Title

Rapid Ventricular Pacing for Landing Zone Precision During Thoracic Endovascular Aortic Arch Repair: A Case Series.

Journal

Journal of cardiothoracic and vascular anesthesia, 31(6)

ISSN

1053-0770

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Publication Date

2017-12-01

DOI

10.1053/j.jvca.2017.03.034

Peer reviewed

*Title Page (complete with Author details)

Title:

Rapid ventricular pacing for landing zone precision during thoracic endovascular aortic arch repair

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Acknowledgments:

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

*Structured Abstract/Summary

Structured Abstract:

1. Objective: Precise stent deployment during thoracic endovascular aortic repair of the aortic arch and proximal descending aorta requires transient hypotension (systolic blood pressure < 60 mm Hg during stent deployment). The objects of this study were to establish a protocol for vascular anesthesiologists to perform rapid ventricular pacing for deliberate hypotension during thoracic endovascular aortic repair, and describe the hemodynamics and safety of this technique in a cohort of patients.

2. Design: This was a retrospective, observational study.

3. Setting: Hybrid vascular operating room at a single, tertiary care center.

4. Participants: Seven patients undergoing endovascular or hybrid repair for aneurysm or pseudoaneurysm involving the aortic arch in 2015-2016.

5. Interventions: After induction of general anesthesia, a right ventricular pacing wire was placed to provide rapid ventricular pacing during stent graft deployment. Pacing was delivered at 175 ± 9 beats per minute. Vasopressors were administered by background infusion or bolus dose to maintain hemodynamic stability after cessation of rapid ventricular pacing.

6. Measurements and Main Results: Characteristics of patients and endovascular or hybrid procedures were gathered from the electronic medical record. Patients undergoing thoracic endovascular aortic repair with rapid ventricular pacing were elderly (70 ± 7 years) and classified as American Society of Anesthesiologists physical status 3 or 4. All patients had cardiac comorbidities, most typically coronary artery disease, history of congestive heart failure, diastolic dysfunction, or mild to moderate valvular disease. Patients required one to three episodes of rapid ventricular pacing during the endovascular procedure. In all cases, rapid ventricular pacing yielded excellent transient hypotension and stent deployment in the aortic arch was technically successful. No patients had persistent hypotension, ventricular arrhythmias, or cardiac arrest after pacing.

7. Conclusions: Rapid ventricular pacing is a useful and feasible technique for inducing deliberate, transient hypotension. In a cohort of seven patients with cardiac comorbidities, rapid ventricular pacing was well tolerated and facilitated technically successful endovascular repair of the aortic arch.

Key Words: Thoracic endovascular aortic repair (TEVAR), rapid ventricular pacing, deliberate hypotension, aortic arch, hemodynamics, vascular stent graft

Introduction

Thoracic endovascular aortic repair (TEVAR) is a modern approach for repair of aortic pathology including aneurysm, dissection, and trauma.[1] TEVAR may spare high-risk patients a morbid open surgical repair with left-heart or cardiopulmonary bypass. Endovascular techniques have gained momentum with the advent of fenestrated and branched stent grafts that allow revascularization of major aortic branches.[2] Aortic arch pathology is also amenable to TEVAR, but often requires a concurrent or staged open "debranching" procedure such as carotid-carotid or carotid-subclavian bypass. Debranching permits stent deployment across the origins of the arch vessels while maintaining perfusion to the head and upper extremities.[1]

Anesthetic management of TEVAR must facilitate precise deployment of stents at short proximal landing zones near the arch vessels.[3] Deployment is complicated by the hydrodynamics of aortic blood flow that force the stent distally ("wind-sock" effect). Transient hypotension (systolic blood pressure < 60 mmHg) is required during deployment to limit stent migration. Various drugs have been used for this purpose,[4, 5] but rapid ventricular pacing (RVP) is emerging as a preferred technique.[6] The bulk of published data on RVP arises from the transcatheter aortic valve replacement (TAVR) literature, where RVP is utilized during balloon valvuloplasty and valve deployment. Small studies have shown efficacy and safety of RVP for TEVAR,[7-9] but deaths have been reported.[10]

During TAVR procedures, the interventional cardiologist typically controls RVP, and the catheterization laboratory staff is familiar with pacing techniques. TEVAR of the aortic arch is generally performed in the hybrid vascular operating room or interventional suite, an environment where a cardiology team experienced in RVP is generally not available. Anesthesiologists, who have expertise in acute hemodynamics and the determinants of myocardial performance, are a natural choice to control and implement RVP. While cardiac anesthesiologists are likely familiar with the technique of RVP during TAVR, we expect that general anesthesiologists will be increasingly called upon to perform anesthesia for TEVAR as the surgical technique becomes more widespread. Herein, we describe our technique for RVP, and report patient and procedural factors in seven cases where RVP facilitated a successful TEVAR. We hypothesized that RVP would be well tolerated by patients with mild to moderate cardiac disease in this cohort.

Methods

Approval was obtained from the local Committee on Human Research, and the Committee waived the need for informed consent. Seven operations employing RVP for TEVAR were identified from 2015-16. The medical chart and anesthetic records of each patient were reviewed. Details about aortic pathology and the surgical procedure were gathered from imaging studies and operative reports. Data on anesthetic management, intraoperative RVP, and hemodynamics were extracted from the electronic anesthesia record. Descriptive statistics were calculated using Microsoft Excel.

Results

Patients presenting for TEVAR with RVP in this study were elderly (70 ± 7 y) and had American Society of Anesthesiologists (ASA) physical status classifications of 3 or 4 (Table 1). Two patients were classified as ASA 4E: one for a rapidly enlarging pseudoaneurysm (patient #2), and one for a ruptured, partially contained aortic arch pseudoaneurysm (#7). A variety of aortic arch pathologies were treated with TEVAR in the case series including aneurysms, enlarging or ruptured pseudoaneurysms, and penetrating atherosclerotic ulcer (Figure 1). One patient (#1) had an extensive thoracoabdominal aortic aneurysm extending to the arch in the setting of chronic type B dissection.

The majority of patients had cardiac comorbidities (Table 1). Coronary artery disease (CAD) was present in six patients, and four had been revascularized previously with coronary artery bypass grafting or percutaneous coronary intervention. A history of congestive heart failure (CHF) was present in three patients, and another (#2) had elevated B-type natriuretic peptide on admission. One patient in the study had a mildly depressed ejection fraction (#1). Diastolic dysfunction was present in four patients. One patient (#2) had pulmonary hypertension due to severe chronic obstructive pulmonary disease, and one patient had moderate aortic stenosis (#3). Due to an acute presentation of ruptured aneurysm, no transthoracic echocardiogram was available for one patient (#7). Most patients were taking a beta blocker, angiotensin converting enzyme inhibitor or angiotensin-receptor blocker, statin, and aspirin preoperatively (Supplemental Table). Blood pressure (systolic 122 ± 15 mm Hg, diastolic 76 ± 13 mm Hg) and heart rate (74 ± 13 bpm) were overall well controlled in the series.

Two patients had endovascular procedures only (#2 and 4, Table 1). Four had hybrid procedures with open aortic arch debranching (carotid-carotid-subclavian bypass, CCSB, Figure 2) followed by TEVAR during the same operation. One patient (#6) had previously undergone open debranching with deep hypothermic circulatory arrest - left carotid-subclavian bypass and TEVAR with RVP were performed as the second procedure. The term "landing zone" describes the position of the proximal stent margin relative to the arch vessels.[3] Four patients had stents placed in proximal landing Zone 0 (ascending aorta or covering the innominate artery), two in Zone 1 (covering the left common carotid artery), and one in Zone 3 (distal to the left subclavian artery, Figure 1). Of the four landing Zone 0 procedures, one stent was isolated to the ascending aorta (#4), while the other three required arch debranching to preserve cerebral perfusion. Two patients required innominate snorkel stents (#3 and 7, Figure 2),[11] while the other had previously undergone open aorto-innominate-carotid bypass (#6).

To perform rapid ventricular pacing, an introducer sheath was inserted into a central vein with site dictated by the surgical procedure (Table 2). The right subclavian vein was preferentially used if the neck was planned for carotid-left subclavian bypass. A 5-French balloon-tipped Swan-Ganz bipolar pacing catheter (Edwards) was inserted into the right ventricle under fluoroscopic guidance. The pacing catheter tip was ideally positioned at the apex of the right ventricle.[12] In one case, oozing of blood was observed around a pacing catheter passed through a 9 Fr introducer (Arrow MAC). 7 Fr locking introducer sheaths (St. Jude) were found to be a better size match for the pacing catheter and no oozing was observed. Pacing capture thresholds ranged from 0.3 to 3 mA with a target of < 1 mA. The target pacing rate was 180 bpm to achieve adequate hypotension, a rate achieved in five (71%) of the cases. In two cases the pacing rate was adjusted down to 160-165 bpm to achieve consistent capture. All patients received one or two aortic stents, requiring between one and three episodes of RVP (some stents required balloon dilatation after deployment). In all seven cases, RVP yielded excellent hypotension (Supplemental Video 1 online) and accurate stent deployment. The duration of RVP was less than one minute in each instance. In one case (#4), the team first attempted to induce asystole with two doses of adenosine 12 mg IV. When this was unsuccessful, RVP was performed.

All patients were hemodynamically stable after RVP (Table 2). Six patients were maintained on a low dose vasopressor infusion (norepinephrine or phenylephrine) throughout the procedure, and no increase in infusion rate was required during or after RVP. One patient (#7) had sepsis prior to the start of the operation and required higher doses of vasopressors throughout, yet no increase was required after RVP. In one case (#5), a bolus of epinephrine was given prophylactically prior to RVP. No episode of RVP led to hypotension lasting longer than one minute, which is the minimum time resolution of the electronic anesthesia record. Blood pressure typically recovered to baseline in ≤ 10 seconds after discontinuation of RVP (Supplemental Video 2 online). No significant arrhythmias were observed and defibrillation was not required. Three of seven patients were extubated in the OR at the end of the procedure, and one of those who had CCSB was re-intubated immediately post-op in the intensive care unit for airway edema.

Discussion

TEVAR of the aortic arch is gaining in popularity and will be increasingly encountered by cardiovascular and general anesthesiologists. Patients undergoing TEVAR are likely to have cardiac comorbidities including CAD, CHF, dysrhythmias, and valvular disease. A key aspect of successful TEVAR is transient hypotension during stent deployment at the proximal landing zone. Rapid and reversible reduction of systolic blood pressure to less than approximately 60 mm Hg helps the surgeon accurately deploy the stent and achieve optimal outcomes for the patient. In our cohort, RVP was well tolerated by patients with a variety of mild-moderate heart disease (Table 1). No direct complications of RVP were seen in this study. Data from TAVR indicate a 2-3% incidence of ventricular fibrillation after RVP.[13, 14] It is therefore prudent to have ready access to defibrillation in the operating room. We observed no hemodynamic deteriorations at RVP cessation. However, cardiovascular collapse requiring cardiopulmonary bypass and deaths have been reported during TAVR[14] and TEVAR[10] procedures for patients with severe valvular disease. Titration of vasopressors to achieve a mean arterial pressure > 75 mm Hg has been recommended to optimize coronary perfusion prior to initiating RVP.[14]

Finally, we recommend a few practical considerations for anesthesiologists new to the technique of RVP for TEVAR. Careful consideration must be given to central access. Common introducer sheaths (8.5 or 9 Fr) used for volume resuscitation during vascular surgery may have poor size match with temporary pacing catheters and risk bleeding, infection, or air embolus. We recommend a small (7 Fr) dedicated introducer sheath for passage of the pacing catheter. The choice of central venous access site should be discussed with the surgeon, as access to jugular and femoral veins may be limited, particularly if carotid-subclavian bypass is planned. If additional central access is needed for fluids or medications, consideration should be given to placement of a second, dedicated central venous catheter of appropriate size.

Our practice is to place and test the pacing catheter in the operating room after induction of general anesthesia. Pacing thresholds should be checked, usually at a paced rate of 80 to 90 beats per minute, and the catheter position optimized if capture is not reliable at currents below 3 mA. For effective capture and pacing on demand, the pacer output should be set to at least double the initial threshold (with an upper output limit of about 10 mA).[12] Depending on the number of aortic stent graft components to be deployed (such as overlapping grafts or snorkel stents), multiple episodes of RVP may be required. It is not uncommon for pacing thresholds to change slightly over the course of a lengthy operation or with multiple rounds of RVP. Thus, it is important to achieve the best possible initial catheter position and low thresholds. After thresholds are recorded and pacer output is set, we recommend testing RVP at the targeted pacing rate (about 180 bpm) prior to surgical incision. This allows the anesthesiologist to ensure adequate systolic hypotension and assess for prompt hemodynamic recovery at cessation of pacing. If a patient does not tolerate RVP, it is preferable to know this fact well prior to the crucial moments of the surgical procedure (aortic arch stent graft deployment) and devise an alternate plan if necessary.

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Figure Legends

Figure 1. Schematic of aortic arch pathology in patients undergoing thoracic endovascular aortic repair (TEVAR) with rapid ventricular pacing (RVP) in this study. (Patient #1) Aneurysm with chronic Type B dissection, (#2) aneurysm enlarging due to endoleak after prior TEVAR, (#3 and #6) isolated arch aneurysm, (#4) ascending aortic pseudoaneurysm due to leaking patch at prior aortic cannulation site from coronary artery bypass grafting, (#5) penetrating atherosclerotic ulcer of the aortic arch, and (#7) ruptured aortic arch aneurysm. Dashed lines indicate landing zone (Z) for proximal margin of stent deployed under RVP. Arrows indicate leak or extravasation of blood. Lightning bolt indicates dissection.

Figure 2. Intraoperative digital subtraction angiography showing completed thoracic endovascular aortic repair with arch debranching after stent deployment with rapid ventricular pacing (RVP) in patient #3. (*A*) Overview of arch revascularization showing arch stent graft, innominate artery snorkel stent, and carotid-carotid-subclavian bypass (denoted by *). Right common carotid artery (R CA), left common carotid artery (L CA), and left subclavian artery (L SCA) are labeled. The temporary pacer wire used to deliver RVP is visible entering the image from the top left. (*B*) Close up of snorkel stent (S) extending from the ascending aortic arch into the innominate artery. The snorkel stent maintains flow to the carotid and subclavian arteries, and allows deployment of a stent graft with proximal landing zone zero.

Supplemental Legends

Supplemental Video 1. Electrocardiogram and arterial blood pressure recordings during start of rapid ventricular pacing at 182 beats per minute.

Supplemental Video 2. Electrocardiogram and arterial blood pressure recordings during termination of rapid ventricular pacing and recovery.

Table 1

Table 1. Patient and procedure characteristics.

Patient	Age (y)	Sex	BMI (kg/m^2)	ASA status	Diagnosis	CAD	CHF	EF	Diastolic dysfunction	Valvular disease	Pulmonary hypertension	Procedure	Proximal landing zone
1	66	M	29	4	TAAA, chronic type B dissection	MI, DES	yes	50 %	Grade 1	no	no	CCSB, arch TEVAR	1
2	66	M	22	4E	Thoracic aortic PA, re-do TEVAR	yes	elevated BNP	65 %	Grade 1	mild AS	PASP 47 mm Hg, RV pressure overload	TEVAR (distal arch)	3
3	85	F	26	3	Aortic arch aneurysm	no	no	70 %	Grade 1-2	moderate AS	PASP 34 mm Hg	CCSB, TEVAR (arch)[a]	0
4	69	M	26	4	Ascending aortic PA	CABG	yes	65 %	Grade 1	no	no	TEVAR (ascending aorta)	0

5	66	M	42	3	PAU, distal aortic arch aneurysm	CABG	yes	60 %	no	mild MR, mild TR	no	CCSB, TEVAR (arch)	1
6	72	F	29	4	Aortic arch PAs x2	yes	no	75 %	no	no	no	Left carotid-subclavian bypass, TEVAR (arch)[b]	0
7	66	M	27	4E	Ruptured aortic arch PA	CABG, recent DES	no	unknown	unknown	unknown	unknown	CCSB, TEVAR (arch)[a]	0
Summary (mean ± s.d.)	70 ± 7		29 ± 7					64 ± 9 %					

AS = aortic stenosis; ASA = American Society of Anesthesiologists; BMI = body mass index; BNP = B-type natriuretic peptide; CABG = coronary artery bypass grafting; CAD = coronary artery disease; CCSB = carotid-carotid-subclavian bypass; CHF = congestive heart failure;

DES = drug eluting stent; EF = ejection fraction; MI = myocardial infarction; MR = mitral regurgitation PA = pseudoaneurysm; PASP = pulmonary artery systolic pressure; PAU = penetrating atherosclerotic ulcer; RV = right ventricle; TAAA = thoracoabdominal aortic aneurysm; TEVAR = thoracic endovascular aortic repair; TR = tricuspid regurgitation.

[a] Patient received an innominate artery snorkel stent.

[b] Patient had prior arch debranching with aorto-innominate-left common carotid bypass via sternotomy with deep hypothermic circulatory arrest.

Table 2

Table 2. Characteristics of rapid ventricular pacing and other procedural aspects.

Patient	# of aortic stents	# RVP episodes	RVP rate (min^{-1})	Time MAP < 60 (min)	Pressor infusion (mcg/ min)	Pressor bolus	Other hypotensive modality	Introducer for pacing wire	Complications of vascular access	Extubated in operating room
1	2	1	180	1	NE 5	no	no	9 Fr	no	No (edema)
2	1	3	181	3	NE 2, P 35	no	no	9 Fr, right IJ	leak, oozing	Yes
3	2	3	165	0	NE 5-7, P 0-20	no	no	7 Fr, right SC	no	Yes (re-intubated in ICU for edema)
4	1	1	160	1	P 10	no	Adenosine 12 mg IV x2 (failed)	9 Fr, right IJ	no	Yes
5	2	2	180	1	NE 3-4	Epineph-rine 32 mcg	no	7 Fr, right femoral	no	No (rapid shallow breathing, obesity)
6	2	1	180	1	NE 7	no	no	7 Fr, right SC	no	No
7	2	1	182	0	NE 14, Vaso-pressin	no	no	7 Fr, right SC	no	No (edema, coagulopathy)

					0.06 units/min					
Summary (mean ± s.d.)	1.7 ± 0.5	1.7 ± 1.0	175 ± 9	1 ± 1						

Fr = French; ICU = intensive care unit; IJ = internal jugular; IV = intravenous; MAP = mean arterial pressure; NE = norepinephrine; P = phenylephrine; RVP = rapid ventricular pacing; SC = subclavian.

Supplemental Table. Other preoperative comorbidities, medications, and resting hemodynamics in patients presenting for TEVAR.

Patient	COPD (FEV1 % if known)	Smoking (pack-years)	CKD / stage	CVA	Beta blocker	ACEI/ARB	other anti-hypertensive or loop diuretic	Statin	Anti-platelets	SBP (mm Hg)	DBP (mm Hg)	Heart rate (bpm)
1	yes	15	3	IPH	carvedilol	yes	chlorthal-idone	yes	aspirin 81	129	81	74
2	yes (18%)	100	no	no	no	no	no	no	no	126	83	78
3	yes (normal)	40	no	no	no	yes	amlodipine	yes	aspirin 81	142	87	91
4	no	3	3	stroke	metoprolol tartrate	no	furosemide	no	no	102	58	78
5	yes (66%)	40	3	no	metoprolol tartrate	yes	HCTZ, amlodipine	yes	aspirin 81	111	55	79
6	yes	50	2	stroke	metoprolol succinate	yes	clonidine, HCTZ, amlodipine	yes	aspirin 81	138	85	81
7	no	unknown	probable	no	metoprolol	yes	isosorbide	yes	aspirin	108	50	68

			3 vs. acute kidney injury		tartrate, labetalol infusion		mononitrate		81, ticagrelor			
Summary (mean ± s.d.)		41 ± 34								122 ± 15	76 ± 13	74 ± 13

COPD = chronic obstructive pulmonary disease; FEV1 = forced expiratory volume in one second; CKD = chronic kidney disease; CVA = cerebrovascular accident; ACEI = angiotensin converting enzyme inhibitor; ARB = angiotensin receptor blocker; SBP = systolic blood pressure; DBP = diastolic blood pressure; IPH = intraparenchymal hemorrhage; HCTZ = hydrochlorothiazide.

Figure 1

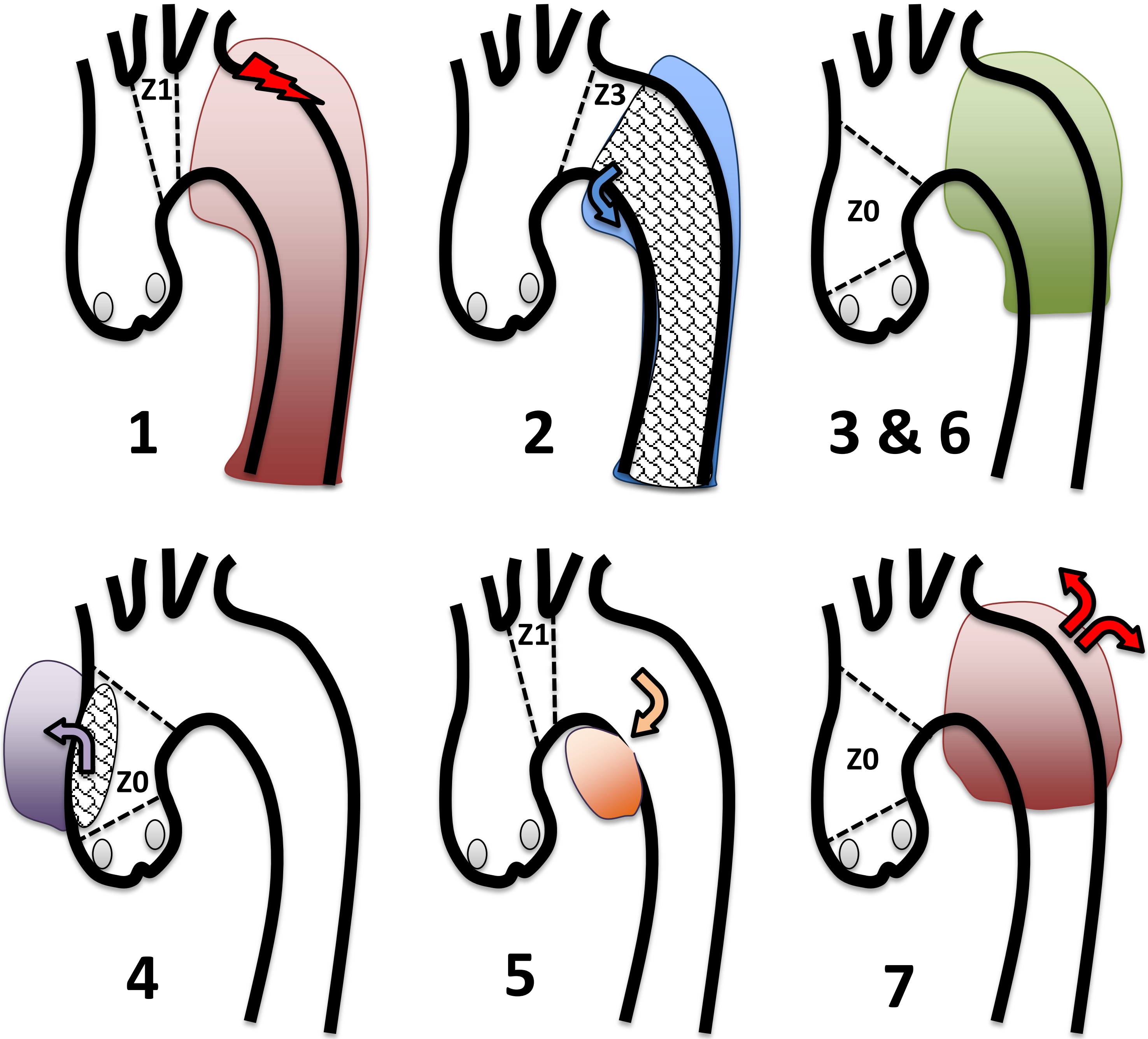

Figure 2
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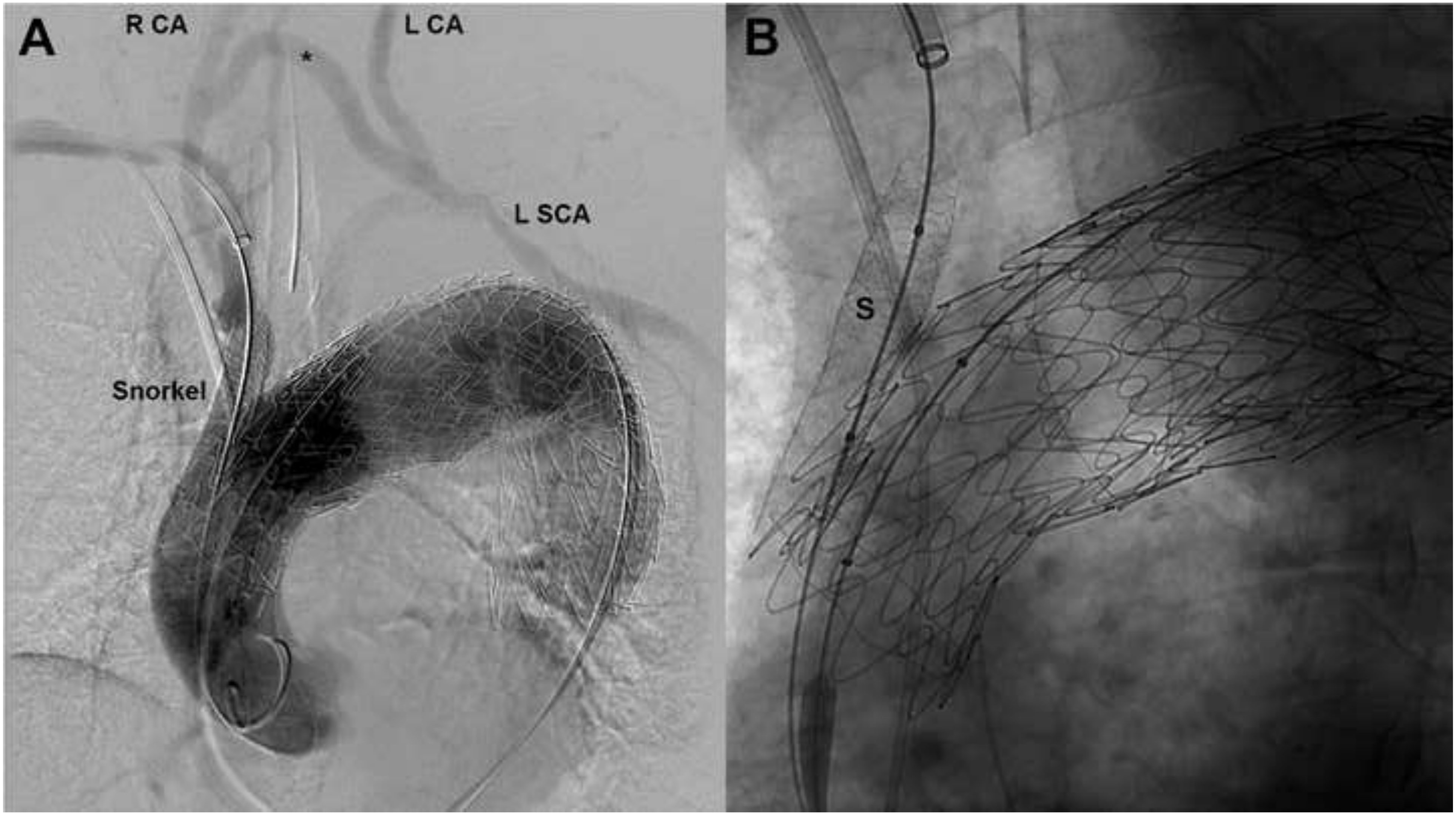

Supplemental Video 1

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Supplemental Video 2

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