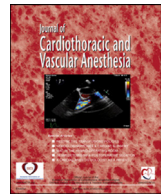




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Review Article

The Use of Subcostal Echocardiographic Views to Guide the Insertion of a Right Ventricular Temporary Transvenous Pacemaker—Description of the Technique

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The need for temporary cardiac pacing may occur in emergency and elective situations and may require transvenous right ventricular lead placement. The treatment of bradyarrhythmias presents the most common perioperative emergency indication. Intraoperatively, temporary rapid right ventricular pacing is accepted as a safe, titratable, and highly reliable method to achieve deliberate hypotension, and it has become a routine practice in the anesthetic management of cardiovascular interventions.

The navigation of the lead into the right ventricle often requires fluoroscopy to guide placement and to confirm position. Ultrasound guidance has been accepted widely by perioperative physicians as a safe technique for central venous access. Basic ultrasound and transthoracic echocardiographic skills rapidly are becoming integral to anesthesiologists' practice. When used to guide transvenous pacemaker wire insertion, subcostal echocardiographic imaging offers attractive advantages over blind or fluoroscopic placement, including rapid deployment, avoidance of radiation, real-time visualization of the lead in relation to the cardiac structures, and early detection of potential complications, such as tamponade.

Although several articles on echocardiographic guidance for transvenous pacing have been published in other acute care specialty fields in the last decade, this is the first description of the technique and of the recommended echocardiographic views in a perioperative context. In addition, a review of the current literature is presented, and the specific advantages and disadvantages of the approach are discussed in this article.

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SYMPTOMATIC BRADYARRHYTHMIAS are the most common indications for the insertion of temporary or permanent pacemakers.^{1,2} In the perioperative setting, elective rapid ventricular pacing may be required for certain surgical and percutaneous interventional procedures in patients with

structural heart disease.^{3,4} For example, the intraoperative management of thoracic endovascular aortic aneurysm repair and transcatheter aortic valve implantation may involve rapid right ventricular pacing to achieve deliberate hypotension, which is needed for stent deployment. The goal is to minimize the risk of graft migration by causing a brief reduction in cardiac output.^{5–9} Similarly, deliberate hypotension through the induction of a paced ventricular tachycardia is a common approach used to facilitate the intraoperative management of cerebral aneurysms.¹⁰

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Pacemaker lead insertion can be performed blindly, as often is the case with flow-directed leads used in emergencies, or it can be guided by an electrocardiogram (ECG), fluoroscopy, transthoracic echocardiography (TTE), or transesophageal echocardiography (TEE).² A cardiothoracic anesthesiologist is familiar with the transesophageal technique, which commonly is used to guide the placement of catheters and cannulas for anesthetized patients. There are situations when the TEE approach is not feasible for pacemaker lead insertion: interventional procedures increasingly are performed under sedation, or the patient may have contraindications to TEE. In addition, the TEE probe may not be available or the pacemaker may be placed by an anesthesiologist without TEE training. Fluoroscopy commonly is used for intracardiac catheterization, but it requires an imager and a compatible operating table. Moreover, hospitals may dictate that special privileges are obtained by nonradiologist physicians who intend to use fluoroscopy. Given that it requires no sedation or airway management and the equipment is becoming widely available, TTE can fill these gaps. A parallel review of considerations, advantages, and disadvantages is provided in the Table.

This article focuses on those aspects of temporary transvenous pacemaker insertion that are relevant when surface echocardiography, the subcostal window in particular, is used as the imaging modality. A detailed description of the recommended echocardiographic views and the visualization of the intracardiac lead is presented.

The Technique

The transvenous temporary pacemaker insertion procedure entails 3 stages: (1) establishing central venous access and inserting the introducer sheath, (2) guiding and positioning the lead into the right ventricle to achieve electromechanical capture, and (3) optimization of the pulse generator settings.

Technical Aspects of Transvenous Pacemaker Insertion

When choosing the venous access site, several factors are considered, including the operator's experience, the anticipated duration of pacing, and the coagulation status. For an anatomic alignment, most conducive to successful lead navigation into the right ventricle (RV), the sites most commonly used are the right jugular and the left subclavian veins. Ultrasound imaging is used widely to identify anatomic landmarks, to confirm vessel patency, and to guide cannulation in real time while minimizing complications.¹¹

The pacemaker lead types available for temporary transvenous cardiac pacing vary based on maneuvering technique, polarity, caliber, rigidity, and fixation ability.² The rigid non-floating lead is torque directed and typically positioned using fluoroscopy. Similar to a pulmonary artery catheter, the softer floating lead (with or without a balloon tip) can be floated blindly into the RV or into the right ventricular outflow tract. A variation of the pulmonary artery catheter design allows for the introduction of 2 endocardial pacemaker wires into the

right atrium as well as the ventricle and can be used for dual-chamber pacing.¹²

After the venous sheath is in place, the lead electrodes are connected to the appropriate output ports on the external pacemaker pulse generator. The output current should be set at a maximum (usually 20 mA), the sensitivity at a minimum (asynchronous pacing), and the rate at 10 to 20 beats per minute higher than the patient's native rate.²

As the lead is advanced to its final position, electromechanical capture is signaled by the appearance of pacing electrocardiogram "spikes" followed by QRS complexes with a left bundle branch block morphology. Once pacing is established, the output current can be reduced gradually to determine the pacing threshold (minimal current that causes electromechanical capture), ideally under 1 mA.² This value multiplied by 2 to 2.5 is considered the appropriate final setting for pacemaker output. If required, a further optimization of the settings can include the selection of the sensing threshold. Finally, the lead should be secured at the skin to prevent displacement and a loss of capture.

Complications of Temporary Transvenous Pacemaker Lead Placement

Technical complications during transvenous pacemaker insertion can result from difficulties in vessel identification, trauma or infection at the site of insertion, inadvertent arterial cannulation, difficulty traversing the tricuspid valve, trauma to a tricuspid leaflet or the valvular apparatus, ventricular perforation, arrhythmias, or a failure to achieve or sustain capture. The incidence of complications can be as high as 30% to 50% when infection and a loss of pacing are included.¹³

Although operator experience cannot be discounted as a significant factor in safe transvenous pacing, there can be numerous patient and equipment-related factors that contribute to complications. Anomalous venous anatomy or stenosis can preclude successful vessel or right atrial (RA) entry. Significant tricuspid regurgitation (TR) and RA dilatation can prevent the advancement of the lead into the RV. Multiple attempts at placement can increase the risk of complications, such as sustained ventricular arrhythmias from a mechanical irritation of the endocardium, significant TR from a tricuspid valve injury, and a free wall perforation of the RV.^{14,15}

Echocardiographic Visualization and Guidance

All catheters and lead types can be visualized using surface echocardiography. A case report describes the use of echocardiographic contrast injected into the catheter tip balloon to increase its echocardiographic visibility.¹⁶ Anecdotally, a similar enhancement of echogenicity can be achieved by injecting the balloon with saline, although the safety of the maneuver has not been investigated. Preprocedure scanning to ensure adequate acoustic windows is recommended, although in the authors' experience, conversion to an alternative mode of guidance (TEE or fluoroscopy) owing to poor surface echocardiographic image quality is rare. The assisting echocardiographer uses the subcostal (also

referred to as subxiphoid) acoustic window to visualize the right atrium and ventricle. This window provides imaging access away from the sterile field and allows the operator to view the pacemaker tip as it advances into the right side of the heart. The subcostal window is accessed best in a supine position and is not obscured by lung expansion in mechanically ventilated patients, making it particularly useful in a perioperative setting.

From the subcostal 4-chamber view (Fig 1), the transducer is rotated counterclockwise and oriented in the sagittal plane until the inferior vena cava (IVC) and the RA are visualized. To obtain the subcostal bicaval view, the transducer is directed further slightly toward the patient's right and angled cephalad until the superior vena cava (SVC) is observed (Fig 2, Video 4).¹⁷ Although visualizing the SVC beyond its entry into the RA can be challenging, it is not necessary for successful guidance. The described transducer position allows the pacemaker tip to be followed as it first enters from the SVC into the RA (Fig 3) or passes into the IVC.

Once the lead is in the RA (Video 1), the usual maneuvers of directing the lead curvature to the left and advancing through the tricuspid valve are performed by the operator, who can

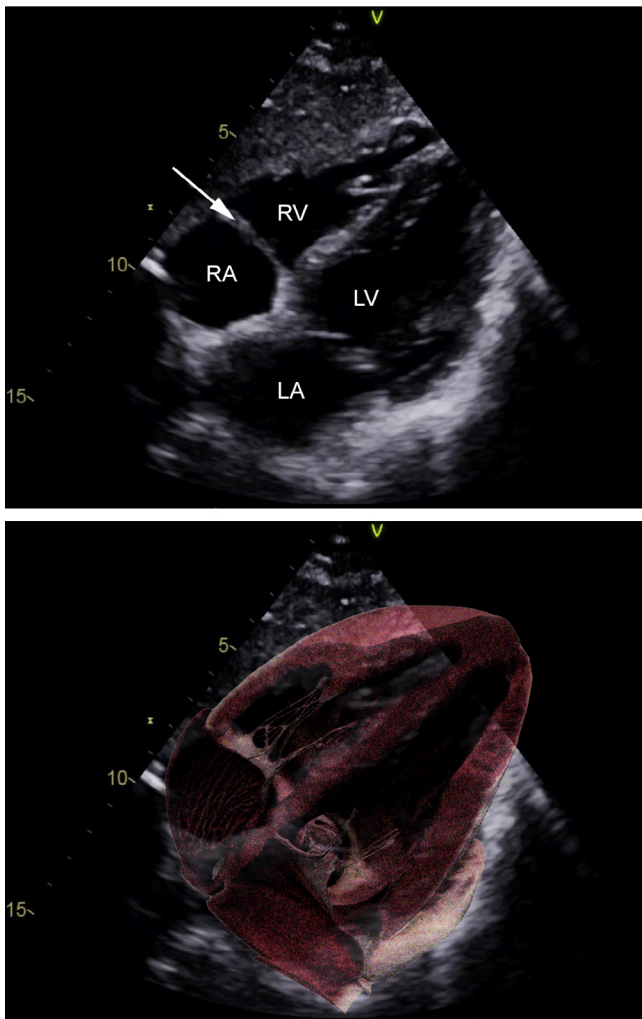


Fig 1. Subcostal 4-chamber view—2-dimensional echocardiographic image (top image) with a superimposed 3-dimensional drawing of the heart (lower image). LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle; arrow, tricuspid valve.

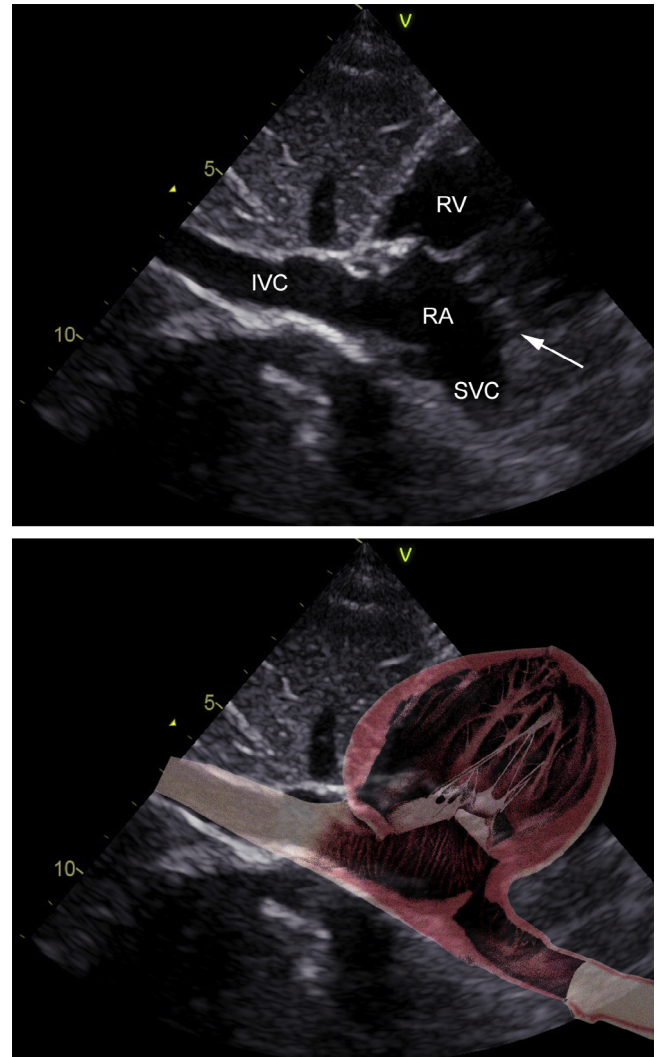


Fig 2. Subcostal bicaval view—2-dimensional image (top image) and a superimposed 3-dimensional drawing of the heart (lower image). IVC, inferior vena cava; RA, right atrium; RV, right ventricle; SVC, superior vena cava; arrow, tricuspid valve.

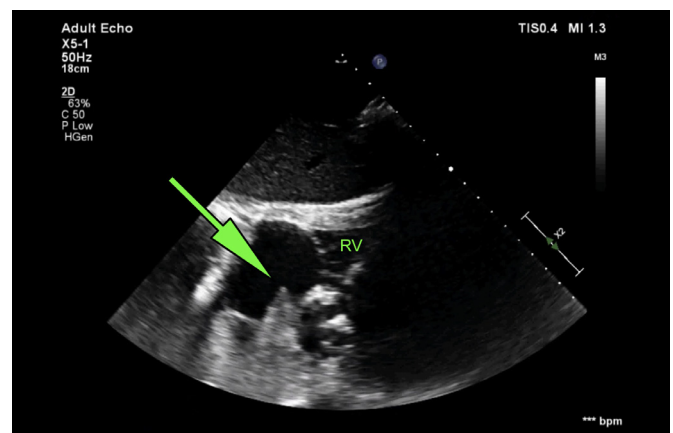


Fig 3. Wire enters the right atrium. Modified subcostal 4-chamber view showing an out-of-plane image of a pacemaker lead with its cross-section creating a “dot” appearance (arrow) and the associated acoustic artifact. RV, right ventricle.

observe the lead movement in real time. To follow the pacemaker lead as it passes through the tricuspid valve into the RV, the transducer is repositioned in the coronal plane to return to the subcostal 4-chamber view (Fig 4, Video 2). Visualizing the valve can allow the operator to synchronize the lead advancement with its opening. The echocardiographer should strive to identify the lead tip and to keep it in view as much as possible by making fine adjustments to the transducer orientation. The ideal position of the wire tip is usually in the RV apex, and it can be documented in the subcostal 4-chamber view (Fig 5, Video 3). To prevent the loss of contact between the lead and the endocardium owing to respiratory movements, cough, or changes in patient position, a small amount of slack (forward tension) in the lead is required to form a slight curve. Adding excessive length should be avoided; this is considered to be a risk factor for cardiac perforation because it predisposes to forward lead movement and causes transmission of additional pressure to the myocardial wall.¹⁸ On the other hand, insufficient slack can lead to catheter dislocation, which has been reported to be responsible for a loss of pacing in 9% to 19% of the cases in 2 series of 194 and 568 patients.^{13,14} Although this description of the technique focuses on the subcostal window, if visualizing the lead in another plane is required, apical views can be used. The apical window is less likely to yield adequate echocardiographic images when the patient is positioned supine or mechanically ventilated.

Discussion

Pioneering work by Jesus in 1992 and Aguilera in 2000 confirmed the feasibility and safety of surface echocardiography guided transvenous pacer lead placement.^{19,20}

In 2013, Pinneri compared 53 patients who underwent TTE-guided pacemaker insertion against an equal number guided by fluoroscopy. He found that both primary endpoints (time-to-pacing and complication rate) were improved significantly in the echocardiographically guided group. Time-to-pacing in the echocardiography guided group was 439 ± 179 seconds,

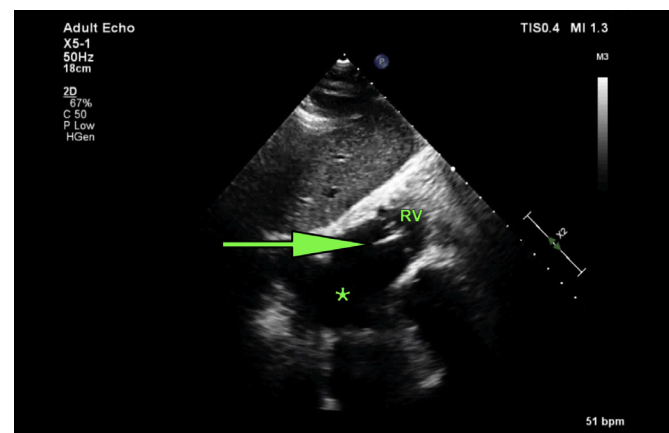


Fig 4. Wire crosses the tricuspid valve. Subcostal 4-chamber view showing an in-plane image of a pacemaker lead (arrow) as it traverses the tricuspid valve. RV, right ventricle.

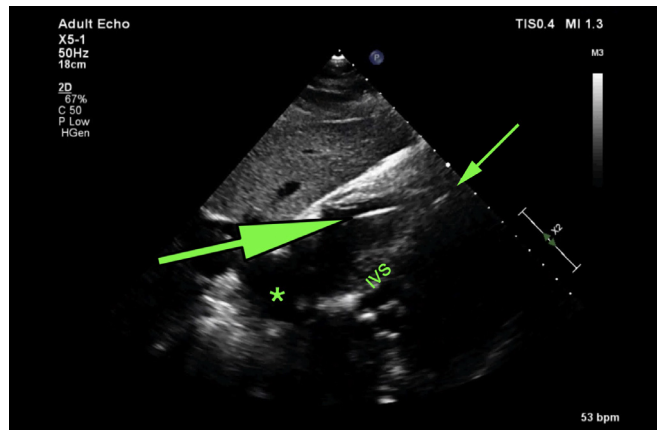


Fig 5. Final position of the wire positioned in the apex of the right ventricle. Pacemaker lead (arrows) in the right ventricle observed from the subcostal window. This window can be used to rule out pericardial effusion and to assess tricuspid regurgitation by applying color Doppler. IVS, interventricular septum.

and in the fluoroscopy-guided group, it was 716 ± 235 seconds. Failure of pacing was more common in the fluoroscopy-guided group; however, this difference was attributed to the access site because the right internal jugular site used for the echo-guided technique (as opposed to the femoral in the fluoroscopy group) is known to be associated with fewer incidences of loss of capture.²¹ In 2016, Ferri et al. compared TTE-guided pacemaker insertion to the fluoroscopy-guided technique in an observational prospective study of 203 emergency cases. There was no difference in complications or pacing thresholds; however, the indication-to-pacing time was significantly shorter in the echo-guided group (19–39 minutes compared to 23–55 minutes, $p < 0.001$).²²

Overall, in terms of safety and efficacy, the use of echocardiography to guide a temporary transvenous pacemaker wire is supported by current evidence to be at least equal to fluoroscopy.

Authors' Experience

A retrospective review of the echocardiography case log for a tertiary center specializing in endovascular procedures revealed that, between January 2010 and October 2016, 36 nonconsecutive procedures were recorded in which temporary RV transvenous pacemaker insertion was attempted under TTE guidance. Of these cases, 32 cases were thoracic endovascular aortic aneurysm repair (30 elective and 2 emergency), and 2 cases were emergency cerebral aneurysm clipping. One patient requiring emergency abdominal surgery was found to have a complete heart block. One patient admitted for the elective revision of abdominal aortic aneurysm repair had an advanced conduction block. The pacemaker lead could not be placed in 1 patient who was found to have innominate vein stenosis when fluoroscopy with an IV contrast subsequently was employed to troubleshoot the placement. The leads were removed before exiting the operating room in all but 2 cases (one was paced, one on standby). No complications were recorded during the intraoperative course. Late complications of introducer sheath placement were not recorded.

Table 1
Techniques Used to Facilitate Placement of Temporary Transvenous Pacemakers

	TTE	TEE	Fluoroscopy	ECG Guided	Blind
Risks and contraindications	None known	Risks of dental, pharyngeal, esophageal injuries, arrhythmias Contraindicated if history of esophageal disease or esophageal surgery	Risk of radiation exposure to patient and personnel Contraindicated in pregnancy	None known	Lead malposition
Required equipment	Ultrasound imaging unit Cardiac (phased array) transducer	Ultrasound imaging unit Transesophageal probe	C-arm, fluoroscopy imager Fluoroscopy compatible stretcher or table	Electrode adapter compatible with ECG lead connector	Flow-directed catheter electrode
Anesthesia, sedation, and airway management	None required	Sedation with topical airway anesthesia or endotracheal intubation	None required	None required	None required
Training requirement for imaging assistant	Basic principles of medical ultrasound and basic cardiac sonoanatomy	Basic principles of medical ultrasound and basic cardiac sonoanatomy with specific competency in TEE	Radiology technician or other appropriate training	n/a	n/a
Training requirement for pacemaker insertion procedure operator*	Basic principles of medical ultrasound and basic cardiac sonoanatomy	Basic principles of medical ultrasound and basic cardiac sonoanatomy	Intracardiac catheter imaging by fluoroscopy May require institution-specific certification and/or credentialing	Understanding of ECG waveforms sensed at specific locations in the right heart and the variation in IVC v SVC approaches	No specific additional training
Advantages	Time-efficient Portable Diagnoses complications such as TR, myocardial perforation, and pneumothorax Compatible with CPR Confirms mechanical capture when transcutaneous pacing is used as a bridge to transvenous radiation free	Detailed imaging of cardiac anatomy and pacemaker lead Compatible with CPR Confirms mechanical capture when transcutaneous pacing is used as a bridge to transvenous Radiation free	Shows extracardiac position of the lead IV contrast can delineate abnormal vascular anatomy Shows projection of the full length of the wire	No need for additional personnel or imaging equipment	No need for additional personnel or imaging equipment
Disadvantages	Operator- and patient-dependent image quality Complicated by abdominal or sternotomy surgical bandage Inadequate for right atrial lead placement	Requires sedation or endotracheal intubation Potential for rare but significant complications related to esophageal probe placement TEE probe less widely available	Radiation exposure can be significant Requires transfer of patient if not on fluoroscopy compatible bed	Interpretation of ECG cues may be complicated by abnormal baseline rhythm or ECG morphology Requires radiographic confirmation of position	No feedback regarding lead position Inappropriate for non-floating lead types Inappropriate in cardiac arrest due to lack of flow Requires radiographic confirmation of position

Abbreviations: CPR, cardiopulmonary resuscitation; ECG, electrocardiogram; IVC, inferior vena cava; SVC, superior vena cava; TEE, transesophageal echocardiography; TR, tricuspid regurgitation; TTE, transthoracic echocardiography.

* In addition to the training required for central venous cannulation and temporary cardiac pacing.

Although previous publications have focused on emergency indications and procedures performed in emergency departments, intensive care, and cardiac care units, the authors' experience is exclusive to the intraoperative environment.^{19–22} Given the retrospective nature of the records, comparisons with the published data could not be drawn reliably. The authors' subjective experience of convenience and reliability has made TTE their technique of choice.

Advantages and Disadvantages of Transthoracic Echocardiographic Guidance

Transthoracic echocardiography is a radiation-free imaging modality that is devoid of risks and contraindications. Although beyond the scope of this article, in addition to the ability to guide the procedure, TTE is an excellent diagnostic tool that provides a wealth of information regarding cardiac function and anatomy. Provided the operator has the expertise, this feature is unique to echocardiography and especially important during cardiac emergencies.

Although it has a limited capability to image the lead trajectory outside the heart, echocardiography can be used to visualize the lead in the SVC (or in the IVC with the femoral vein approach). Otherwise, the operator can switch to an alternative access site.²³ If tricuspid insufficiency is observed using color Doppler, the lead can be advanced in time with a ventricular diastole to avoid the regurgitant jet. Tricuspid valve function can be assessed post-insertion to document the valve integrity or to identify patients with a significant worsening of TR or leaflet trauma, which can predispose them to future morbidity.²¹ If electromechanical capture is lost, the wire can be repositioned quickly with the aid of surface echocardiography. The presence of a hemopericardium can be diagnosed promptly and treated before the development of tamponade should the rare but serious complication of RV perforation occur.

The echocardiographic approach avoids radiation exposure for the patient and the personnel. In addition, the equipment is portable and generally requires less space than a fluoroscopy unit.

When describing the use of TTE to guide the placement of echocardiographic leads, it is important to consider the disadvantages of the technique (Table 1). The success of the technique depends on the skill of the imaging assistant to obtain the required echocardiographic views and keep the pacemaker lead in view as it moves through the cardiac chambers. Poor image quality from the subcostal window can preclude successful visualization in patients who are obese and pregnant. Similarly, the window may not be accessible after sternotomy and upper abdominal surgery. In cases in which dual chamber pacing is favored, the subcostal window is unlikely to offer adequate visualization for the placement of an RA lead, and advanced echocardiographic imaging may be required.

Conclusion

Transthoracic echocardiography is a safe and time-efficient technique that fills an important gap when elective or emergency temporary pacemaker insertion is required.

Anesthesiologists in general have become increasingly skilled in ultrasound imaging, and some form of basic echocardiography training is becoming an integral part of point-of-care ultrasound training. Although relatively recent in comparison with emergency medicine and critical care specialties, TTE increasingly is taught at all levels of anesthesiology training.

Future research that focuses on the perioperative setting should use a prospective design to address concerns, such as safety and effectiveness of the technique across the range of operator skill levels and in challenging patient populations, including the morbidly obese and those with structural right heart disease.

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Conflict of Interest

There is no conflict of interest to declare.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1053/j.jvca.2019.01.033.

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