EXPERT REVIEW

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Section Editor

New Frontiers in Aortic Therapy: Focus on Deliberate Hypotension During Thoracic Aortic Endovascular Interventions

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THORACIC AORTIC ENDOVASCULAR interventions have blossomed in recent years and have progressed around the aortic arch all the way to replacement of the aortic valve. The entire thoracic aorta is now amenable to endovascular repair in selected patients. These transcatheter procedures frequently require brief deliberate hypotension to facilitate precise hardware deployment. The described techniques for deliberate hypotension in these settings include nitrovasodilators, adenosine, balloon vena cava occlusion and rapid ventricular pacing. Rapid ventricular pacing has evolved to become the current gold standard in the contemporary era due to its efficacy, predictability, consistency, rapid reversibility, and potential to assist in hemodynamic recovery after endovascular device deployment. Further clinical trials will likely explore alternatives in the setting of this current clinical paradigm.

Thoracic endovascular aortic repair (TEVAR) has evolved as a standard endovascular intervention for diverse pathologies of the descending aorta.[1,2] Furthermore, this endovascular therapeutic approach recently has been applied successfully more proximally in the thoracic aorta, including the aortic arch, ascending aorta, and the aortic valve in selected high-risk patients.[3–5] The advent of hybrid aortic arch repair and transcatheter aortic valve replacement (TAVR) has rendered the entire thoracic aorta amenable to minimally invasive endovascular intervention, taking into account the current status quo of the endovascular platforms and concomitant controversies.[6]

The precise deployment of the endovascular graft remains a central priority in thoracic aortic endovascular interventions.[1,2] The deliberate induction of temporary hypotension to facilitate graft deployment and to minimize the risk of graft migration is a recognized adjunct in TEVAR and its derivatives, including TAVR.[1,2,7,8] This graft migration can be catastrophic, depending on extent and aortic segment. For example, graft migration in TAVR can result in severe aortic regurgitation and acute coronary syndrome.[7–9] The extensive clinical experience with TEVAR has highlighted the importance of minimizing graft migration to prevent critical aortic branch vessel occlusion such as the celiac artery and the left subclavian artery.[10,11] The search for further refinements in the conduct and design of thoracic endovascular interventions to optimize outcome is ongoing and includes a focus on techniques to induce graft migration resistance.[12]

The different techniques for deliberate hypotension in thoracic aortic endovascular interventions will be the focus of this expert review, given its clinical importance and prevalence in the contemporary era of cardiovascular anesthetic practice. The major techniques described in the literature for deliberate hypotension in this setting include rapid cardiac pacing, adenosine, and systemic vasodilators including sodium nitroprusside. This review will not discuss the therapeutic application of deliberate hypotension in alternative perioperative scenarios such as ruptured aneurysm or complicated intracerebral aneurysm repair.[13–16]

DELIBERATE HYPOTENSION WITH RAPID VENTRICULAR PACING

A method widely used to induce deliberate hypotension is rapid right ventricular pacing. This type of pacing results in ventricular tachycardia with profound systemic hypotension and minimal cardiac output to facilitate precise deployment of the endovascular device within the thoracic aortic segment of interest.[17] The electric stimuli are given at rates of (180-220) beats per minute, titrated to produce the desired hemodynamic profile. As soon as graft deployment is completed, the rapid ventricular pacing is terminated to allow hemodynamic recovery to occur.

The temporary ventricular pacing can be achieved with a transvenous pacing wire typically floated from the right internal jugular vein or a femoral vein.[18,19] An alternative access for

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temporary right ventricular pacing also has been described via a pacing pulmonary arterial catheter.[20] Furthermore, direct epicardial pacing wires are also a possibility for achieving rapid ventricular pacing in endovascular thoracic aortic interventions with access through the left ventricular apex via a mini-thoracotomy.[21–22]

Recent clinical trials have demonstrated the efficacy and safety of rapid pacing for induction of deliberate hypotension in thoracic aortic endovascular interventions. In the setting of transcatheter balloon aortic valvuloplasty in patients with critical aortic stenosis, Witzke and colleagues (N = 111: 2005-2008: 60.3% exposed to ventricular pacing) demonstrated that rapid ventricular pacing facilitated precise balloon placement with no compromise of clinical safety in this high-risk very symptomatic patient cohort with a mean aortic valve area of 0.64 cm^2.[23] In the setting of TEVAR (n = 70: mean age 63 years), Nienaber and colleagues contrasted the clinical effects of deliberate hypotension induced with rapid ventricular pacing (n = 27/70: 38.6%), titrated sodium nitroprusside (n = 27/70: 38.6%), and adenosine (n = 16/70: 22.8%).[24] In this clinical trial, rapid ventricular pacing induced the most profound hypotension (mean arterial pressure 20 ± 4 mmHg: $p < 0.001$) with the shortest duration (20 ± 10 seconds; $p < 0.001$) and the fastest recovery to baseline hemodynamics (within 1 minute).[24] Furthermore, rapid ventricular pacing, as compared to pharmacologic hypotension with adenosine or sodium nitroprusside, significantly improved precision of graft deployment ($p < 0.05$), shortened procedure time by an average of 25 minutes, and did not compromise clinical safety. These investigators concluded that rapid ventricular pacing is safe and superior to pharmacologic alternatives for deliberate hypotension during TEVAR in the setting of selected patients managed by an experienced perioperative team.

In a randomized controlled trial (n = 197: 2007-2009) in elective TEVAR, patients were exposed to deliberate hypotension induced either by titrated sodium nitroprusside (n = 98) or rapid ventricular pacing (n = 99).[25] In this trial conducted at Guangdong Cardiovascular Institute at Guangzhou in China, rapid ventricular pacing was safe and free from technical difficulty in all patients. Rapid pacing induced significantly greater levels of systemic hypotension ($p = 0.003$) with significantly faster return to baseline hemodynamics (9 ± 2 seconds versus 481 ± 107 seconds: $p < 0.01$).[25] Furthermore, rapid pacing significantly shortened the TEVAR procedure time (94 ± 16 minutes versus 103 ± 24 minutes: $p < 0.01$) and significantly improved precision of graft deployment ($p < 0.01$) with no differences in clinical outcomes such as neurocognition, stroke, spinal cord ischemia, renal function, and graft endoleaks.[25] On the basis of this analysis, the investigators concluded that rapid ventricular pacing was superior to titrated sodium nitroprusside for deliberate hypotension during elective TEVAR, a finding consistent with observational trials.[25–27]

A small clinical trial (N = 27: mean age = 74 years) evaluated rapid ventricular pacing via a pulmonary arterial catheter in elective TEVAR.[20] Patients typically required a median of 2 pacing episodes (range 1-4) with a mean duration of 11 seconds (range 8-14 seconds). The mean pacing rate was 170 ± 15 beats per minute, which rapidly achieved an average mean arterial pressure of 42 ± 8 mmHg. The recovery time to baseline hemodynamics after cessation of pacing was less than 5 seconds, with a mean of 2 seconds. All the grafts were deployed precisely with these parameters for brief deliberate hypotension with no unintentional branch vessel coverage.[20] Despite the brief duration of hypotension from rapid pacing in this clinical study, there was 1 mortality in a patient with severe valvular disease. The investigators concluded that this technique is effective and safe, but requires caution in patients with severe valvular and/or ischemic heart disease.[20]

In the setting of temporary pacing for an endovascular thoracic aortic intervention, perioperative vigilance and contingency planning remain essential to recognize and recover effectively from complications such as pericardial tamponade and ventricular fibrillation.[28] It is essential to have the ability for immediate defibrillation and vasopressor administration since rapid ventricular pacing may at times in this setting trigger ventricular fibrillation and hemodynamic instability.[7,8]

Pericardial tamponade can result from right heart perforation from a pacing wire and/or pacing pulmonary arterial catheter.[28] The appearance of a new pericardial effusion during the procedure either on fluoroscopy or transesophageal echocardiography often can alert the procedural team before hemodynamic collapse ensues.[28,29] This early detection can facilitate an orderly and comprehensive management of the complication. Pulmonary artery rupture also has been reported after pulmonary artery catheterization and, even though it is rare, must be kept in mind in the setting of unexplained airway bleeding.[30] Although this complication often has a high mortality, successful transcatheter occlusion of the ruptured pulmonary artery branch recently has been described and represents an important rescue option.[30] Temporary cardiac pacing in thoracic aortic endovascular interventions typically is achieved via central venous access, even though a recent trial has demonstrated its feasibility via a major peripheral vein of the upper extremity.[32] Central venous access is very common in these major procedures for rapid volume resuscitation and secure central drug administration.[7,8]

Although cardiac pacing often is considered for induction of deliberate hypotension, it also may be utilized to aid hemodynamic recovery after deployment of the endovascular device such as a vascular graft or heart valve.[31–34] Symptomatic heart block is a described complication after TAVR that may require intraoperative temporary ventricular pacing and, ultimately, implantation of a permanent pacemaker in the absence of clinical recovery.[32] Acute significant aortic regurgitation may precipitate congestive heart failure immediately after balloon aortic valvuloplasty and/or TAVR for severe aortic stenosis.[33] In this setting, the hypertrophic left ventricle has limited compliance and advanced diastolic dysfunction that severely limits its hemodynamic tolerance of acute aortic regurgitation. A recent trial has described the therapeutic application of high ventricular pacing rates for short-term hemodynamic rescue in this scenario by diminishing diastolic filling time due to the increased heart rate.[33] These investigators also noted that this strategy is particularly helpful in patients with permanent pacemakers who cannot easily increase their native heart rate.[33] A second consequence of the significant left ventricular hypertrophy in patients with severe aortic stenosis undergoing TAVR is their dependence on left atrial contraction for adequate diastolic filling to the extent that left atrial