

Rapid Ventricular Transvenous Pacing *via* Pulmonary Artery Catheter: Deliberate Hypotension Technique for Precise Proximal Thoracic Aortic Stent Graft Deployment

Erica D. Wittwer^{*}, William J. Mauermann, Norman E. Torres, Gustavo S. Oderich and Juan N. Pulido

Mayo School of Graduate Medical Education, Mayo Clinic College of Medicine, USA

Abstract: Deliberate hypotension facilitates precise deployment of endovascular stent grafting in the thoracic aorta. We describe a practical technique using pulmonary artery catheter (PAC) guided transvenous rapid ventricular pacing *via* transjugular approach and delineate pertinent anesthetic considerations. Anesthesiologists performed PAC guided rapid ventricular pacing in thirty-nine (39) patients (27 men and 12 women, mean age 74 ± 11 years) undergoing thoracic endograft deployment for aneurysm repair. Patient characteristics, hemodynamic parameters, pacing rate, and number of pacing events were recorded. Post-operative complications were evaluated. PAC guided rapid ventricular pacing successfully provided controlled hypotension without technical complications. Mean pacing rate was 177 ± 17 beats/min with an average of 2.6 ± 2 pacing events/surgical procedure. Average pacing duration was 34 ± 29 seconds (MAP of 47 ± 5 mmHg). One intraoperative death occurred in a patient with severe valvular heart disease. In all other cases, recovery time to baseline hemodynamics was short. Postoperative complications included atrial fibrillation in five patients (12%), elevated troponin levels in eight (21%), and stroke in three (8%). No patients had PAC related complications.

Pulmonary artery catheter guided rapid ventricular pacing allows for accurate deployment of thoracic aorta endovascular stent-grafts. Patients with severe valvular or ischemic heart disease are likely poor candidates for this technique.

Keywords: Cardiac pacing, deliberate hypotension, endovascular procedures, pulmonary artery catheter, rapid pacing, thoracic aortic aneurysm.

INTRODUCTION

Endovascular repair of proximal thoracic aortic aneurysms requires strict control of blood pressure and cardiac output during stent-graft deployment to prevent malposition of the stent-graft from a “wind sock” effect due to pulsatile forces displacing the stent-graft. Techniques to achieve a reduction in blood pressure include adenosine induced asystole, intravenous vasodilators, beta blockade, balloon occlusion of the IVC [1], and rapid ventricular pacing.

Adenosine has been safely administered for endovascular aneurysms repair [2]. However, the duration of asystole is unpredictable [2], and some patients may require temporary pacing after adenosine treatment [3]. Hypotension has also been achieved using combinations of vasodilators and beta-blockers. These medications require precise titration and frequently result in surgical delays while the desired effect is achieved. Nitroprusside, nitroglycerin and esmolol have been used in this manner [4-6]. Following graft deployment the anesthesiologist must either wait for the drug effects to resolve or administer additional medications to counter the hypotension and/or bradycardia. Depending on the

complexity of the operation this sequence may need to be repeated multiple times.

A mechanism for precise hemodynamic manipulation that allows reliable decreases in cardiac output and blood pressure for a controlled duration of time with an immediate recovery when terminated is ideal for endograft deployment. Rapid ventricular pacing allows for quickly ceasing cardiac output with fast recovery when the pacing is discontinued. This technique has been described by cardiologists for use *via* transfemoral venous approach in the cardiac catheterization laboratory for aortic endograft deployment [7-9], aortic valve balloon valvuloplasty [10] and transcatheter aortic valve replacement [11]. Nevertheless, the use of a standard pulmonary artery catheter (PAC) for rapid ventricular pacing by anesthesiologists is a practical option that has recently been described in the surgical literature [12]. Currently, rapid ventricular pacing is being used widely for controlled hypotension in aortic procedures [13]. We describe the technique and anesthetic considerations of PAC guided pacing, as well as the growing experience of a single tertiary care institution using rapid ventricular pacing to facilitate precise thoracic aortic endograft placement.

MATERIALS AND METHODS

After Institutional Review Board approval, clinical and operative records for patients undergoing PAC directed rapid

^{*}Address correspondence to this author at the Mayo School of Graduate Medical Education, Mayo Clinic College of Medicine, USA; Tel: 507-255-6032; Fax: 507-255-6463; E-mail: Wittwer.Erica@mayo.edu

ventricular pacing at our institution from April 2008 until July 2014 were reviewed. Patients were included in this review if they underwent PAC directed rapid ventricular pacing for endovascular repair of aortic arch or thoracic aortic aneurysms. Thirty-nine (39) consecutive patients underwent a total of 41 endovascular aortic procedures utilizing rapid ventricular pacing. Emergent patients and patients undergoing complex combined or staged procedures were included in the study. The rate of ventricular pacing, number of pacing episodes performed, and mean arterial pressure (MAP) during the pacing episodes were recorded. Operative time, estimated blood loss, intraoperative red blood cell transfusion, hospital length of stay, intra-operative death, and 30 day postoperative complications such as electrocardiogram (ECG) changes, elevations in troponin, stroke, and death were also reviewed.

Description of Technique

After standard induction of general endotracheal anesthesia patients received invasive radial arterial monitoring. Based on the planned extent of aorta stent coverage, some patients underwent placement of a spinal drain for spinal cord protection prior to induction. Defibrillation pads were placed on all patients. Subsequently, a central venous sheath

and a PAC (Edwards® Life Sciences Swan-Ganz Standard Thermodilution Pulmonary Artery Catheter - 7.5 F) were placed under sterile conditions along with a ventricular pacing wire (Edwards® Lifesciences Chandler Transluminal V-pacing probe), which was advanced through the RV pacing port. The PAC was placed by observation of the hemodynamic waveforms. Two transducers were connected for simultaneous venous pressure tracing observation; one (PA tracing transducer) to the distal port on the PA catheter and one (RA-CVP tracing transducer to the right ventricular (RV) pacing port (Fig. 1A). While advancing the catheter with the balloon inflated, the pressure tracing from the distal port was observed for progression from the superior vena cava, right atrium, right ventricle, and into the pulmonary artery (Fig. 1B). Additionally, the RV pacing port pressure tracing was observed for entrance into the RV. Correct placement occurred when a clear right ventricular waveform was seen on a transducer connected to the RV pace port and the PA waveform was observed on the transducer connected to the distal port (Fig. 1B). If the distal port demonstrated the balloon to be in the wedge position the balloon was deflated and the catheter was withdrawn and repositioned. After correct placement was ensured *via* pressure tracings and the RV pacing wire was advanced (Fig. 1C), the transducer was disconnected from the RV pace port and connected to the

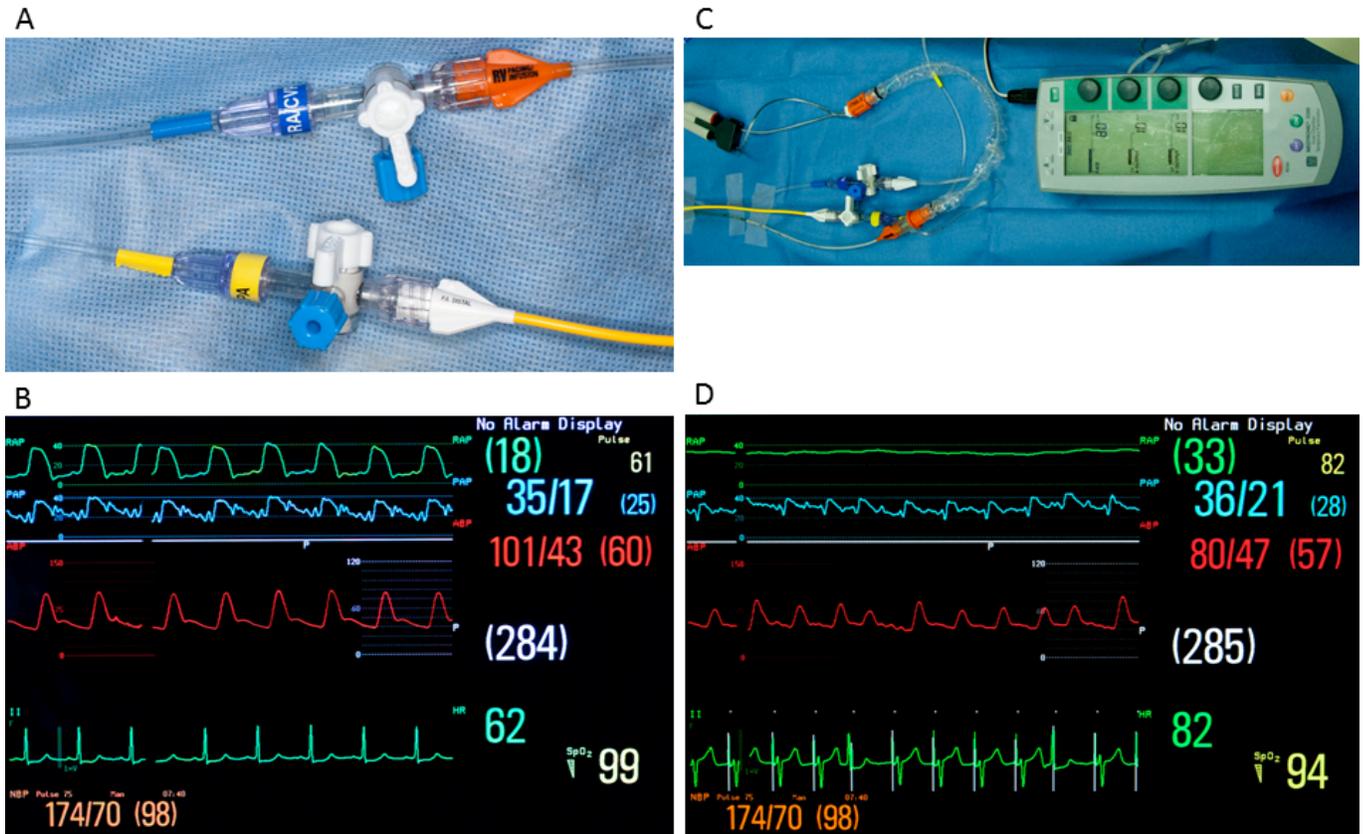


Fig. (1). (A) (top left) – Transducer set up for PAC (pulmonary artery catheter) placement. Note RAP (right atrial pressure – blue/white) transducer connected to the RV (right ventricular/pacing - orange) port and the PA (pulmonary artery – yellow) connected to the distal PA (white) port. 1B (bottom left) - Intraoperative pressure wave forms measured after pulmonary artery catheter advancement to optimal position for V (ventricular) wire placement. Note the RV (right ventricular) waveform (green) obtained by transducing the RV pacing port with the RAP (right atrial pressure) transducer and the PA (Pulmonary artery) waveform (blue) obtained by transducing the distal PA (white) port. (B) (top right) – Transducer set up after V wire advancement through the RV port. 1D (bottom right) – Confirmation of adequate electromechanical ventricular capture. Note V pacing spike prior to QRS.

proximal (right atrial) port as per standard monitoring set up. Typically electromechanical capture was obtained by advancing the pacing wire 5 cm out of the catheter's RV pacing port (Fig. 1D). Due to the natural delay with rapid rate changes, two pacemaker boxes were set up. The rapid pacing box at 160-200 bpm and an emergency settings box set at rate of 80 bpm with 20 mA, to use in case of delayed return of rhythm or rescue pacing needs. After fluoroscopic placement of the endograft into position for deployment, the surgical team leader indicated readiness for rapid ventricular pacing. Hemodynamics were closely monitored in clear view of both the vascular surgical and anesthesia teams. Prior to initiation of pacing the patient would be placed on 100% oxygen for several minutes in anticipation of the upcoming apneic event. The surgeon would request ventilation be held, followed by a request for initiation of pacing. The anesthesiologist would respond with an acknowledgement when the task was completed. Following the loss of pulsatility confirmed by the arterial tracing and a mean arterial pressure (MAP) between 40 and 55, the graft was deployed. After successful deployment the surgeon would ask for termination of pacing and to resume ventilation. Patients were scrutinized for return of normal rhythm and MAP. This process would be repeated for any additional graft deployments or balloon dilations of the grafts (Fig. 2).

Postoperative ECG and serial troponin levels were obtained in all patients. Neurologic assessment was performed in the recovery area as well as on each postoperative day until dismissal.

RESULTS

There were thirty-nine (39) patients included in this series and a total of forty-one (41) operative events as two of the patients had two separate operative procedures involving endograft deployment using rapid ventricular pacing. Twenty-seven (27) patients were male (69%) and the average age was 74 ± 11 years. Patient characteristics are noted in Table 1.

Pacing *via* a PAC was performed in all patients without technical difficulty. The mean rapid ventricular pacing rate was 177 ± 17 bpm and the mean number of pacing events per patient was 2.6 ± 2. The duration of the pacing events was 34 ± 29 seconds with a MAP of 47 ± 5 mmHg. Pacing decreased the MAP rapidly taking on average 3 seconds to achieve the goal MAP and loss of pulsatility. There was one intraoperative death in a patient with severe mitral

regurgitation, moderate aortic regurgitation and left ventricular systolic dysfunction who failed to recover after multiple pacing episodes required due to difficult endograft placement.

Table 1. Patient characteristics.

Characteristics	No. (%) or Mean ± SD ^a
Age (years)	74 ± 11
Men	23 (66)
Women	12 (34)
ASA status ^b	3 ± 0.5
Weight (kg)	84 ± 18
Height (cm)	1.7 ± 0.1
Smoking	5 (14)
Diabetes	7 (20)
Hypertension	5 (14)
Hyperlipidemia	15 (43)
COPD ^c	7 (20)
Previous MI ^d	8 (23)
Previous PTCI or CABG ^e	5 (14)

a) SD: Standard deviation. b) ASA status: American Society of Anesthesiologists status. c) COPD: Chronic obstructive pulmonary disease. d) MI: Myocardial infarction. e) PTCI: Percutaneous transluminal coronary intervention, CABG: Coronary artery bypass graft.

Excluding the intraoperative death, recovery time to baseline MAP was approximately 2.4 seconds (range: 1-12). A spinal drain was placed in 54% of patients. The average operative time was 249 ± 156 minutes with an average estimated blood loss of 844 ± 1735 mL. Average intraoperative transfusion of red blood cells was 799 ± 1570 mL, and 19 patients (46%) did not receive any transfusions intraoperatively (Table 2).

Postoperatively, patients were monitored in the intensive care unit. Five patients (12%) had new onset atrial fibrillation. Postoperative troponin elevation was seen in 8 patients (20%), however, no patients had subsequent troponin increases at the three and six hour measurement periods and no patients had postoperative ECG changes indicative of ischemic injury. There was not a correlation between the pacing heart rate or number of pacing episodes

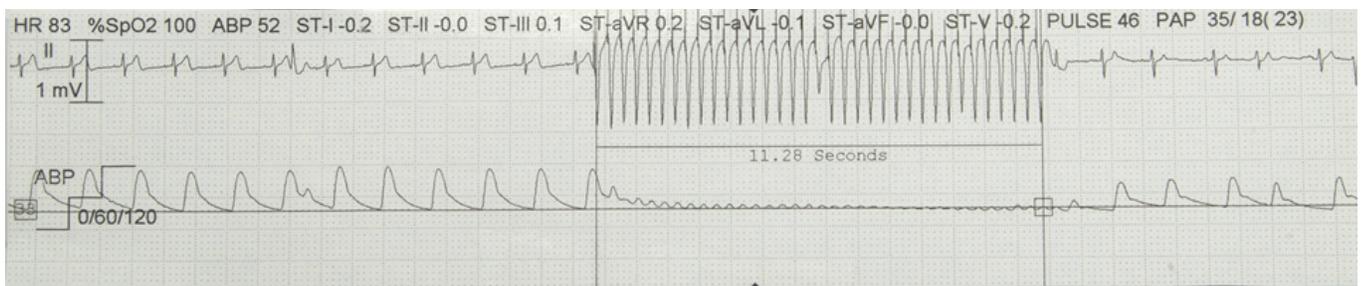


Fig. (2). Characteristic hemodynamic tracings during rapid ventricular pacing. Top: ECG tracing demonstrating initiation and cessation of rapid ventricular pacing. **Bottom:** Arterial blood pressure (ABP) tracing demonstrating the decrease in pulsatile blood flow and mean arterial pressure with return to baseline after pacing cessation.

and development of an elevated postoperative troponin. Stroke occurred in 3 patients (7%). None of the patients who suffered a stroke had atrial fibrillation, neither new onset nor a history of atrial fibrillation. The mean discharge was on postoperative day 10 ± 13 days with 45% of discharges occurring on or before postoperative day 5. Mortality at 30 days was 5%, consisting of the patient who suffered the intraoperative death and one patient who was discharge from the hospital but returned with a retrograde, proximal aortic dissection. The dissection extended into the left coronary artery causing a STEMI and severe left ventricular dysfunction. Despite aggressive treatment, including left ventricular assist device placement and extra corporeal membrane oxygenation, he developed multiorgan failure and ultimately care was withdrawn.

Table 2. Procedural characteristics.

Variable	No. (%) or Mean \pm SD ^a
Total procedures	37
Pacing rate (bpm) ^b	177 ± 17
Pacing events/ patient	2.7 ± 2
Pacing duration (seconds)	34 ± 29
MAP during pacing (mmHg) ^c	47 ± 5
Time to achieve MAP (seconds)	3 ± 5
Time to recover pre-pacing MAP (seconds)	1.3 ± 0.5
Operative time (minutes)	234 ± 155
Estimated blood loss (mL) ^d	580 ± 964
Intraoperative RBC ^e transfusion (mL)	609 ± 935
Spinal drain placement	20 (54)

a) SD: Standard deviation. b) bpm: beats per minutes. c) MAP: Mean arterial pressure, mmHg: millimeters of mercury. d) mL: milliliters. e) RBC: Red blood cell.

Table 3. Postoperative complications.

Complications	No. (%)
Troponin elevation	7 (19)
Atrial fibrillation	4 (11)
Neurologic (stroke)	3 (8)
Mortality (30 day)	1 (3)

DISCUSSION

We describe a practical technique for deliberate hypotension in thoracic endograft interventions. While caution must be used in drawing conclusions from this small series, the use of transvenous PAC guided rapid ventricular pacing for endovascular aortic surgery appears safe, reliable, and reproducible. Careful patient selection and familiarity with the equipment and physiology of pacing is necessary, but when used properly provides controlled and precise episodes of hypotension and decreased pulsatility with rapid recovery of hemodynamics.

Analysis of the complications following the procedure demonstrated that the occurrence of stroke was not associated with either a history of atrial fibrillation or new onset atrial fibrillation following the procedure. While a troponin elevation was seen in several patients, it is a common finding after this procedure, regardless of the deliberate hypotension technique utilized. Moreover, it was not associated with either the rate at which the patient was rapidly paced or the number of pacing episodes.

Hemodynamics during deployment of a thoracic aortic endograft are ideally such that there is little to no forward flow to cause misplacement of the graft as it is deployed. An ideal system to allow such hemodynamics is easily controllable, has a rapid onset and offset, and allows return of normal hemodynamics when the therapy is stopped with no side effects. Additionally, it is important that the therapy be able to be reemployed when needed for deployment of additional endografts, such as in branch endografts, or for balloon dilations. Rapid ventricular pacing *via* PAC provides optimal hemodynamics for endograft deployment with a rapid onset and quick return to baseline hemodynamics and provides a backup system in case of bradyarrhythmias, such as after transcatheter aortic valve replacement. As patients undergoing this procedure would usually have a central line placed for the procedure, placement of a PAC instead does not increase the preparation time. While there are risks associated with the placement and use of a PAC, no patients in our series suffered PAC related complications. The PACs were not routinely advanced into the wedge position, instead relying on the right ventricular pacing port waveform for correct positioning. The wire and PAC were removed after the operation in all patients. The intraoperative death described, was in a patient with severe mitral valve regurgitation, moderate aortic valve regurgitation, and moderate left ventricular dysfunction. Open repair was deemed unfeasible and after careful, extensive discussion the patient elected to proceed with stent graft placement. The aneurysm repair was difficult and required several pacing episodes due to challenging graft deployment, after which the patient did not recover hemodynamics and subsequently developed ventricular fibrillatory arrest. Patients with severe valvular disease or severe ischemic cardiomyopathy may not be candidates for rapid ventricular pacing, and patient physiology needs careful re-evaluation when performing multiple pacing episodes with attention paid to ensuring adequate hemodynamic recovery between pacing episodes.

There are several important points of consideration for the anesthesia team when using rapid ventricular pacing for thoracic aortic endograft deployment:

1. Patient selection – Patients with COPD, smoking history, diabetes, and hypertension tolerated this procedure well, however, patients with severe valvular disease, severe ischemic cardiomyopathy, or poor ventricular function may be inappropriate candidates.
2. Pulmonary artery catheter and pacing wire placement – Confirmation of reliable pacing wire capture is extremely important. Failure to capture or loss of capture during endograft deployment can be devastating. Thus, it is important to ensure capture at the time the pacing wire has been placed, but to also

ensure the neither the wire nor the PAC have moved prior to pacing for each deployment.

3. Visualization of loss of pulsatility - Allowing both the surgical and anesthesia teams to visualize the arterial waveform and ECG during pacing is also a crucial step. After the surgeon asks for pacing, all team members observe for the rapid ventricular rate on the ECG and loss of pulsatility on the arterial waveform. If the pacer fails to capture or pacing failed to decrease pulsatility the surgeon can avoid graft deployment in unsuitable conditions.
4. Clear communication – Communication is essential for this procedure such that timing of the onset and offset of rapid ventricular pacing are appropriate.
5. Recognizing complications – Users of a PAC for rapid ventricular pacing should have experience with both the use of a PAC and use of a pacing wire. Knowledge of possible complications arising from the use of each is essential for timely recognition and treatment. Allowing adequate hemodynamic recovery after the graft deployment is essential prior to repeating the rapid V-pacing episode if procedurally indicated. Potential complications include but are not limited to ventricular arrhythmias, right ventricular or pulmonary artery perforation, and temporary heart block [14-17]. A defibrillator should be immediately available with pad placed on the patients prior to the procedure.

In conclusion, endovascular repairs in the aortic arch and proximal thoracic aorta are challenging due to anatomic angulation of the arch, proximity to the aortic valve and hemodynamic forces. The use of transvenous PAC guided rapid ventricular pacing adequately ceases cardiac output to facilitate precise deployment of thoracic aortic stent-grafts. We describe a practical technique that can be safely used by anesthesiologists, after careful preoperative planning and familiarity with the equipment. Moreover, this technique can successfully be used in other procedures such as transcatheter aortic valve replacements. The complications listed in this series reflect procedural complications commonly associated with these procedures regardless of the technique used for hemodynamic control during graft deployment.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

Declared none.

REFERENCES

- [1] Lee WA, Martin TD, Gravenstein N. Partial right atrial inflow occlusion for controlled systemic hypotension during thoracic endovascular aortic repair. *J Vasc Surg*. 2008; 48: 494-8.
- [2] Plaschke K, Bockler D, Schumacher H, Martin E, Bardenheuer HJ. Adenosine-induced cardiac arrest and EEG changes in patients with thoracic aorta endovascular repair. *Br J Anaesth* 2006; 96: 310-6.
- [3] Kahn RA, Moskowitz DM, Marin ML, *et al*. Safety and efficacy of high-dose adenosine-induced asystole during endovascular AAA repair. *J Endovasc Ther* 2000; 7: 292-6.
- [4] Bernard EO, Schmid ER, Lachat ML, Germann RC. Nitroglycerin to control blood pressure during endovascular stent-grafting of descending thoracic aortic aneurysms. *J Vasc Surg* 2000; 31: 790-3.
- [5] Diethrich EB. A safe, simple alternative for pressure reduction during aortic endograft deployment. *J Endovasc Surg* 1996; 3: 275.
- [6] Neuhauser B, Perkmann R, Greiner A, *et al*. Mid-term results after endovascular repair of the atherosclerotic descending thoracic aortic aneurysm. *Eur J Vasc Endovasc Surg* 2004; 28: 146-53.
- [7] Pomratanarangi S, Webster MW, Alison P, Nand P. Rapid ventricular pacing to lower blood pressure during endograft deployment in the thoracic aorta. *Ann Thorac Surg* 2006; 81: e21-3.
- [8] Ramponi F, Valley MP, Stephen MS, Bannon PG, Bayfield MS, White GH. Transapical wire-assisted endovascular repair of thoracic aortic dissection. *J Endovasc Ther* 2011; 18: 350-4.
- [9] Lioupis C, Abraham CZ. Results and challenges for the endovascular repair of aortic arch aneurysms. *Perspect Vasc Surg Endovasc Ther* 2011; 23: 202-13.
- [10] Eisenhauer AC, Hadjipetrou P, Piemonte TC. Balloon aortic valvuloplasty revisited: the role of the inoue balloon and transeptal antegrade approach. *Catheter Cardiovasc Interv* 2000; 50: 484-91.
- [11] Leon MB, Smith CR, Mack M, *et al*. Transcatheter aortic-valve implantation for aortic stenosis in patients who cannot undergo surgery. *N Engl J Med* 2010; 363: 1597-607.
- [12] Ricotta JJ, 2nd, Harbuzariu C, Pulido JN, *et al*. A novel approach using pulmonary artery catheter-directed rapid right ventricular pacing to facilitate precise deployment of endografts in the thoracic aorta. *J Vasc Surg* 2012; 55: 1196-201.
- [13] Tagarakis GL, Whitlock RP, Gutsche JT, *et al*. New frontiers in aortic therapy: focus on deliberate hypotension during thoracic aortic endovascular interventions. *J Cardiothorac Vasc Anesth* 2014; 28: 843-7.
- [14] Practice guidelines for pulmonary artery catheterization: an updated report by the American Society of Anesthesiologists Task Force on Pulmonary Artery Catheterization. *Anesthesiology* 2003; 99: 988-1014.
- [15] Lyew MA, Bacon DR, Nesarajah MS. Right ventricular perforation by a pulmonary artery catheter during coronary artery bypass surgery. *Anesth Analg* 1996; 82: 1089-90.
- [16] Patel C, Laboy V, Venus B, Mathru M, Wier D. Acute complications of pulmonary artery catheter insertion in critically ill patients. *Crit Care Med* 1986; 14: 195-7.
- [17] Sprung CL, Elser B, Schein RM, Marcial EH, Schrage BR. Risk of right bundle-branch block and complete heart block during pulmonary artery catheterization. *Crit Care Med* 1989; 17: 1-3.