aneurysm and re-closed the wound with two large felt strips and 2-0 polypropylene sutures. The patient was easily weaned off cardiopulmonary bypass. Postoperative TEE revealed that all the cardiac defects were successfully repaired. He recovered well and was discharged from the hospital 6 days later.

Comment

Penetrating trauma to the heart is well described in the literature. Two steps are imperative in managing such an injury: (1) early damage control to stop bleeding, and (2) use of imaging studies (possibly delayed) to guide future treatment.

We believe that this is the first reported case of four cardiac structural defects caused by a single stab wound to the heart. We do know of a case report of three lesions caused by a simple stab wound [1]. A retrospective review by Mollod and Felner [2] revealed that TEE influenced the treatment plan of 16 patients with cardiothoracic trauma, enabling quick acquisition of data. As with any ultrasound-based study, operator experience and ability dictate the amount of information obtained.

Our case demonstrates the profound damage that a single stab wound can do to the heart. Controlling the damage by simple closure of the wound is initially imperative to stop the bleeding and resuscitate the patient. However, intraoperative TEE, if available on site, can add crucial information to help the surgeon diagnose any missed injuries and to guide the repair. For example, the finding of an LAD artery fistula or an akinetic left ventricular apex would alert the surgeon to a potential LAD artery injury. If TEE reveals an ischemic myocardium, it could be salvaged through an off-pump single-vessel bypass using a left internal thoracic artery to the distal LAD artery graft. Mitral regurgitation and a VSD could be repaired at a later stage, again with the guidance of TEE.

Transesophageal echocardiography performed by an experienced cardiologist is the key to locating the exact level and depth of VSDs. Our patient's VSD was repaired through the actual stab wound, an approach that we would not have entertained if the intraoperative TEE had not demonstrated the close proximity of the VSD to the stab wound. Clearly, intraoperative real-time TEE images are important, ensuring that the surgeon comprehends the nature and the extent of the injuries so that accurate repair is possible, despite complex destruction. Our case underscores the essential role of TEE in reliably revealing the details of lesions caused by a penetrating cardiac injury.

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FEATURE ARTICLES

Left Ventricular Pacing Site-Timing Optimization During Biventricular Pacing Using a Multi-Electrode Patch

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A 71-year-old man with class IV congestive heart failure and an infected pacemaker/implantable cardioverter defibrillator (ICD) underwent median sternotomy for removal of endocardial leads with a 15-mm vegetation. Cardiac output during biventricular pacing was optimized with an aortic flow probe, a multi-electrode left ventricular patch, and a randomized protocol assessing 54 combinations of pacing site and right ventricle–left ventricle delay. Results that were assessed with response surface methodology determined permanent epicardial lead position and timing. The difference between the best and worst site-timing combinations altered cardiac index by nearly 70%. This experience demonstrates potential importance of the epicardial approach to site-timing optimization for biventricular pacing.

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Clinical trials have demonstrated that the addition of a left ventricle (LV) pacing lead through the coronary sinus to standard dual chamber mode lead configurations can narrow the QRS duration, improve exercise capacity and quality of life, and reduce mortality in patients with severe heart failure and intraventricular conduction delays [1]. This case report details the relative importance of site and timing in a patient who met current criteria for implementation of biventricular pacing (BiVP).

A 71-year-old man with dilated cardiomyopathy and class IV congestive heart failure was referred for *Staphylococcus epidermidis* bacteremia. Transesophageal echocardiography revealed a mobile, 15-mm echodensity on the right atrial lead of a dual chamber pacemaker/implantable cardioverter defibrillator (ICD) system. The QRS duration was 220 ms on electrocardiogram. Ejection fraction was estimated at 15% with moderate mitral regurgitation and dyssynchrony of contraction between the interventricular septum and left ventricular free wall.

The patient underwent a median sternotomy with extraction of endocardial pacemaker/ICD leads on cardiopulmonary bypass and removal of the ICD generator.

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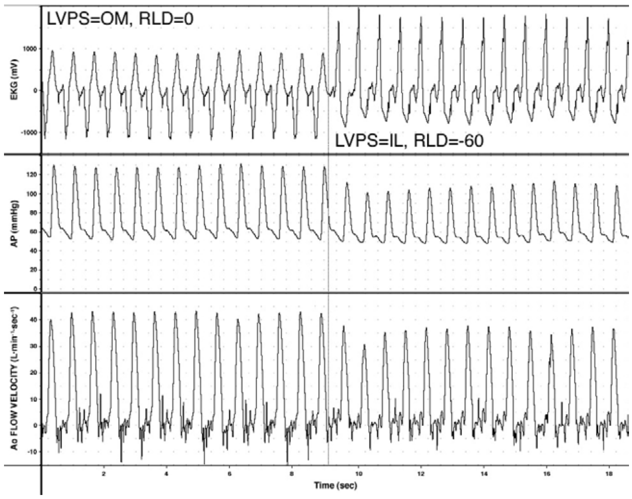

Fig 1. Representative data from Chart 3.6.3/s include cardiac electrocardiogram (EKG) in mV, arterial pressure (AP) in mm Hg, and aortic (Ao) flow velocity in L/min/sec. Transition between two consecutive left ventricular pacing site/right ventricle-left ventricle delay combinations is associated with a sharp drop in arterial pressure and aortic flow velocity. (IL = inferolateral; LVPS = left ventricular pacing site; OM = obtuse margin; RLD = right ventricle–left ventricle delay.)

In anticipation of permanent BiVP, temporary BiVP was tested before cardiopulmonary bypass. Mapping of the LV was performed using an aortic flow probe, a multi-electrode patch, and a randomized protocol to identify the optimal lead position and right ventricle–left ventricle delay (RLD) [1–2]. Permanent LV epicardial leads were implanted at the conclusion of the procedure, and temporary leads were used for perioperative BiVP.

Informed consent was obtained by an approved protocol of the institutional review board. The chest was entered through a standard midline sternotomy and a pericardial well was created. The pericardial space was free of adhesions with clear fluid. During anticoagulation, cannulation, and excision of the ICD generator and leads from the chest wall, temporary pacing was established through the right atrial appendage and anterior right ventricle (RV). An epicardial pacing patch incorporating six bipolar pacing leads was placed behind the posterolateral LV and was connected to a temporary pacing unit containing a Medtronic InSync III pacemaker (Medtronic Inc, Minneapolis, MN). A 90-mm electromagnetic flow probe (Carolina Medical Inc, King, NC) was placed around the ascending aorta. Dual chamber mode BiVP was initiated at a heart rate of 90 and an atrioventricular delay of 150 ms. Fifty-four combinations of nine RLDs and six LV sites were tested at 15-second consecutive intervals in a randomized sequence. The LV sites were apex, inferomedial, inferolateral, posterior descending artery, circumflex, and obtuse margin. The RLDs covered a range from 80 ms (right ventricle first pacing) to −80 ms (LV first pacing) in 20 ms increments.

Analog data for electrocardiogram, arterial blood pressure, and aortic flow velocity (Fig 1) were acquired and transferred through a 16 channel analog to digital converter (MacLab, ADInstruments Inc, Milford, MA) to a personal computer (iMac, Apple Computer, Cupertino, CA). Data were then imported into Matlab (The MathWorks, Inc, Natick, MA). Using customized routines, a relatively small number of arrhythmic beats were eliminated. Aortic flow velocity was integrated over each 15-second interval to give cardiac output and was divided by body surface area to give cardiac index. Results were plotted using response surface methodology producing a two-dimensional plot in which percentage change in cardiac index was indicated by color.

Pacing the obtuse margin site at a RLD of −40 or 0 and the circumflex site at a RLD of 0 yielded the highest cardiac index, 64% to 66% greater than the worst combination, pacing the inferolateral site at a RLD of −80. Figure 2 represents a response surface plot of percentage change of cardiac index from each LV site/RLD combination. This plot, constructed retrospectively, allowed greater insight into the effects of BiVP in this patient than was available during real time analysis in the operating room.

After removal of the infected leads and closure of the atriotomy, permanent epicardial pacing leads were positioned on the LV epicardium directly over the circumflex site on the pacing array. Temporary leads were placed in the right atrial appendage, anterior right ventricle, and circumflex and obtuse margin sites of the LV. The patient was weaned from cardiopulmonary bypass with temporary BiVP and dobutamine and transferred to the intensive care unit. The permanent leads were capped and stored in a subcutaneous pocket in the right upper abdomen. As there was little advantage of a RLD offset, simultaneous BiVP was implemented with a RLD equal to 0 ms.

Biventricular pacing was objectively compared with no pacing on several occasions. On the first postoperative day, cardiac index increased 13% with BiVP. At the time of permanent pacemaker/ICD implantation, initiation of BiVP immediately increased radial artery systolic pressure from

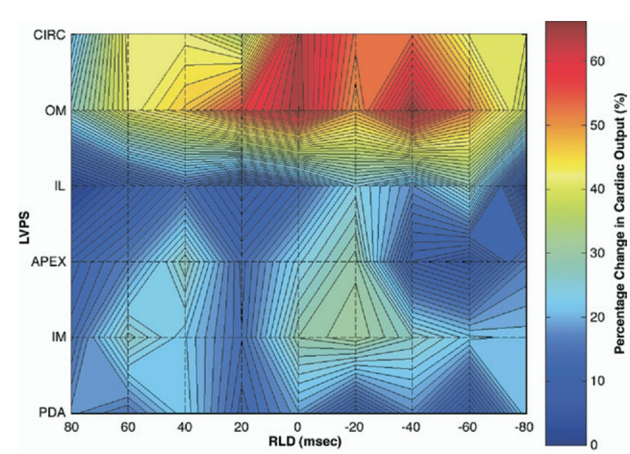

Fig 2. Response surface plot illustrates percentage change in cardiac index for each left ventricular pacing site/right ventricle–left ventricle delay (RLD) combination. Solid black lines indicate a 1% change in cardiac index. (APEX = apical; CIRC = circumflex; IL = inferolateral; IM = inferomedial; LVPS = left ventricular pacing site; OM = obtuse margin; PDA = posterior descending artery.)

104 to 148 mm Hg. The patient was discharged from the hospital after completion of antibiotic therapy and implantation of a new pacemaker/ICD with BiVP capability.

Comment

Recent studies of endocardial BiVP differ in suggesting that cardiac function is maximized by localization of LV pacing leads in the mid-lateral region of the LV [3, 4] or other locations [5, 6]. Endocardial LV lead position is limited by anatomy of the cardiac veins. Furthermore, many locations are unstable or inaccessible, resulting in implantation failure in 5% to 14% of attempts [7, 8]. Consequently, only a limited subset of LV pacing sites has been mapped, and the relative importance of site and timing in BiVP have been inferred but not directly measured. Thoracoscopy has been used to map the epicardial surface of the LV, but randomized study of site and timing has not been previously reported [9].

The surgical procedure described in this report allowed BiVP optimization under an approved protocol of the institutional review board. The effect of posterior, inferior, and lateral LV pacing as well as timing were defined, and a distinct effect of both LV site and RLD on cardiac index was demonstrated.

The hemodynamic benefits of BiVP in this patient were particularly profound. Biventricular pacing is more likely to be effective as ejection fraction decreases and as intraventricular conduction delay, LV dyssynchrony, and mitral regurgitation increase [10]. Our patient's cardiomyopathy was relatively advanced in all of these respects. The precise mechanism of benefit in this patient may include restoration of synchronous contraction of the free wall and septum, reduction of mitral regurgitation, or both. Most importantly, we do not know whether the profound benefit experienced by this patient reflects the advanced nature of his cardiomyopathy or mapping of the optimal site-timing relation. However, it is clear that additional studies in this area are needed and that the question of how to best optimize clinical results of BiVP may need further attention.

Despite limitations, this is the first clinical report of the relative importance of site and timing in BiVP. Results indicate that BiVP optimization can increase cardiac output by 66% when best and worst pacing protocols are compared and provide a rational basis for additional studies aimed at maximizing the clinical response to pacing for heart failure.

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Left Ventricular Posterior Wall Pseudoaneurysm: A Rare Sequela of Mitral Valve Infective Endocarditis in a Chronic Patient of HLA-B27 Positive Spondyloarthritis

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Left ventricular posterior wall pseudoaneurysm after native mitral valve infective endocarditis is a very rare occurance. We report such a case in a patient with HLA-B27-associated spondyloarthritis and normal coronary arteries. Excision of the aneurysm with left ventricular reconstruction and mitral valve replacement resulted in an excellent outcome.

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