veins.

Therapeutic anticoagulation treatment with low-molecular-weight heparin was initiated, and 12 hours later, the patient was sent for treatment in the vascular and interventional radiology unit.

INTERVENTION

The procedure was performed under conscious sedation and a total volume of 5,000 IU heparin was administrated intravenously. Retrograde vascular access to the venous segment was performed under ultrasound guidance using an 8-F short sheath in the left brachial vein. Venography confirmed thrombus in the subclavian and axillary veins (Figure 1). An 85-cm CAT8 XTORQ85 aspiration catheter was advanced over an 0.035-inch guidewire facing the occlusion. Aspiration was initiated and CAT8 was used with the SEP8 to facilitate thrombus engagement into the canister. After only 10 minutes of a few passes with power aspiration, a 90% thrombotic load reduction was achieved (Figure 2). Subsequent venography showed underlying focal stenosis in the infraclavicular subclavian vein segment, which could be secondary to thoracic operculum syndrome. Simple angioplasty was performed using an 8-mm X 4-cm balloon catheter (Mustang, Boston Scientific Corporation), with significant stenosis resolution (Figure 3A and 3B).

PATIENT FOLLOW-UP AND DISCHARGE

A control venogram showed minimal residual clot (Figure 4). The procedure lasted approximately 45 minutes. The patient was asymptomatic at 24 hours and discharged with low-molecular-weight heparin for 3 months. The patient's thoracic operculum syndrome will be followed on an outpatient basis to plan surgery.

DISCUSSION

The Indigo System can be considered a safe and efficient instrument for the removal of acute venous

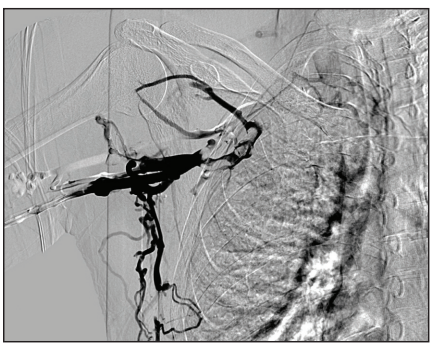

Figure 1. An intraoperative venogram showed occlusion of the subclavian vein.

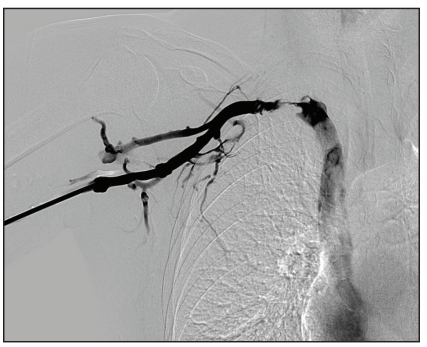

Figure 2. The first result after power aspiration using CAT8/SEP8 showed successful thrombus removal.

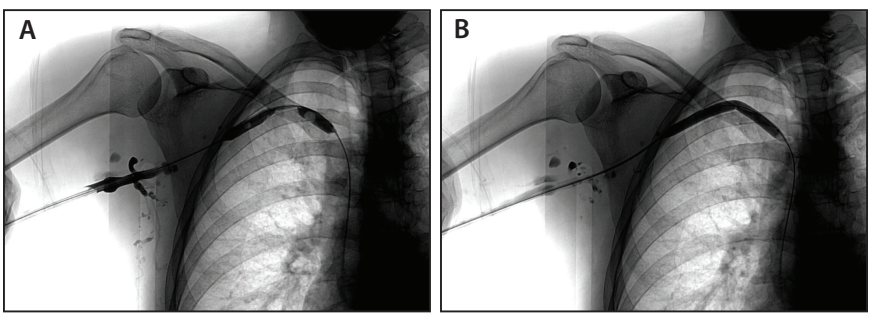

Figure 3. Placement of the 8-mm X 4-cm Mustang balloon catheter for angioplasty of stenosis in the infraclavicular subclavian vein segment.

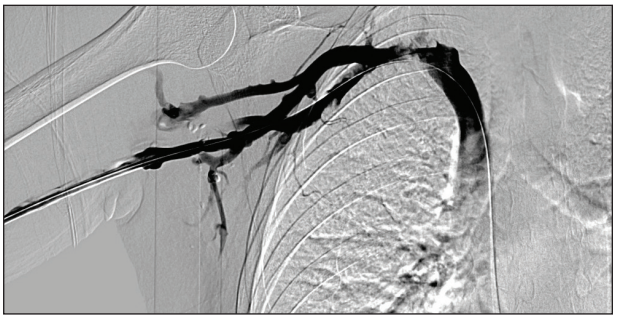

Figure 4. The final venogram demonstrated almost complete removal of thrombus in the subclavian and axillary veins.

thrombosis of the upper limb. In cases of heavy clot burden, its main advantage includes the use of continuous power aspiration through large lumen catheters to help with thrombotic load removal while helping to reduce hemolysis complications. In addition, it may reduce the risk of bleeding complications by potentially limiting or diminishing the need of fibrinolytic agents, which can help avoid the need for intensive care to help shorten the length of hospital stay.[1]

1. Vemuri C, Payam S, Benarroch-Gampel J, et al. 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. doi: 10.1016/j.jvsv.2016.01.004

PORTAL VEIN THROMBOSIS AFTER LIVER TRANSPLANT TREATED WITH INDIGO SYSTEM AND THROMBOLYSIS

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PATIENT PRESENTATION

A 71-year-old man presented to a local hospital with abdominal pain, vomiting, and weight loss. He had a liver transplant for hepatitis C cirrhosis in 2006. His initial blood tests, including white blood cell count, liver function tests, and serum lactate, were normal. A dual-phase CT of the liver demonstrated extensive portal vein thrombosis involving the intrahepatic portal vein branches and extending into the superior mesenteric vein (SMV) and splenic vein. Despite mesenteric fat stranding, there were no signs of bowel ischemia. Low-molecular-weight heparin was started, and the patient was subsequently transferred to our tertiary liver transplant center for further management.

Despite a prolonged lytic drip, a second CT scan showed no change in the distribution and volume of portal venous-mesenteric thrombosis. Endovascular treatment options included either a transjugular intrahepatic portosystemic shunt (TIPS) or percutaneous transsplenic/transhepatic thrombectomy and thrombolysis. A TIPS procedure was undertaken given the extensive intrahepatic portal vein thrombus and the need to establish satisfactory outflow.

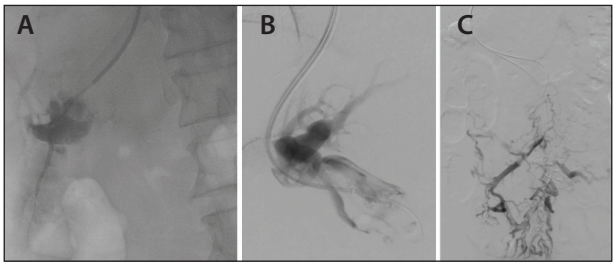

Figure 1. Initial portal venogram showed extensive portal vein (A, B) and SMV (C) thrombus.

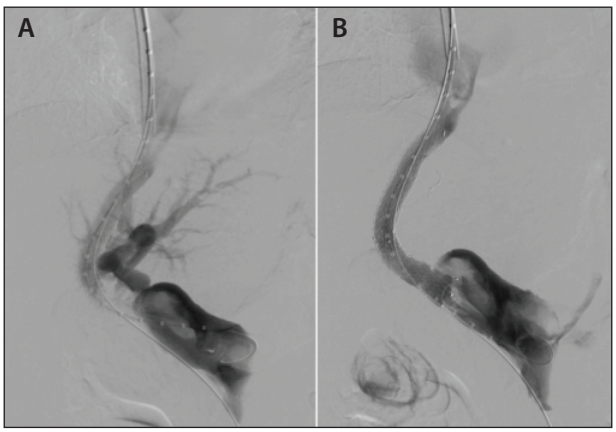

Figure 2. Significant residual thrombus in portal vein after TIPS implantation (A). Improved flow across the TIPS after deployment of 12-mm Venovo stent into the thrombosed main portal vein (B).

INTERVENTION

The thrombosed portal vein was accessed from the right hepatic vein under ultrasound guidance, and initial venography correlated with the CT findings of the extensive portal and SMV thrombosis (Figure 1). A 10-mm (7 + 2 cm) Viatorr TIPS endoprosthesis (Gore & Associates)

Figure 3. Extensive residual SMV thrombus after 24 hours of catheter-directed thrombolysis.

was implanted between the right portal vein and right hepatic vein. Extensive residual thrombus remained, therefore, a 12-mm Venovo venous stent (BD Interventional) was placed into the portal vein, resulting in improved flow; however, significant thrombus remained (Figure 2). Consequently, an overnight lytic drip was attempted.

After 24 hours of lysis, repeat venography demonstrated suboptimal results with residual thrombus (Figure 3). Mechanical thrombectomy of the portal vein, SMV, and its tributaries was undertaken using the Indigo System. The CAT8 XTORQ aspiration catheter was delivered through a transjugular approach via the 10-F sheath to the thrombus. Aspiration was commenced allowing for gentle removal of the high thrombus burden at the main portal vein using the CAT8 in conjunction with SEP8. An Indigo CAT6 catheter was telescoped through the CAT8 XTORQ to facilitate thrombus removal in the smaller vessel of the SMV and deep into its tributaries to improve the inflow to the portal vein (Figure 4). The postprocedure venogram showed restoration of flow through the TIPS, portal vein, and the main trunk of the SMV and its tributaries (Figure 5).

Liver Doppler ultrasound performed on day 3 after TIPS demonstrated patent TIPS and portal vein with residual nonocclusive thrombus within the SMV and splenic vein. Systemic anticoagulation (apixaban) was commenced on discharge. CT scan at 2 months and a TIPS surveillance angiogram (Figure 6) at 3 months showed a patent portal vein, SMV, and TIPS stent with a portocaval pressure gradient of 7 mm Hg.

DISCUSSION

The incidence of portal vein thrombosis after liver transplantation is uncommon but can cause significant mortality and morbidity. TIPS provides access into the portal vein with a theoretically lower bleeding risk because of a reduced risk of liver capsule transgression as well as increased portal vein flow, which helps dissolve residual thrombus.

This case illustrates the versatility of the Indigo System, with its wide range of highly trackable and atraumatic

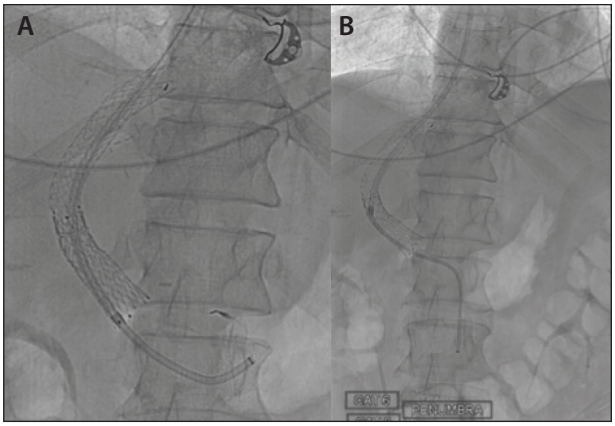

Figure 4. Power aspiration with CAT8/SEP8 the SMV and portal vein (A). Telescoping of the CAT6 through CAT8 (B).

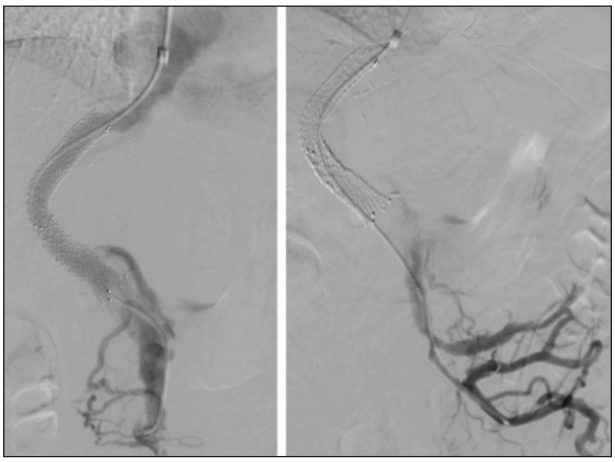

Figure 5. Postthrombectomy venogram demonstrated patent TIPS, portal vein, main trunk of the SMV, as well as partial recanalization of some of its tributaries.

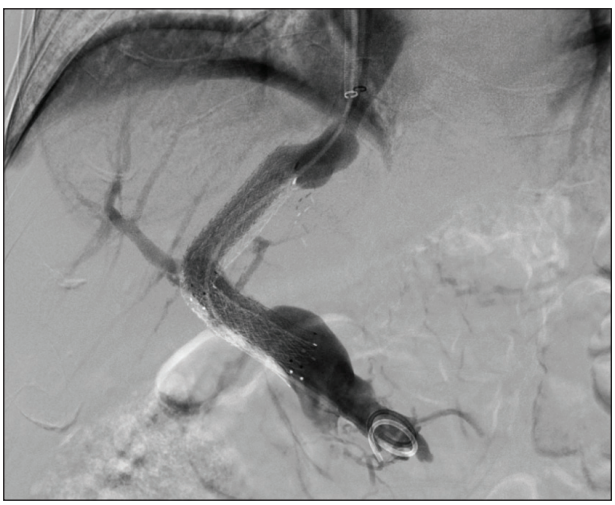

Figure 6. TIPS surveillance angiogram at 3 months showed a patent TIPS. The portocaval pressure gradient was 7 mm Hg.

catheters facilitating thrombectomy deep within the mesenteric venous system. The powerful aspiration pump generates a sustained vacuum that facilitates thrombus extraction in cases with significant thrombus burden. The Indigo System can potentially reduce the volume of fibrinolytic agents administered, which may help lowering the risk of hemorrhage in these patients.

ACUTE ISCHEMIA OF THE LEFT UPPER LIMB TREATED WITH INDIGO SYSTEM

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PATIENT PRESENTATION

A 70-year-old man presented in the emergency department with acute ischemia of the left hand. He had a history of coronary artery disease, cardiac arrhythmia, chronic obstructive pulmonary disease, and chronic lymphatic leukemia and was undergoing antiplatelet therapy. CTA showed evidence of parietal thrombosis in the subclavian and axillary arteries that looked slightly dilated. Furthermore, the distal part of the radial artery, ulnar artery, and the superficial and deep palmar arch were thrombosed. In the clinical examination, the hand looked cyanotic and ischemic with a deficit in mobility and sensitivity and, therefore, was scheduled for revascularization with thrombolysis. The cause of the ischemic hand was an embolic event from atrial fibrillation. An attempt of intra-arterial thrombolysis was unsuccessful (heparin and urokinase infusion).

Figure 1. Preprocedural angiogram showed total occlusion of the radial artery after thrombolysis.

INTERVENTION

Percutaneous access was performed through the right femoral artery with a 6-F, 90-cm sheath

Figure 2. CAT6 and SEP6 tracked to the distal radial artery.

Figure 3. Postprocedural angiogram after CAT6 and CAT3 showing successful recanalization.

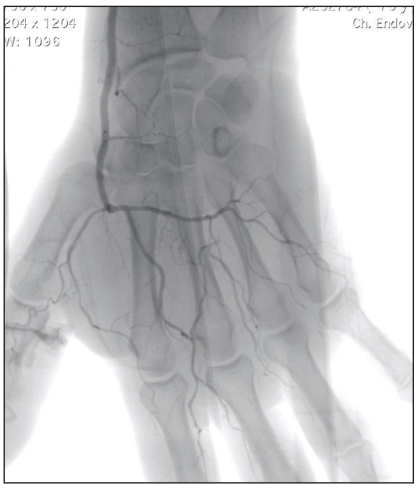

Figure 4. Complete restoration of flow after Indigo System and thrombolysis.

(Destination, Terumo Interventional Systems) up to the left axillary artery, and angiography was performed. Despite the thrombolysis treatment, the radial artery was occluded distally with no runoff into the palmar or interdigital branches (Figure 1).

A 135-cm Indigo CAT6 aspiration catheter was inserted through the Tuohy-Borst adapter of the 6-F sheath. It easily tracked over an 0.018-inch Command ST (Abbott) guidewire into the radial artery. Mechanical thrombectomy using power aspiration was performed. CAT6 and SEP6 were used to engage the emboli occluding the distal radial artery (Figure 2). Partial thrombectomy was achieved with CAT6, and a 150-cm CAT3 was telescoped through the CAT6 to reach the superficial and deep palmar arch, resulting in complete revascularization. The patient's clinical conditions improved, showing parenchymal enhancement at the level of the radial and palmar artery as well as the interdigital branches. Control angiography was performed (Figure 3).

To further improve flow, a 24-hour intra-arterial low-dose thrombolysis was continued. Final angiography showed a complete resolution of the thrombotic obstruction of the radial artery, the superficial palmar arch, and a full recovery of the interruption of the interdigital arteries (Figure 4). The patient was discharged with anticoagulation therapy considering the embolic background of acute ischemia.

DISCUSSION

Catheter-directed thrombolysis provides a therapeutic option in situations of acute occlusive thrombus of the hand. There are times when thrombolytics are contraindicated or fail to lyse the thrombus. In this case, the Indigo System offered an alternative treatment option for thrombus removal in vessels of different diameters. The Indigo System catheters range from 3 to 8 F, permitting power aspiration as far as into the superficial palmar arch.

THROMBOSIS OF THE MAIN BODY AND RIGHT LIMB OF AN AORTIC STENT GRAFT TREATED WITH INDIGO SYSTEM

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PATIENT PRESENTATION

A 79-year-old man underwent total endovascular aneurysm repair (EVAR) of his abdominal aortic aneurysm in 2015. The patient's medical history included arterial hypertension and hyperlipidemia. In 2019, he presented with bilateral iliac aneurysms. Iliac side branch (ISB) grafts were planned on both sides to maintain blood flow into the internal iliac arteries and prevent buttock claudication. In May 2019, he received his left ISB, and in July 2019, an E-liac side branch prosthesis (Jotec) was implanted. Before discharge, the patient underwent a control CTA showing thrombus formation in the aortic stent graft bifurcation extending into the right limb.

INTERVENTION

Right femoral access was achieved with a 5-F short sheath. An angiogram through a 5-F pigtail catheter confirmed the findings from the CTA. There was free-floating thrombus formation riding on the bifurcation of the main body extending into the right ISB (Figure 1).

An 8-F, 45-cm sheath (Destination, Terumo Interventional Systems) was inserted to stabilize the position of the Indigo aspiration catheter within the stent graft limb (Figure 2).

An 85-cm CAT8 TORQ aspiration catheter was carefully advanced over an 0.035-inch guidewire aspiration catheter through the crosscut valve of the 8-F sheath using the peel-away introducer. Once the CAT8 was facing the thrombus, the guidewire was removed and power aspiration was turned on. The first pass was completed without the Separator, however, the thrombus was already too organized to be removed without the Separator technique. CAT8 and SEP8 were advanced carefully into the thrombus from proximal to distal. The Separator was cycled back and forth to facilitate clot fragmentation at the catheter tip.

When the tip of the catheter appeared to be blocked, the CAT8 was withdrawn by the millimeter with thorough movement of SEP8 until flow appeared in the tubing and then advanced again.

A shot of contrast through the sheath confirmed the full removal of thrombus after only 20 minutes (Figure 3). Control angiography showed runoff in both legs and ruled out distal thrombosis or emboli resulting

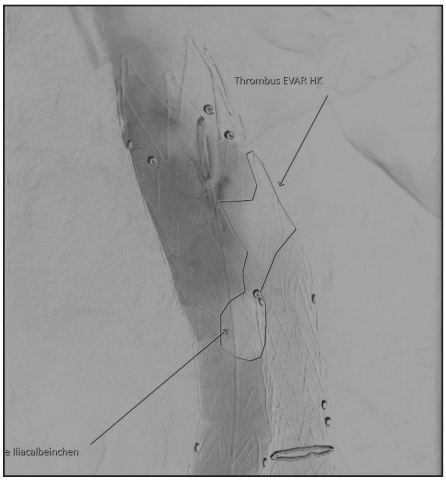

Figure 1. Thrombus presenting in the main body extending into the right limb.

Figure 2. Stabilization of retrograde access through the right ISB.

Figure 3. Successful thrombus removal after the procedure with CAT8/SEP8.

from the intervention. The total procedure time was 52 minutes.

The patient was discharged with 100 mg of aspirin and 75 mg clopidogrel for 3 months, then monotherapy with aspirin.

DISCUSSION

The treatment of occluded or partially occluded stent graft limbs is challenging. Full anticoagulation with vitamin K antagonists or open embolectomy might be an option in patients without symptoms. The risks associated with full anticoagulation are a potential increased risk of hemorrhagic or other complications. Residual thrombus removal and the risk of dislodging stent graft limbs with open embolectomy may limit the success rate of these procedures.

The Indigo System is an essential tool that can help treat challenging complications that may arise after EVAR. In this case, continuous power aspiration resulted in restoration of blood flow in only 20 minutes without complication. The Indigo System's large lumen aspiration catheter and its atraumatic distal tip allowed saving access into the existing prosthesis and enabled targeted thrombus removal. ■

Drs. Robert A. Lookstein, Miguel A. de Gregorio, Andrew Gemmell, Juan José Ciampi-Dopazo, AbdulRahman Alvi, Francesco Intrieri, and Heiko Wendorff drafted articles as consultants to Penumbra and may have been compensated in association with the articles.

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