Author's response to reviews

Title: The Utility of Pocket-Sized Echocardiography to Assess Left Ventricular Systolic Function Prior to Permanent Pacemaker Implantation

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Abstract

Background: A subset of patients receiving first-time permanent pacemakers (PPM) may also benefit from an implantable cardioverter defibrillator (ICD) based on the presence of left ventricular systolic dysfunction (LVSD). Routine screening using pocket-sized echocardiography (PSE) may be useful in identifying such patients.

Objective: To determine whether PSE can be used by an inexperienced sonographer to adequately screen for LVSD in a patient population receiving a first-time PPM.

Methods: A sonographic trainee (medical student) acquired images using PSE, which were then evaluated by an experienced echocardiologist, for both image quality and presence of LVSD. The sensitivity and specificity of assessment by the inexperienced sonographer was determined in comparison to the echocardiologist.

Results: The patient population included 71 individuals (66% male, mean age 77±12 years). Interpretable images where left ventricular ejection fraction (LVEF) could be adequately assessed were obtained in 93% of the patient population. As compared with the echocardiologist, the sonographic trainee had a sensitivity of 60% and a specificity of 98% in detecting LVSD.

Conclusions: For patients receiving first-time PPM, the use of PSE by a sonographic trainee combined with interpretation by an experienced imaging cardiologist can triage for the need to perform standard transthoracic echocardiography (sTTE) by determining the presence of LVSD.

Key Words: Systolic function, pacemaker, pocket-sized echocardiography, echocardiography, implantable cardioverter defibrillator
Background

Permanent pacemakers (PPM) are established therapy for patients with bradyarrhythmias due predominantly to sinus node dysfunction or atrioventricular block [1]. The majority of these patients present with a combination of symptoms including syncope, pre-syncope, fatigue, palpitations, dyspnea, and exercise intolerance. Clinical assessment including a complete history, physical examination, and electrocardiogram or other cardiac rhythm monitoring device usually determines the association between these symptoms and the underlying conduction abnormality. Within the population receiving PPM, there is a subset of patients with an underlying predisposition to sudden cardiac death (SCD) due to a cardiomyopathy that may elude detection by clinical assessment. Potential etiologies include coronary artery disease, dilated cardiomyopathy, hypertrophic cardiomyopathy, arrhythmogenic right ventricular dysplasia, or infiltrative cardiomyopathy.

The assessment for structural heart disease follows if there is evidence of abnormality on clinical examination, usually comprised of standard transthoracic echocardiography (sTTE). The detection of structural heart disease, in particular left ventricular systolic dysfunction (LVSD), is pertinent in patients receiving PPM as these patients may have indications for an implantable cardioverter defibrillator (ICD) for prevention of ventricular tachyarrhythmia death. Several trials have previously demonstrated reduced mortality associated with implanting an ICD as primary prevention against sudden cardiac death in patients with left ventricular systolic dysfunction in the setting of both ischemic and nonischemic heart disease [2,3]. Accordingly, current practice guidelines recommend ICD implantation for patients with a left ventricular ejection fraction (LVEF) of less than 30 to 35%, despite optimal medical therapy and, where appropriate, revascularization [4,5].
Although it is appropriate for patients to receive sTTE to rule out structural heart disease in the context of cardiac syncope, it is unclear whether all patients evaluated for PPM implantation should receive routine echocardiography pre-operatively. The relatively resource intensive nature of the sTTE examination may preclude routine evaluation for all patients undergoing device implantation.

Pocket-sized echocardiography (PSE) may be a tool that can support routine sTTE evaluation [6]. PSE, a miniaturized version of the sTTE machine, has the capacity for two-dimensional conventional echocardiography and color Doppler. Its size confers the advantage of portability, making PSE ideal for point-of-care evaluation, either at the bedside, or in the outpatient setting. Previous studies have examined the diagnostic accuracy of PSE, its potential clinical applications, and the training involved to maximize safety and effectiveness of its use [7-11]. Several studies have reported that PSE can qualitatively assess LVEF with good reliability, even when a sonographic trainee acquires and/or interprets images [12-18]. Current recommendations limit the use of PSE to triaging candidates to receive sTTE evaluation [19].

Although PSE is not currently routinely used prior to the implantation of PPM, growing interest in its application warrants formal evaluation of its use in this setting. PSE can screen for LVSD in this patient population and determine candidacy for sTTE evaluation, thereby ensuring that all patients undergoing implantation receive the appropriate device. Currently, the need for, and logistics of, performing PSE on this population of patients have yet to be described. This study aimed to determine if left ventricular systolic function could be adequately assessed by a sonographic trainee in patients receiving first-time PPM implantation.

Methods
A prospective study of adult patients undergoing first-time PPM insertion was conducted at a university-affiliated tertiary care hospital between 2012 and 2013. Patients were included if they were ≥18 years of age, had an indication for permanent pacemaker insertion, and consented to participate. Informed consent was obtained from all eligible patients. Exclusion criteria were patients under 18 years of age, undergoing revision of an existing pacing system, or unable to provide informed consent. Ethics approval was granted by the University of Manitoba Biomedical Research Ethics Board (BREB) [B2012:034] and the St Boniface Hospital institutional review committee.

**Training in echocardiography**

Prior to recruiting patients for the study, a first-year medical student with no previous background in ultrasound (“sonographic trainee”) prepared for one month in obtaining and interpreting echocardiographic images. Training was focused on assessing LVEF from parasternal long-axis, parasternal short-axis, apical four-chamber, apical two-chamber, and subcostal echocardiographic windows with both PSE (Vscan, GE Healthcare, Milwaukee, WI, USA) and sTTE (Vivid 7, GE Healthcare, Milwaukee, WI, USA). Visual estimations of LVEF on PSE were compared to the LVEF quantitatively determined using biplane Simpson’s on sTTE. During the training period, a total of 80 scans were completed with both PSE and sTTE. The sonographic trainee also interpreted an additional 150 images previously assessed by a level 3 trained echocardiologist to improve accuracy of visual estimation of LVEF.

**Image and data acquisition**

Patients were approached by the sonographic trainee in the pre- and post-cardiac procedure area within two hours of PPM implantation. Immediately after providing informed consent, patients were scanned by the sonographic trainee with PSE. Video loops of parasternal long- and short-axes, apical four- and two-chamber, and subcostal views were obtained and digitally recorded on the PSE device. Relevant medical history was obtained from the patient history, hospital charts, and procedural notes.
Assessment of LVEF

LVEF was assessed by PSE according to the algorithm represented in Figure 1. Promptly following PSE scanning, the recorded video loops were reviewed by the sonographic trainee and a cardiologist with level 3 competency in echocardiography, and assessed qualitatively for LVEF and image quality. Each interpreter was blinded to the others. Overall LVEF was graded by visual estimation as being normal (≥50%), mildly reduced (40-49%), moderately reduced (30-39%), or severely reduced (<30%). If a significantly reduced LVEF (defined as <40%) was found, the patient was subsequently considered for evaluation with sTTE. If this sTTE examination was consistent with LVSD, the cardiologist implanting the pacemaker was informed.

Results

Study population

Of the 75 eligible patients, 71 were enrolled in the study. Four patients were excluded because they declined to provide consent for participation in the study. The baseline clinical characteristics of the study population are summarized in Table 1. The study population consisted of 71 individuals, 47 male and 24 female with a mean age of 77±12 years. Of the total study population, 27 (38%) received a PPM due to sinus node dysfunction, 30 (42%) due to second or third degree atrioventricular block, and 14 (20%) due to a combination of sinus and atrioventricular node dysfunction. Twenty-three patients (32%) were referred for PPM implantation as outpatients, while 48 (68%) were referred from an inpatient unit. The prevalence of presenting symptoms is summarized in Table 2. Twenty-eight patients (39%) had received sTTE prior to participating in the study.

PSE image acquisition and interpretation

PSE video clips were obtained and recorded for all enrolled participants. Image quality was assessed as "good" in 40%, "fair" in 51%, and "poor" in 9%. Overall, LVEF could be reliably
assessed from PSE images in 66 of the 71 patients (93%). The distribution of LVEF in the study population as assessed by PSE is summarized in Table 3. Of these interpretable images, there was 91% concordance between the sonographic trainee and echocardiologist in the assessment of LVEF, with a linearly weighted Cohen kappa value for inter-observer concordance of 0.725±0.112 (95% CI 0.505-0.945). As compared to the echocardiologist, LVEF was overestimated in 5% and underestimated in 5% by the sonographic trainee. The mean time required to perform the scan was 6±3 minutes (range: 2–15 minutes). The assessment of significant LVSD (LVEF < 40%) made by the sonographic trainee was compared to the assessment made by the echocardiologist, which was the gold standard (Table 4). The sonographic trainee correctly determined that 3 (5 %) scans showed the presence of LVSD and that 60 (91%) interpretations suggested absence of LVSD. Therefore, the inter-observer concordance between the sonographic trainee and echocardiologist was 96% for the ability to assess presence or absence of LVSD. Conversely, the sonographic trainee falsely identified the presence of LVSD in one (2%) scan, while missing the presence of LVSD in two (3%) scans. The sensitivity and specificity of the sonographic trainee’s evaluation compared to the cardiologist’s evaluation for LVSD was 60% and 98%, respectively. The kappa value for inter-observer variability in the assessment of LVSD was 0.643±0.201 (95% CI 0.247-1.0).

Accuracy of PSE compared to sTTE

Of the total study population, 28 patients (39%) received sTTE to assess LV systolic function as part of the pre-pacemaker implantation assessment, up to one month prior to inclusion in this study. Of these patients, 2 (7%) had PSE exams that were not interpretable. For the 26 remaining PSE scans interpreted, accuracy of LVEF estimation as compared to sTTE was 96% for the echocardiologist and 88% for the sonographic trainee. The echocardiologist correctly assessed 100% of patients for the presence or absence of LVSD (LVEF either greater or less than 40%) using PSE images, whereas the sonographic trainee correctly assessed 96%.
Discussion

With the advancement of cardiovascular imaging, it is tempting to seek out new clinical applications to justify new technology. While individual patients may benefit from increased access to diagnostic tools, formal evaluation of the overall feasibility of this tool is necessary prior to routine institution. The goal of this study was to explore the feasibility of implementing routine screening of left ventricular systolic function using PSE in the first-time pacemaker population. As there may be a subset of patients receiving first-time PPM with otherwise undetected LVSD who are at increased risk of sudden cardiac death, routine PSE can triage patients who may benefit from further investigation using sTTE. Patients who have demonstrated LVSD on sTTE are then indicated to receive an ICD instead of a PPM to reduce the risk of arrhythmogenic cardiac death. The results of this study suggest that PSE can effectively identify these patients prior to the implantation of any cardiac pacing device.

Acquisition of PSE images

The use of the Vscan PSE to visualize left ventricular wall motion and systolic function has been previously evaluated. Several studies have demonstrated that the Vscan can obtain interpretable images in the vast majority (85-100%) of patients by inexperienced sonographers, in both the inpatient and outpatient settings [10-12]. The present study demonstrates that PSE can be appropriately applied for use in the population awaiting PPM implantation. Interpretable images were obtained by the sonographic trainee for the majority (94%) of patients within an average acquisition time of 6 minutes. In comparison, a complete sTTE study takes approximately 15 minutes to acquire [20]. At present, the cost of the PSE machine is approximately one quarter the cost of a standard ultrasound machine.

Images could not be adequately acquired in 6% of patients due to a variety of factors including: limited mobility (due to the presence of a temporary pacing wire, an intravenous line, or a previous stroke) and/or poor access to echocardiographic windows. However, this study
demonstrated that overall, a medical student without a previous background in sonography can be trained to obtain and record images of reasonable quality, quickly and efficiently using PSE.

**Interpretation of PSE images**

Previous studies of PSE have compared images acquired by an inexperienced sonographer (e.g., medical resident) versus an experienced sonographer (e.g., cardiologist with level 3 competency in echocardiography), and have shown that there is good correlation between PSE and sTTE for the assessment of LVEF [12-18]). These studies did not evaluate inter-observer correlation of the assessment of a single set of PSE images between inexperienced (e.g., medical student or resident) and experienced (e.g., echocardiologist) sonographers. Rather, they compared images acquired and assessed separately. In the present study, high inter-observer correlation between the student and the imaging cardiologist is important in order to appropriately triage patients for sTTE in the setting of pre-PPM implantation. This study found that inter-observer concordance between the sonographic trainee and echocardiologist in determining the presence or absence of LVSD was 96% with a kappa value suggesting good concordance. There was also good concordance (κ = 0.725) in categorizing LVEF into normal, mildly reduced, moderately reduced, and severely reduced. This was similar to the concordance rate (κ = 0.606) described by Panoulas and colleagues, although in their study medical students and the cardiologist evaluated separately acquired images [18]. Compared to the evaluation by the echocardiologist, the sonographic trainee had a good specificity (98%) but a poor sensitivity (60%), reflecting a tendency to “over-call” LVSD. This interpretation of LVSD, however, may then be ruled out by a more sensitive evaluation with sTTE. This study suggests that a sonographic trainee can interpret the presence or absence of LVSD on PSE with reasonable concordance compared with an echocardiologist, in order to triage candidates for sTTE evaluation.

**Accuracy of PSE versus sTTE**
Previous reports show that LVEF estimation using PSE appears to correlate well with using sTTE. However, strength of correlation is dependent upon level of training in echocardiography [15-18,21]. Although a variety of patient populations have been studied, so far no studies have examined patients awaiting first-time PPM implantation. This study did not compare PSE directly with sTTE; however, 28 of the 71 patients were concomitantly evaluated with sTTE as part of their pre-pacemaker clinical assessment. In this group, LVEF as estimated by the imaging cardiologist from PSE images obtained by the medical student compared to images obtained by sTTE were concordant in 96% of these 28 patients. As expected, the sonographic trainee was slightly less accurate in describing LVEF from PSE images (88% concordance). There was greater success in detecting LVSD than estimating LVEF; the echocardiologist was able to identify the presence or absence of LVSD in all (100%) patients, and the medical student was able to do so in all but one patient (96%). Overall, the evaluation of LVEF with PSE in the PPM pre-implant population was comparable to that of sTTE as reference standard.

**Implementation of PSE into pre-operative workflow**

This study provides insight into how PSE may be implemented into the pre-procedural assessment prior to the insertion of a PPM. There are few published studies describing the pre-procedural or pre-operative role of PSE. Frederiksen and colleagues demonstrated that PSE can be used for pre-operative assessment for day surgery patients and determined that the parasternal long axis view alone, taken with the patient in a sitting position, suffices to estimate LVEF [7]. In contrast, all participants in this study were scanned with PSE in a supine position, which enabled a comprehensive echocardiographic exam. Patients were more compliant with maneuvers to enhance echocardiographic windows, especially rotating into a left lateral decubitus position, when PSE scanning occurred prior to intravenous line placement and procedure site preparation. This improved image quality and reduced the time needed to complete the PSE exam.
Conclusions

This study demonstrated the feasibility of PSE screening prior to the implantation of a PPM. To further elucidate the workflow of performing PSE routinely in this setting, future studies may evaluate the use of PSE by health care allies already involved in pre-operative care. In the population who receives PPM, PSE may be implemented as an adjunct to the clinical examination to evaluate for sTTE candidacy. Several studies have previously reported on the added benefit of performing PSE after a thorough history, physical exam, and electrocardiogram. Performing PSE on all patients in this setting might standardize, as well as reduce the need for, referral for sTTE to evaluate for PPM candidacy. The introduction of PSE as a powerful new technology in health care presents many opportunities for application; however, more research will be required to clarify its appropriate and safe usage.

Pocket-sized echocardiography is a tool that can accurately screen for left ventricular systolic dysfunction at the bedside, thereby identifying patients requiring permanent cardiac pacing who would benefit from primary prevention of sudden cardiac death with implantation of an implantable cardioverter defibrillator. This method of screening can be implemented with minimal disruption of the existing pre-operative workflow, and may eventually play an adjunctive role to the clinical assessment for cardiac device candidacy.

Limitations

This study presented several limitations. First, as a pilot study, the number of patients included was small, and accordingly, was not intended to affect clinical management of patients undergoing PPM implantation who were enrolled as participants. Although the cardiologist implanting the pacemaker was notified of the presence of possible LVSD on PSE, a protocol for management of LVSD found on PSE was not formally instituted. In addition, although this study commented on the accuracy of PSE compared to sTTE in a subset of patients, a more rigorous study would perform both PSE and sTTE immediately prior to PPM implantation to evaluate accuracy in this population. However, image accuracy has been previously well described in
various other patient populations [7-18]. Finally, although this study validated the use of PSE in assessing LVEF, a pre-implantation assessment using sTTE is ultimately superior to PSE with regards to detecting pertinent cardiac pathology aside from LVSD. It follows that there are limitations in training a sonographer only to interpret LVEF; broader training with PSE in other aspects of echocardiography may be important to maintain safe usage of this promising technology.

Competing interests
The author(s) declare that they have no competing interests.

Authors' contributions:
CS and DJ conceived of the study, and participated in its design and coordination and helped to draft the manuscript.
DJ supervised the PSE training of LL
LL performed the echocardiograms, consented participants and helped draft the manuscript.
RD and JR assisted in the PSE training of LL as well as identifying study participants
All authors read and approved the final manuscript.
References


### Table 1. Baseline clinical characteristics of the study population \( (n = 71) \)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years) ± SD</td>
<td>77±12</td>
</tr>
<tr>
<td>Male</td>
<td>47 (66)</td>
</tr>
<tr>
<td>Indication for implantation</td>
<td></td>
</tr>
<tr>
<td>Sinus node dysfunction (SND)</td>
<td>27 (38)</td>
</tr>
<tr>
<td>Atrioventricular nodal block (AVB)</td>
<td>30 (42)</td>
</tr>
<tr>
<td>Both SND and AVB</td>
<td>14 (20)</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>28 (39)</td>
</tr>
<tr>
<td>Smoking history (&gt;10 pack years)</td>
<td>28 (39)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>52 (73)</td>
</tr>
<tr>
<td>Diabetes mellitus type 2</td>
<td>16 (23)</td>
</tr>
<tr>
<td>Dyslipidemia</td>
<td>22 (31)</td>
</tr>
<tr>
<td>Coronary artery disease</td>
<td>20 (28)</td>
</tr>
<tr>
<td>Previous myocardial infarction</td>
<td>19 (27)</td>
</tr>
<tr>
<td>Previous stroke or transient ischemic attack</td>
<td>13 (18)</td>
</tr>
<tr>
<td>Congestive heart failure</td>
<td>15 (21)</td>
</tr>
</tbody>
</table>

### Table 2. Symptoms at initial patient presentation to health care centre \( (n=71) \)

<table>
<thead>
<tr>
<th>Presenting symptom</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syncope</td>
<td>25 (35)</td>
</tr>
<tr>
<td>Presyncope</td>
<td>43 (61)</td>
</tr>
<tr>
<td>Fatigue</td>
<td>23 (32)</td>
</tr>
<tr>
<td>Exercise intolerance</td>
<td>11 (15)</td>
</tr>
<tr>
<td>Dyspnea</td>
<td>26 (37)</td>
</tr>
<tr>
<td>Palpitations</td>
<td>9 (13)</td>
</tr>
<tr>
<td>Edema</td>
<td>10 (14)</td>
</tr>
</tbody>
</table>

### Table 3. LV ejection fraction based on estimation of PSE images \( (n = 71) \)

<table>
<thead>
<tr>
<th>LV ejection fraction</th>
<th>Sonographic Trainee</th>
<th>Echocardiologist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal (&gt;50%)</td>
<td>60 (85%)</td>
<td>58 (82%)</td>
</tr>
<tr>
<td>Mild dysfunction (40-50%)</td>
<td>6 (8%)</td>
<td>3 (4%)</td>
</tr>
<tr>
<td>Moderate dysfunction (30-40%)</td>
<td>2 (3%)</td>
<td>2 (3%)</td>
</tr>
<tr>
<td>Severe dysfunction (&lt;30%)</td>
<td>2 (3%)</td>
<td>3 (4%)</td>
</tr>
<tr>
<td>Uninterpretable</td>
<td>1 (1%)</td>
<td>5 (7%)</td>
</tr>
</tbody>
</table>
### Table 4. Assessment of PSE images for presence or absence of significant LVSD by sonographic trainee vs. echocardiologist (n = 66)

<table>
<thead>
<tr>
<th>Sonographic trainee interpretation</th>
<th>Echocardiologist evaluation</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LVSD absent (LVEF &gt; 40%)</td>
<td>60 (91%)</td>
<td>2 (3%)</td>
</tr>
<tr>
<td>LVSD present (LVEF &lt; 40%)</td>
<td>LVSD present (LVEF &lt; 40%)</td>
<td>1 (1%)</td>
<td>3 (5%)</td>
</tr>
</tbody>
</table>

**Figure Legend**

**Figure 1.** Comparison of images acquired using (a) sTTE and (b) PSE on the same patient.