

Randomised controlled trial to assess the effect of a Just-in-Time training on procedural performance: a proof-of-concept study to address procedural skill decay

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ABSTRACT

Background A subset of high-risk procedures present significant safety threats due to their (1) infrequent occurrence, (2) execution under time constraints and (3) immediate necessity for patient survival. A Just-in-Time (JIT) intervention could provide real-time bedside guidance to improve high-risk procedural performance and address procedural deficits associated with skill decay.

Objective To evaluate the impact of a novel JIT intervention on transvenous pacemaker (TVP) placement during a simulated patient event.

Methods This was a prospective, randomised controlled study to determine the effect of a JIT intervention on performance of TVP placement. Subjects included board-certified emergency medicine physicians from two hospitals. The JIT intervention consisted of a portable, bedside computer-based procedural adjunct. The primary outcome was performance during a simulated patient encounter requiring TVP placement, as assessed by trained raters using a technical skills checklist. Secondary outcomes included global performance ratings, time to TVP placement, number of critical omissions and System Usability Scale scores (intervention only).

Results Groups were similar at baseline across all outcomes. Compared with the control group, the intervention group demonstrated statistically significant improvement in the technical checklist score (11.45 vs 23.44, $p<0.001$, Cohen's d effect size 4.64), the global rating scale (2.27 vs 4.54, $p<0.001$, Cohen's d effect size 3.76), and a statistically significant reduction in critical omissions (2.23 vs 0.68, $p<0.001$, Cohen's d effect size -1.86). The difference in time to procedural completion was not statistically significant between conditions (11.15 min vs 12.80 min, $p=0.12$, Cohen's d effect size 0.65). System Usability Scale scores demonstrated excellent usability.

Conclusion A JIT intervention improved procedure performance, suggesting a role for JIT interventions in rarely performed procedures.

INTRODUCTION

Rapid and successful performance of life-saving procedures is a core element of the

practice of emergency medicine (EM). Unfortunately, procedure-related errors pose a threat to patient safety.¹ A review of emergency department (ED) malpractice cases showed that procedure-related errors were responsible for 17% of all malpractice claims and were associated with the highest average indemnity payment of all sources of medical error.²

Safety threats are especially significant for a subset of procedures that share key high-risk characteristics. These high-risk procedures (HRPs) are (1) performed infrequently, (2) executed under significant time constraints and (3) critical for patient survival.³ Because HRP are not regularly performed, they represent a patient safety threat related to skill decay. Studies suggest a marked decay in procedural skills starts anywhere from 2 weeks to several months after final training.³ Additionally, time-sensitive procedural tasks performed under stressful situations decay more rapidly.^{4 5} As a result, practitioners may possess adequate skills on completing training, but are no longer equipped to safely perform a HRP months or years later. Addressing procedural skill decay is of primary importance and has been recognised as a safety improvement target by quality-focused organisations such as the Agency for Healthcare Quality and Research.⁶ However, to date an effective intervention to mitigate the safety impact of HRP skill decay has not been described.

Just-in-time (JIT) training is a strategy that has been used in the manufacturing industry for individuals who must execute

rarely performed tasks or operations in an environment that cannot tolerate error.⁷ The JIT training strategy uses a specific, task-driven intervention to immediately address an identified knowledge or skill deficit. Because it is extremely focused, well-designed JIT interventions are brief (2–5 min).⁸ This allows JIT training to be used at the bedside during the care of critically ill, unstable patients. Additionally, JIT training is designed to be interactive and provides both user-driven and instructor-driven education.⁷ The user-driven component provides an interface that allows practitioners to obtain the specific information/knowledge they feel they need to allow safe execution of the procedure. The instructor-driven component provides information that is critical to the procedure but might not be recognised as such by the practitioner. The result is an immediately available real-time clinical adjunct that provides practitioners with critical diagnostic or procedural information.

A JIT intervention could therefore be an ideal method to address the unique challenges associated with certain HRPs. JIT has been used to improve performance in a variety of procedures, including bystander cardiopulmonary resuscitation (CPR),⁹ emergency dental procedures⁸ and ultrasonography,¹⁰ but it has not yet been specifically applied to HRPs. The objective of this pilot study was to evaluate the impact of a novel bedside JIT training tool on performance of an HRP. We chose emergent transvenous pacemaker (TVP) placement as the HRP for this proof-of-concept study because it is a rarely performed, time-sensitive, life-saving procedure that is considered to be an essential skill for critical care and EM physicians.¹¹ Despite training during residency, the infrequent nature of TVP results in a lack of physician preparation and increased risk of harm to patients.¹²

METHODS

Study design and setting

This was a prospective, randomised controlled study to determine the effect of a JIT intervention on performance of TVP placement by emergency physicians (figure 1). A simulation-based assessment was used due to the relative infrequency of TVP placement in the clinical realm. Baseline performance assessments of all subjects were obtained prior to randomisation, and final assessments were obtained 6 months following the initial assessment. Subjects were scheduled according to their availability, and final assessment dates were randomised in a 1:1 ratio to the control or intervention (JIT) condition using numbered envelopes. Subjects were blinded to the purpose of the study; however, intervention subjects became aware of the JIT intervention when it was introduced during the final simulation-based assessment. Subjects completed demographic questionnaires prior to each simulation. All simulation encounters were performed at the WWAMI Institute for Simulation in Healthcare

(WISH) at the University of Washington Harborview Medical Center. The University of Washington Human Subjects Division determined this study to be exempt from institutional review board review.

Selection of subjects

Subjects included board-certified or board-eligible EM providers practising at two different medical centres within an academic health system. Subjects were recruited via email and at monthly staff meetings and participation was voluntary. Recruitment materials notified subjects they would participate in a ‘study about procedure performance’, but the specific procedure was not identified until the actual assessment. All subjects were compensated with a \$20 gift card upon completing the study. Written informed consent was obtained from all subjects.

Intervention

The investigators used relevant components of the JIT mobile learning framework proposed by Parsons *et al*¹³ to guide the design of the JIT intervention. First the investigators met with subject matter experts (SMEs) to determine key design features and establish evidence of validity of the clinical content. SMEs included a convenience sample of eight board-certified EM physicians and cardiologists from academic and community-based institutions, none of which were subjects in, or otherwise affiliated with, this study. It was determined that the JIT intervention needed to (1) be portable, (2) facilitate rapid completion of the procedure, (3) transmit information to a physician in a sterile field and (4) be resilient enough for the ED clinical environment. From an education standpoint, the JIT intervention needed to (1) provide multiple levels of instruction, (2) support troubleshooting of unsuccessful transvenous pacing attempts and (3) reinforce best practices while emphasising critical actions for success and safety. This tool was specifically designed for physicians with prior familiarity with this procedure, not as a first-time trainer for the novice learner. Based on all of these criteria, the JIT intervention was designed to run as an application on a tablet computer (Google Nexus) that would allow bedside implementation. Pacific Standard Ventures (Newberg, Oregon, USA) worked with the study team to develop the JIT intervention.

The content of the novel JIT intervention includes two main components. First, the training provides a brief (~30s) refresher video with audio narration of the key steps of TVP placement for both the provider and their assistant to review together. This component was designed to establish a baseline procedural awareness for all members of the procedure team. Second, the JIT intervention leads the procedure team through the procedure via a step-by-step interactive checklist based on best-practice recommendations derived from published literature and the aforementioned SME input (online supplementary file 1). The JIT tool is manipulated by the non-sterile procedure assistant; content can be read by the assistant,

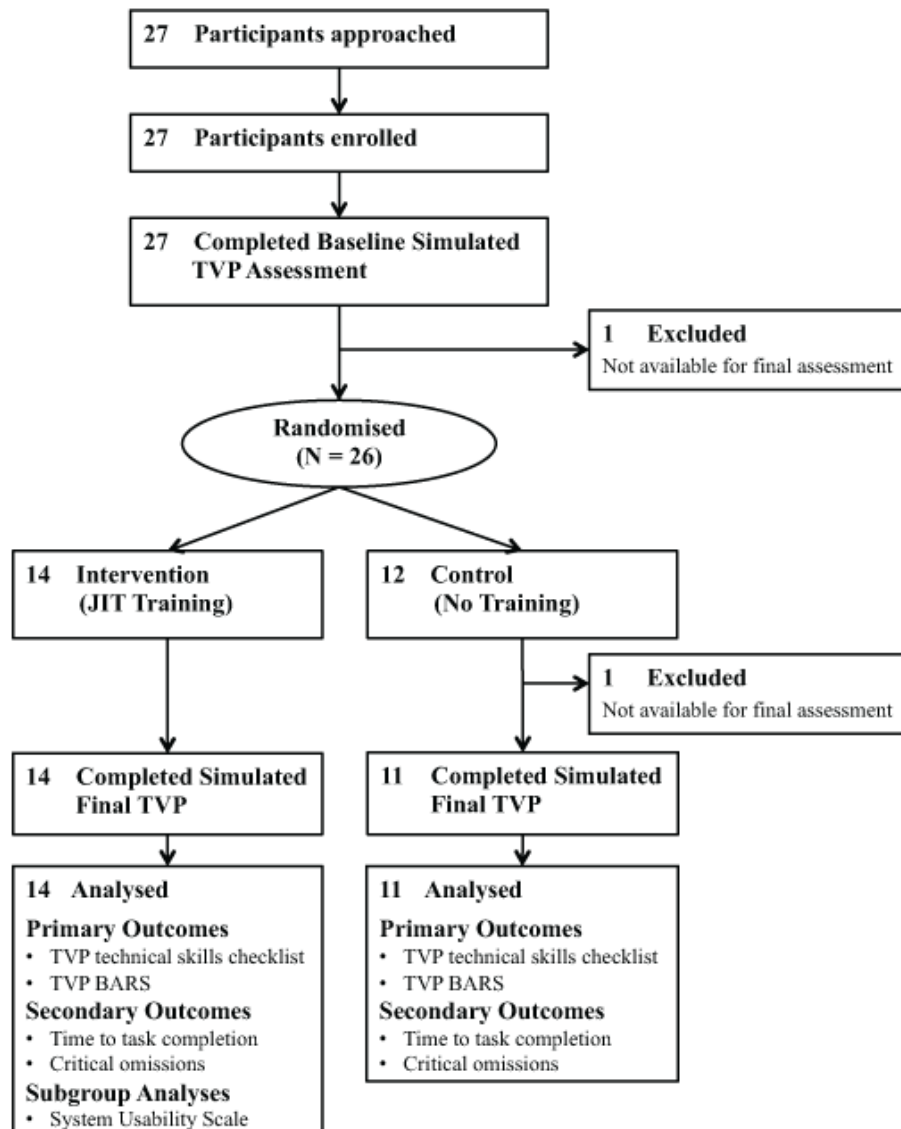


Figure 1 CONSORT diagram. BARS, Behaviorally Anchored Rating Scale; JIT, just in time, TVP, transvenous pacemaker.

or can be shown to the provider directly. Functionality includes user-driven bidirectional navigation through the checklist, task-specific scripting, high-resolution visual cues, and an optional troubleshooting algorithm for failed capture that is situation-specific (eg, no capture, intermittent capture and non-right ventricular capture). The checklist includes all tasks from preparation to disposition and provides a navigation map to allow the care team to note their progress through the procedure.

Measures and assessment

Simulation protocol

TVP performance was assessed using simulated patient encounters (online supplementary file 2). Both simulations were developed using event-based simulation design.¹⁴ The case was designed to target placement

of a TVP and not focus on diagnostic tasks. The simulation space was designed to replicate an ED resuscitation bay, and included typical monitoring and resuscitation equipment. A Simulab Corporation (Seattle, Washington, USA) CentraLineMan manikin was modified to accommodate the TVP wire length and balloon size via right internal jugular approach based on a previously described technique.¹⁵ The manikin was draped with a TVP sheath introducer in place. A simulation technician controlled the patient's vital signs and heart rhythm in real time, with changes based on the subject's actions. A trained actor filled the role of an ED nurse. This standardised nurse served to introduce the subjects to the simulated patient scenario, execute nursing tasks and deliver standardised prompts

to the subject if they were at an impasse defined by (1) statements related to lack of knowledge ('I'm not sure what to do next') or (2) missing steps critical to procedure completion (eg, not connecting the pacing wire to the external pacing generator). For instance, if the subject did not instruct the nurse to turn on the power source, the nurse would prompt the subject to do so after a set period of time if the subject did not self-correct.

Measures

The primary outcome was performance during a simulated patient encounter requiring TVP placement, as assessed by trained raters using a technical skills checklist (table 1). Secondary outcomes included a Behaviorally Anchored Rating Scale (BARS) score (online supplementary file 3) of procedure performance, time to completion of the TVP procedure and the number of missed critical actions (critical omissions). Additionally, System Usability Scale (SUS) scores (box 1) were obtained for the intervention group.

TVP performance checklist (primary outcome) and critical omissions

Several published checklists for TVP assessment exist, but they have not been well validated. The investigators therefore worked with SMEs from cardiology and EM to develop a novel 26-point technical skills checklist that was divided into four broad components: (1) preparation, (2) troubleshooting failed capture, (3) achieving capture and (4) postprocedure care (table 1). These SMEs were distinct from those involved in the design of the intervention. The TVP checklists^{16 17} were reviewed and individual checklist items were distributed to SMEs who then rated the checklist items for importance, adherence to standard of care, and clarity. Items identified as unclear, inappropriate or not necessary for successful TVP placement were reviewed and either revised or discarded based on recommendations. The investigators piloted and refined the checklist on several test simulations to enhance reliability and to obtain evidence of response process validity.

Through this process a subset of 11 items were identified as critical actions, defined for this study as 'a behavior without which the subject could not complete the procedure or an action that posed a significant safety threat'. Failure to perform a critical action was considered a *critical omission*.

TVP performance BARS

Checklist assessments have been criticised for rewarding thoroughness rather than competency.¹⁸ Therefore a BARS was also developed for this study (online supplementary file 3). The BARS ranged from 1 to 5, where '5' indicates highest performance. A total of five rating scales were created, one for each of the four components of the procedure, and one for the overall procedure. Each BARS was reviewed for content and clarity by the authors and the SMEs involved in

checklist development. The BARS provided a holistic assessment of procedural performance. Investigators also piloted and refined the BARS on several test simulations to enhance reliability.

Time to completion

Time to completion was measured for all subjects. Time was defined as the time from the completion of the scripted introduction by the nurse confederate until the point at which the study subjects affirmed that they had no more actions they would like to perform as part of the scenario.

Usability

The usability of the JIT intervention was assessed using the SUS as there is validity evidence supporting its application to hardware and software technologies.¹⁹ The SUS verbiage was slightly modified from a focus on a 'system' to the JIT 'tool'. Briefly, the SUS contains 10 statements (box 1) scored on a 5-point scale to reflect agreement with the given statement. Raw scores are adjusted to account for both positively and negatively oriented questions.¹⁸ Final overall SUS scores range from 0 to 100, with higher scores representing greater usability. Subjects in the intervention arm completed the SUS immediately following the completion of their simulation.

Data collection and coding

All simulations were recorded using two stationary cameras, one placed at the foot of the bed to capture the monitor and procedure field, and one positioned overhead to capture the procedure field. Both video feeds were synchronised and entered into Noldus Observer XT (Leesburg, Virginia, USA) software for coding of performance during TVP placement (technical skills checklist, critical actions and BARS) and time to completion of procedure. This study used a data coding strategy following evidence-based practices as previously described.^{20 21} Raters were EM physician members of the study team, and they were trained until they reached a Cohen's $k > 0.75$ across a range of subject performance. Because the JIT training was easily visible in the recordings, raters could not be blinded to the study condition. We therefore had two independent raters code each simulation using the TVP placement technical skills checklist and TVP BARS. Inter-rater reliability for raters coding each class of behaviours met research standards.²² For the TVP placement technical skills checklist and BARS, the initial average Cohen's $k = 0.66$ ($SD = 0.09$). This demonstrates adequate agreement for both measures.²³ For encounters with significant disagreement ($k < 0.7$; nine simulations), both raters met to review the recording and achieve consensus.

Table 1 TVP technical skills checklist scoring tool (primary outcome measure)

Item	Assessment criterion	Scoring comments
Phase 1: Preparation		
1*	Sterile garb applied†	Includes the following: 1. cap 2. gown 3. mask 4. gloves
2	Balloon checked	Inflates the balloon <i>prior</i> to the wire insertion
3*	Adapter leads attached	Attaches the included adapter lead tips to the end of the wire
4	Pacer wire protective sheath placed on wire	Places the protective sheath on the wire in the proper orientation. Note: Reversing the direction of the sheath, or attaching the sheath to the wire only after attempting to pace, is incorrect
5*	Pacer wire attached to generator	Instructs the confederate nurse to physically attach wires to the generator Note: If sterility broken, see 'Sterility was broken' in <i>Any Phase Items</i> below
6*	Initial generator setting – HEART RATE	Instructs confederate nurse to set heart rate between 60–100 beats per minute
7*	Initial generator setting – OUTPUT	Instructs confederate nurse to set output to maximum (20mA)‡
8	Initial generator setting – SENSITIVITY	Instructs confederate nurse to set sensitivity to 'asynchronous' OR 'lowest' setting
Phase 2: Failed Capture and Troubleshooting		
9	Balloon inflated in start position before attempting to pace	Inflates balloon when pacer tip is between 15–20 cm
10*	Generator power turned on	Ensures generator power is 'ON'.
11	Troubleshooting: actions for failed capture§	Makes attempt(s) to troubleshoot failed capture: 1. confirms power on 2. confirms wire attached to external pacing generator 3. reviews/confirms generator settings 4. reviews pacer wire polarity 5. makes small adjustments to wire position 6. confirms wire depth between 25 and 40 cm 7. considers need for new batteries 8. considers need for new wire 9. considers wire may be in aberrant location 10. considers underlying comorbid conditions (e.g., electrolyte abnormality)
12*	Withdrew pacing wire to start position	Pulls back pacing wire to start position with intent to readvance for second attempt at capture Note: if the balloon is left up while pulling back, also score 'Balloon UP while PULLING BACK' in <i>Any Phase Items</i> below
Phase 3: Achieving Capture		
13*	Electrical capture identified	Statements or actions indicating capture (e.g., check a pulse or blood pressure)
14*,¶	Confirmed physiological capture by checking pulse	Palpates a pulse corresponding to the telemetry tracing
15*,¶	Confirmed physiological capture with blood pressure††	Repeats blood pressure measurement after achieving electrical capture
16	Deflated the balloon	Deflates balloon after capture is confirmed Note: this can be done anytime before the end of the procedure
17	Demonstrated capture threshold	Turns down output until capture is lost, then turns output up to the minimum value at which capture is regained Note: default capture threshold was 1.0 mA
18	Final generator settings: HEART RATE	Reviews the final heart rate setting
19	Final generator settings: OUTPUT	Selects correct final output setting at 2-5x higher than capture threshold (see 17)
20	Final generator settings: SENSITIVITY	Reviews final sensitivity setting Note: can keep an asynchronous setting or give rationale for increasing the sensitivity, however, random settings without providing a rationale are considered 'not done'
Phase 4: postprocedure		
21	Protective sheath secured at patient end	Secures the protective wire sheath; if it is left floating/unattached, it is incorrect
22	Protective sheath extended over wire	Fully extends protective sheath before handing to the confederate nurse

Continued

Table 1 Continued

Item	Assessment criterion	Scoring comments
23	Accepting team/provider notified	Give credit for this item if the subject makes any reference to 'calling the admitting team/provider' to take/accept/receive the patient
24	Relevant settings documented¶	Instructs confederate nurse to document settings and provides the following: 1. heart rate 2. output 3. sensitivity 4. wire depth 5. capture threshold
25*	Postprocedure chest radiograph ordered	Verbal request sufficient
26	Postprocedure electrocardiogram ordered	Verbal request sufficient
Any phase items**		
a	Sterility broken	Code if sterility is broken untied gowns falling down, contacting the Mayo stand, non-sterile transfers of the wire, wire slips off the sterile field)
b	Balloon up while wire withdrawn	Moves wire greater than 1 cm in any direction with balloon inappropriately inflated or deflated
c	Balloon down while wire advanced	Note: should not be coded at the initial step when the subject first inserts wire to start position with balloon down
d*	Capture misidentified	Misinterprets partial or non-capture as successful

*Denotes a critical action or omission that could result in a significant safety threat or inability to perform the procedure.
 †Each subitem scored as 0.25 points for a total of 1.0 point available.
 ‡Generator must be set to a 'maximum' output, which is 20 mAmp for the equipment used in the study.
 §Each subitem scored as 0.1 point for a total of 1.0 point available.
 ¶Each subitem scored as 0.2 point for a total of 1.0 point available.
 **Each item can occur at any time during the simulation, but is only coded once and assigned a point value of (-1).
 ††Confirming physiological capture with either blood pressure check or confirmation of pulse correspondence to electrical activity meets the definition of a critical action.
 TVP, transvenous pacemaker.

Data analysis and sample size

Given that the foci of this research study are innovative, estimating anticipated effect sizes represents the major challenge for conducting a power analysis. A systematic review of procedural interventions was consulted to estimate the effect size for procedural training on task performance.²⁴ Based on seven studies

with a total sample size of 326, a standard mean difference of 1.25 was found for procedural training and checklist-based outcome criteria. This was similar to effect sizes reported for a computer-based JIT training for CPR.²⁵ Using an effect size of 1.2, a power analysis that indicated a sample size of 24 (12 per condition) would provide 0.80 power to detect a clinically meaningful difference in performance.

Box 1 Modified System Usability Scale items

- System Usability Scale question (1=strongly disagree, 3=neutral, 5=strongly agree)**
- ▶ I found that the tool was unnecessarily complex in its design.
 - ▶ I thought the tool was easy to use with the nurse.
 - ▶ I think I would need the support of a technical person to use this tool in the actual clinical environment.
 - ▶ I found the various functions (eg, graphics, audio, navigation flow and so on) of the tool were well integrated.
 - ▶ I thought there was too much inconsistency in the performance of this tool.
 - ▶ I would imagine that most people would learn to use this tool quickly in the clinical environment.
 - ▶ I found the tool very cumbersome to use.
 - ▶ I felt very confident using this tool with the nurse.
 - ▶ I needed to learn a lot of things before I could get going with this tool.

Demographic data were represented using descriptive statistics. Technical skills checklist and BARS scores were averaged between raters. We calculated descriptive statistics (mean and SD) for TVP technical skills checklist scores and BARS scores for initial and final assessment measures, as well as for critical omissions and time to completion. The Shapiro-Wilk test was used to evaluate for normality.²⁶ Groups were compared using independent samples t-tests. We performed a mixed-model analysis of variance to evaluate the main effects of time (within-subjects), condition (between-subjects) and their interaction on the primary outcome (TVP technical skills score). Finally, we report descriptive statistics for the calculated SUS score.¹⁹

RESULTS
Characteristics of study subjects

Twenty-seven physicians were enrolled in the study from October 2013 through December 2013 (figure 1).

Table 2 Subject demographics

Subject characteristics	Control group (n=11)	Experimental group (n=14)
Age, mean (SD), years	42 (3.9)	39.8 (8.6)
Male, n (%)	8 (73%)	9 (64%)
Self-reported studying for TVP between assessments, n (%)	5 (46%)	3 (21%)
Number of days between assessments, mean (SD)	182.4 (9.2)	183.3 (9.1)
Prior experience participating in any simulation, n (%)*	7 (64%)	13 (93%)
Number of TVPs performed, † mean (SD)	3.2 (3.3)	2.9 (3.9)

*Includes simulation experience from residency onward.

†Includes simulated and actual patients.

TVP, transvenous pacemaker.

Two physicians completed the baseline assessment but were unable to complete the final assessment: one before the randomisation, and one after. Of the 26 physicians randomised, 25 completed all components of the assessment, and all videos were of acceptable quality to allow coding and analyses. The control and intervention groups were well balanced in terms of

age, gender, number of TVP procedures performed prior to enrolment, and time between baseline TVP assessment and final assessment (table 2). Between the baseline and final assessment, only one subject (assigned to the control condition) performed a TVP procedure outside of the study and eight (n=5 control, n=3 intervention) reported reviewing the procedure using online references or textbooks.

Primary outcome

TVP technical skills checklist

At baseline, both intervention and control groups performed similarly as measured by the TVP technical skills checklist and number of critical omissions (table 3). Baseline performance in the TVP technical skills checklist did not correlate with final performance (TVP technical skills checklist; $r=0.35$, $p=0.09$). In the final assessment, subjects in the intervention group scored significantly higher on the TVP technical skills checklist as compared with the control group (table 3). We found a significant within-subjects effect for time ($F(1, 23) = 76.6$, $p < 0.001$; $\eta^2_p = 0.77$) as well as a significant between-subjects effect of condition ($F(1, 23) = 48.3$, $p < 0.001$;

Table 3 Comparison of baseline and final performance across control and intervention conditions

	Control group (n=11) (mean (SD))	Intervention group (n=14) (Mean (SD))	Absolute difference	p Value	CI	Cohen's d
BASELINE ASSESSMENT						
Primary outcome						
Technical skills checklist score*	9.17 (2.94)	11.60 (4.43)	2.43	0.13	-0.78 to 5.60	0.63
Secondary outcomes						
BARS scores†						
Preparation BARS	2.12 (1.05)	2.64 (1.45)	0.52	0.33	-0.55 to 1.60	0.40
Failed capture and troubleshooting BARS	1.67 (0.43)	2.39 (1.13)	0.73	0.04	0.03 to 1.42	0.80
Achieving capture BARS	2.18 (0.51)	2.68 (0.91)	0.50	0.10	-0.10 to 1.11	0.66
Postprocedure BARS	2.15 (0.94)	2.39 (0.94)	0.24	0.53	-0.55 to 1.03	0.26
Overall performance BARS	1.73 (0.56)	2.18 (0.95)	0.45	0.18	-0.22 to 1.12	0.56
Number of critical omissions	3.59 (1.49)	3.04 (1.78)	-0.56	0.41	-1.94 to 0.83	-0.33
Time to completion, min	11.85 (3.42)	9.62 (1.85)	-2.23	0.07	-4.68 to 0.20	-0.84
FINAL ASSESSMENT						
Primary outcome						
Technical skills checklist score*	11.99 (3.36)	23.44 (1.44)	11.45	$p < 0.001$	9.10 to 13.79	4.64
Secondary outcomes						
BARS scores†						
Preparation BARS	3.14 (1.00)	4.57 (0.43)	1.44	$p=0.001$	0.74 to 2.13	1.95
Failed capture and troubleshooting BARS	2.41 (0.92)	4.11 (1.08)	1.70	$p < 0.001$	0.86 to 2.54	1.68
Achieving capture BARS	2.45 (0.69)	4.68 (0.80)	2.22	$p < 0.001$	1.60 to 2.85	2.96
Postprocedure BARS	2.36 (0.78)	4.89 (0.21)	2.53	$p < 0.001$	2.00 to 3.06	4.70
Overall performance BARS	2.27 (0.75)	4.54 (0.46)	2.26	$p < 0.001$	1.76 to 2.77	3.76
Number of critical omissions	2.23 (1.13)	0.68 (0.50)	-1.55	$p=0.001$	-2.33 to -0.76	-1.86
Time to completion, min	11.15 (2.70)	12.80 (2.38)	1.65	$p=0.12$	-0.45 to 3.75	0.65

*The technical skills checklist had a maximum score of 26.

†All BARS used a Likert scale format with ratings that ranged from 1 to 5 (see online supplementary file 3).

BARS, Behaviorally Anchored Rating Scale.

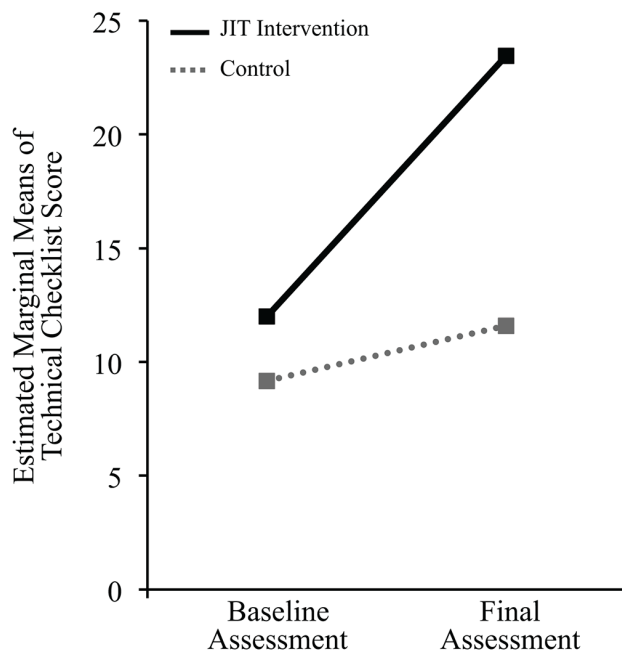


Figure 2 Interaction effect between time and condition on TVP performance. JIT, Just-In-Time; TVP, transvenous pacemaker.

$\eta^2_p = 0.68$). However, these main effects were qualified by a significant time-by-condition interaction ($F(1, 23) = 29.0, p < 0.001; \eta^2_p = 0.56$). **Figure 2** provides a plot of group means for each condition at each time point (baseline and final assessment). While both main effects were significant, the interaction effect revealed that improvement in the experimental condition between baseline and final assessment was significantly larger than in the control condition.

Secondary outcomes

Behaviorally Anchored Rating Scale

Both groups had similar baseline performance in four of the five TVP performance BARS (**table 3**). The intervention group had a higher baseline score on the BARS item ‘Phase 2: Failed capture and troubleshooting’ as compared with the control group. As with the technical skills checklist, baseline performance in the TVP BARS did not correlate with final performance (TVP BARS $r = 0.09, p = 0.67$) across all participants. In the final assessment, subjects in the intervention group had significantly higher scores on each of the BARS as compared with the control group (**table 3**). BARS scores were significantly correlated with the technical skills checklist scores ($n = 50; r = 0.96, p < 0.001$).

Critical omissions

Both groups had a similar number of critical omissions on baseline assessment. While both groups had fewer critical omissions in the final assessment, the intervention group had significantly fewer critical omissions compared with the control group (0.68 vs 2.23, $p = 0.001$, effect size = -1.86).

Time to completion

There was no significant difference in the time to completion between the control and intervention groups for the baseline (-2.23 min, $p = 0.07$) or final (1.65 min, $p = 0.12$) simulations.

Usability

The mean SUS score by the intervention group was 88.4 (SD 9.98), which is considered to be ‘excellent’.²⁷

DISCUSSION

This study demonstrates that use of a JIT intervention for TVP placement can significantly improve procedure performance in a simulated patient scenario. Improved task performance was seen across all subtasks required for the procedure. Most notably, individuals in the control group omitted significantly more critical actions that could either prevent successful completion of the procedure or pose a significant safety threat. This was true despite the fact that almost half (45%) of the control subjects report reviewing the details of pacemaker placement between baseline and final assessments. The fact that such an impact was noted among experienced, credentialed practitioners suggests an important role for JIT interventions in rarely performed, high-risk emergent procedures.

Procedural skill decay, defined as the loss or decline of acquired skills after periods of non-use, represents a major threat to patient safety.⁵ ‘Overlearning’, or training skills beyond what is required for proficiency, is the single most important determinant of skill retention. Unfortunately, this is difficult to achieve with rarely performed procedures. While simulation-based training can fill some of these deficits, it is unlikely that the level of simulation-based training for rare procedures such as TVP placement reaches the level of overtraining necessary to overcome natural skill decay. Additionally, the resources required (eg, learner/instructor time, teaching space, training materials, teaching expertise) to support training of suitable quality and frequency would be prohibitive. A bedside JIT training for such HRP could provide an important safety intervention. This could be especially relevant in smaller, critical access hospitals where procedural frequency is even lower, and procedural backup and more advanced treatment options (eg, fluoroscopy-aided TVP placement) are not available.

Well-designed JIT training can help ensure best practices and facilitate shared knowledge among the healthcare team, further supporting patient safety. This study leveraged several design features that support JIT training effectiveness and usability. Research demonstrates that the use of a multimedia JIT platform is more effective than static, paper-based checklists containing comparable material.^{25 28} Our JIT intervention coordinates video, static pictures and voice-over to facilitate use in a sterile environment. Moreover it is designed to be interactive and to provide both user-driven and

device-driven education that ensures delivery of both learner-specific information and core procedural content.⁷ This combined instructional design moves beyond written instructions and flip charts by utilising a flexible computer-based format. We designed the JIT intervention using common programming language to maximise cross-platform portability, thus facilitating translation to smartphones and bedside monitors. Our usability assessment demonstrated that subjects found the JIT intervention easy to use despite having no preparation time or technical assistance. Overall, this suggests our JIT design is flexible, delivers key information and requires no prep time or prior familiarity with the tool.

One of our secondary outcomes was time to procedural completion. We felt this was important, as a JIT intervention for emergent HRP must carefully balance the delivery of critical information with the need to minimise procedural delays. In a simulated setting, accurately reflecting the 'time to completion' of the procedure presents a challenge. As measured for this study, the mean time to completion was increased in the TVP intervention group as compared with the control group by 1.65 min. During many of the simulations in the control group, however, subjects either reached an impasse where they stated they did not know what to do next, or they omitted a critical step necessary for the progression of the scenario. In these situations, the confederate nurse would perform a scripted prompt to 'force' the subject to perform a critical action. Without the confederate nurse prompt, TVP placement would never be successful (eg, pacing could never occur without the power turned on). Thus, 'time to completion' in such cases is likely a gross underestimate of what would actually transpire if a provider were left to toil unassisted. We suggest that this issue requires further investigation and consideration with any type of JIT intervention.

To our knowledge, this JIT trainer is the first to be designed for use during real-time performance of a clinical procedure. Published reports of JIT training describe preprocedure trainers designed for use prior to performing the targeted task.^{9 29–31} Additionally, our design allows for situation-specific troubleshooting assistance in real time. Such tailored guidance cannot be delivered with a preprocedure training intervention. Taken together, the incorporation of bedside implementation, situation-specific troubleshooting and a focus on optimising the user experience could potentially lead to improved results for future clinical JIT interventions.

Our study has several important limitations regarding the sample population. First, we were limited to a convenience sample of practising emergency physicians from a single academic institution, so our results might not generalise across all ED settings. We note that our randomised groups may have been unbalanced with respect

to simulation experience and scores on one of the BARS items ('Phase 2: Failed capture and troubleshooting'). The intervention group had almost twice as many subjects with prior simulation-based training experience as compared with the control group. This could have led the subjects to be more comfortable with the simulation environment and therefore lead to improved performance.³² However, our analyses demonstrate no correlation between simulation experience and any outcome. This may have been because the baseline simulation in this study provided sufficient priming of the subject to overcome any effect of simulation experience on the final assessment. Additionally, the intervention group demonstrated higher baseline scores on BARS scoring of phase 2 of the simulation. This imbalance could have influenced final assessment scores on this item, but does not account for the significant improvements noted across all items.

A second limitation is the use of a simulation-based assessment platform. This approach was necessary, as the base rate of emergent TVP placement in our institution (as in most institutions) precluded using actual clinical outcomes for the initial JIT evaluation. Several reports describe the advantages of using simulation for this type of technology assessment,^{29–31} and the authors incorporated recommended best practices to ensure high levels of fidelity and simulation reliability throughout the study. However, it is important to note that the simulated clinical event may not replicate the clinical variability present in actual patient care events.

In summary, use of a JIT training intervention improves procedural performance and decreases critical omissions during placement of a TVP in a simulated patient scenario. We focused this study on TVP placement as an example of a high-risk, rarely performed, time-critical procedure. Our results are promising for the use of a JIT tool to improve procedural performance and mitigate skill decay and procedural errors during TVP placement in the actual clinical environment. If TVP is viewed as a model HRP, then there are many other potential emergent procedures (eg, lateral canthotomy, oesophageal tamponade, perimortem caesarean section) that might benefit from this type of intervention. Since we have designed our JIT intervention to provide step-by-step guidance and have troubleshooting capabilities, it is best suited for procedures that may be complicated (eg, intubation, pericardiocentesis, delivery of Advanced Cardiovascular Life Support algorithms) but not complex (eg, teamwork, end-of-life discussion).³³ Complicated procedures/processes (1) have predetermined steps, (2) may have many components that work together in a predefined way and (3) lack ambiguity. Complex procedures require many components to autonomously interact through emerging

processes; thus, adaptation is critical. Complex procedures would not be amenable to an approach like ours, as the need to adapt, the non-linearity of events and high levels of required interdependency would preclude the identification of a universally applicable troubleshooting algorithm.³⁴

Further study is needed to determine the impact of our JIT intervention in the clinical environment. Such research would likely require a multicentre approach to ensure generalisability. In our institution we are working to implement a comprehensive, self-contained TVP cart that includes all necessary materials, a TVP JIT tablet and a postprocedure evaluation tool for nursing and physician providers. These data, combined with system-level metrics, could provide early indication of effectiveness across multiple units, providers and patients.

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