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Effectiveness of a flipped classroom model for enhancing emergency physicians' skills in diagnosing high-risk pulmonary embolism with point-of-care ultrasound: a randomized controlled study

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Abstract

Background High-risk pulmonary embolism is a significant cause of morbidity and mortality in the emergency department. Point-of-care ultrasonography is a valuable tool for identifying high-risk pulmonary embolism at the bedside, but many physicians lack proficiency. A flipped classroom model may enhance point-of-care ultrasound training, but its effectiveness compared to standard teaching remains unclear.

Methods Emergency physicians and residents at a single academic centre were randomized to either a flipped classroom or standard teaching after a baseline assessment of their ability to identify high-risk pulmonary embolism using a database of ultrasound clips. The flipped classroom group completed an online module, while the standard teaching group attended an in-person seminar. Both groups participated in an in-person workshop and subsequently underwent post-training testing. The primary outcome was the difference in final test scores. Statistical analysis included Student's t-test for mean comparisons, while Fisher's exact test and one-way ANOVA were used to assess differences between teaching methods, with significance set at $p \leq 0.05$.

Results A total of 30 participants completed the study (15 in the flipped classroom and 15 in the standard teaching group). Most (80%) reported low baseline confidence in identifying high-risk pulmonary embolism with point-of-care ultrasound. There were no significant differences in baseline scores between the groups (65.0% ± 24.7% for the flipped classroom vs. 64.3% ± 24.9% for standard teaching, $p = 0.93$). Both groups demonstrated significant improvement in scores on final testing (standard teaching: 11% increase, $p = 0.02$; flipped classroom: 7.3% increase, $p = 0.03$). However, there was no significant difference in final test scores between the two groups (75.3% ± 20.1% for standard teaching vs. 72.3% ± 21.4% for the flipped classroom, $p = 0.65$).

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Conclusion We found that both the flipped classroom model and standard teaching were effective for teaching the signs of high-risk pulmonary embolism using point-of-care ultrasound. The results of this study may assist future curriculum development to facilitate asynchronous learning of ultrasound skills.

Clinical trial Not applicable.

Keywords Flipped classroom, Point of care ultrasound, High-risk pulmonary embolism

Introduction

High-risk pulmonary embolism is defined as acute pulmonary embolism (PE) that leads to sustained systemic hypotension (systolic blood pressure less than 90 mmHg for at least 15 min), the requirement for inotropic support, or cardiac arrest. It is a life-threatening condition caused by obstruction of more than 50% of the pulmonary arterial circulation, typically due to emboli originating from deep vein thrombosis, that can result in right ventricular failure and significant mortality if not promptly recognized and managed [1]. Despite advancements in PE management, such as direct-acting oral anticoagulants, catheter-directed thrombolysis, and improved prophylaxis protocols, mortality rates associated with high-risk PE remain high [2]. Accurate and timely diagnosis is critical in improving patient outcomes.

Diagnostic imaging, such as computed tomography pulmonary angiography (CTPA) and ventilation-perfusion (V/Q) scans, is considered the gold standard for diagnosis [3]. However, these investigations can be time-consuming, resource-intensive, or inaccessible for unstable patients. Point-of-care ultrasound (POCUS) has emerged as a valuable bedside tool that provides real-time, dynamic imaging of the cardiovascular system, enabling rapid assessment for high-risk PE [4]. Studies have highlighted the utility of POCUS for identifying features such as right ventricular dilation, interventricular septal flattening, and hyperdynamic left ventricular function, making it particularly beneficial in emergency settings [5].

Despite the increasing integration of POCUS in clinical practice, a significant gap remains in standardized training programs for its use in diagnosing high-risk PE [6]. Many physicians report a lack of confidence in POCUS interpretation, which is compounded by the absence of structured educational curricula [7]. The need for innovative teaching strategies to bridge this gap has led to the exploration of the flipped classroom (FC) approach. The FC model reverses traditional teaching by allowing learners to engage with content independently before attending interactive, instructor-led sessions. This active learning strategy enhances critical thinking, increases retention, and encourages hands-on skill development, which is essential for mastering POCUS techniques [8, 9].

Despite the growing interest in POCUS training, there is a lack of comprehensive studies directly comparing the flipped classroom approach with traditional teaching in the context of diagnosing high-risk PE with POCUS. Based on the advantages of the FC model in promoting learner engagement and deeper understanding, we hypothesized that the FC model would be superior to the standard teaching (ST) method in improving physicians' diagnostic accuracy in identifying high-risk PE through POCUS. Therefore, this study aims to evaluate whether the FC approach results in greater knowledge and image interpretation skills for diagnosing high-risk PE using POCUS compared to ST.

Methods

Study design

We conducted a single-center, prospective, randomized controlled educational study. CONSORT guidelines were followed for this study (Supplementary file 1).

Study population

All emergency physicians and emergency medicine residents rotating through the emergency department at a single academic center were invited to participate in this study. Participants were eligible to participate regardless of previous experience with POCUS. There were no exclusion criteria for participating in the study.

Sampling strategy and sample size

The sample size was calculated based on findings from Rui et al. (2017) [10], where the intervention group demonstrated significantly higher scores compared to the control group.

A simple random sampling strategy was used to enroll the participants. We powered the experiment to find a minimum clinically significant difference (MCID) of $\Delta = 1.0$ unit on the test, with a common SD $\sigma \approx 1.0$–1.01, a two-sided $\alpha = 0.05$, and a power of 80%.

A minimum of n (Sample size) was required for each arm:

$$n = 2\left(\frac{Z_{1-\propto/2+z_{1-\beta}}}{\Delta/\sigma}\right)^2 = 2\left(\frac{1.96+0.84}{\Delta/\sigma}\right)^2$$

With $\sigma = 1.01$ and $\Delta = 1.00$:

$n = 2(2.80/1.00)2 = 15.99n = 15.99 \approx 16$ per arm.
With $\sigma = 1.00$ and $\Delta = 1.00$:
$n = 15.68n \rightarrow \approx 16$ per arm.

The calculated sample size required for this study was 32 participants. However, we were able to recruit 30 participants due to logistical challenges and limited availability of eligible physicians during the study period.

Randomization

The Google random number generator was used as part of a computer-assisted simple randomization technique. Randomly generated even and odd numbers were used to assign participants. It was ensured that each participant had an equal chance of being assigned.

Study protocol

Before the intervention, all participants completed a baseline online questionnaire and assessment through a password-protected platform. The questionnaire collected demographic information, previous POCUS experience, frequency of POCUS use for pulmonary embolism, and confidence levels in identifying signs of high-risk PE. The assessment consisted of 20 questions that evaluated knowledge of POCUS findings for high-risk PE, as well as a series of ultrasound clips to evaluate (Supplementary file 2). The ultrasound clips were selected from a digital archive of actual patient scans from the emergency department and included patients with confirmed high-risk PE as well as other non-PE diagnoses.

Following the baseline assessment, participants were randomly assigned to one of two groups: the FC group (intervention) or the ST group (control). The FC group received access to an online lecture that served as an asynchronous e-learning module. The module included a pre-recorded video presentation (approximately 20 min in duration) that covered the following key areas:

- The role of POCUS in the diagnosis of high-risk PE.
- Step-by-step scanning techniques.
- Normal versus pathological findings.
- Key sonographic signs suggestive of high-risk PE (e.g., hyperdynamic left ventricle, acute right ventricular strain, and dilated non-collapsible inferior vena cava).
- Common pitfalls in the interpretation of cardiac POCUS in this context.

Participants were instructed to complete the module before the in-person hands-on session. The ST group attended a live, in-person didactic session, which covered the same core content as the FC module. This instructor-led session lasted approximately 20 min and followed a structured presentation format, including lecture slides and visual ultrasound examples, delivered by a POCUS-trained faculty member.

Following the initial training, both groups attended a hands-on workshop, where each participant practiced the scan techniques for 20 min using a high-fidelity ultrasound simulator (Vimedix, CAE Healthcare). Participants practiced obtaining views of the heart and inferior vena cava on a simulator that included both signs of high-risk PE as well as non-PE diagnoses. The practice session was supervised by an emergency physician with significant expertise in POCUS for PE, and feedback was provided to participants immediately after each scan.

After a four-week wash-out period, all participants completed an online questionnaire and assessment. This assessment included the same material as the baseline assessment; however, the questions were presented in a different order.

Statistical analysis

Descriptive statistics, including frequencies and percentages, were calculated for demographic and baseline data. The overall percentage difference between pre-test and post-test scores was determined for both the FC and ST groups. Mean ± standard deviation (SD) of percentages for each group was compared. Student's t-test was applied for mean comparison. Fisher's exact test and one-way ANOVA test were applied to assess the significance of differences between the two teaching methods, with a $p\text{-value} \leq 0.05$ considered statistically significant. The internal consistency of the tool was assessed using Cronbach's alpha. All statistical analyses were performed using STATA version 17.

Following a significant one-way ANOVA, Tukey's HSD test was used for multiple pairwise comparisons to identify significant differences between group means. This method controls the family-wise error rate while maintaining statistical power. The test determines whether mean differences between groups exceed a critical threshold based on the studentized range distribution. Groups with mean differences surpassing this threshold were considered statistically significant. Assumptions of normality and homogeneity of variances were assessed before analysis through the Shapiro-Wilk test.

Results

Baseline characteristics

A total of 30 participants completed the study, with 15 (50%) in the FC and 15 (50%) in the ST groups. Baseline characteristics of study participants are listed in Table 1. Among the participants, 20 (66.7%) were staff physicians, 6 (20.0%) were junior residents (PGY 1–2), and 4 (13.3%) were senior residents (PGY 3–5), with a similar distribution between study groups. Overall, 17 (56.7%) participants reported basic POCUS experience. Eighteen

Table 1 Baseline characteristics of study participants

Characteristics	Overall (*n* = 30)		FC (*n* = 15)		ST (*n* = 15)		% Diff ST-FC
	n	%	*n*	%	*n*	%	
Level of training							
Staff Physician	20	66.7%	10	66.7%	10	66.7%	0.0%
Junior resident (PGY 1–2)	6	20.0%	3	20.0%	3	20.0%	0.0%
Senior resident (PGY 3–5)	4	13.3%	2	13.3%	2	13.3%	0.0%
Experience level with POCUS							
None	1	3.3%	0	0.0%	1	6.7%	6.7%
Basic	17	56.7%	10	66.7%	7	46.7%	-20.0%
Advanced	11	36.7%	5	33.3%	6	40.0%	6.6%
Expert	1	3.3%	0	0.0%	1	6.6%	6.6%
CPOCUS independent practitioner							
Yes	18	60.0%	8	53.3%	10	66.7%	13.4%
No	12	40.0%	7	46.6%	5	33.3%	13.3%
How confident are you currently at identifying signs of pulmonary embolism with ultrasound?							
Not at all confident	12	40.0%	7	46.6%	5	33.3%	-13.3%
Slightly confident	12	40.0%	6	40.0%	6	40.0%	0.0%
Somewhat confident	6	20.0%	2	13.3%	4	26.7%	13.3%
Moderately confident	0	0.0%	0	0.0%	0	0.0%	0.0%
Very confident	0	0.0%	0	0.0%	0	0.0%	0.0%
What do you think are the most important barriers for you in using ultrasound for evaluating pulmonary embolism while on shift							
Lack of training	15	50.0%	7	46.7%	8	53.3%	6.7%
Time constraints	10	33.3%	5	33.3%	5	33.3%	0.0%
Lack of evidence supporting its utility	5	16.7%	3	20.0%	2	13.3%	-6.7%

FC = flipped classroom, ST = standard teaching, PGY = postgraduate year

Table 2 Baseline assessment of knowledge and image interpretation with 95% CI

Measure	ST (*n* = 15)	FC (*n* = 15)	*p*-value
Overall (Mean % ± SD)	64.3 ± 24.9 [CI: 51.70–76.90]	65.0 ± 24.7 [CI: 52.50–77.50]	0.93
Knowledge (Mean % ± SD)	64.8 ± 10.9 [CI: 59.28–70.32]	65.0 ± 10.2 [CI: 59.84–70.16]	0.87
Image (Mean % ± SD)	79.0 ± 20.8 [CI: 63.59–94.41]	79.0 ± 14.2 [CI: 68.48–89.52]	0.63

Table 3 Post-intervention assessment of knowledge and image interpretation

Measure	ST (*n* = 15)	FC (*n* = 15)	*p*-value
Overall Score (Mean% ± SD)	75.3 ± 20.1 [CI: 62.29–82.36]	72.3 ± 21.4 [CI: 65.94–84.72]	0.65
Knowledge (Mean % ± SD)	63.6 ± 20.2 [CI: 50.89–76.28]	70.3 ± 21.0 [CI: 57.55–82.95]	0.32
Image (Mean % ± SD)	88.6 ± 10.0 [CI: 79.34–97.79]	84.8 ± 15.2 [CI: 70.65–98.87]	0.60

(60.0%) participants were certified as an Independent Practitioner (IP) by the Canadian Point of Care Ultrasound Society (CPOCUS). At baseline, a majority of the participants (24, 80%) reported a low level of confidence in identifying signs of PE with ultrasound. The most frequently identified barrier to the use of POCUS for PE was a lack of training (50.0%), followed by time limitations (33.3%).

Baseline assessment of knowledge and image interpretation did not show significant differences between the ST and FC groups (Table 2). The mean knowledge score for the ST group was 64.8% ± 10.9%, while the FC group had a mean score of 65.0% ± 10.2% ($p = 0.87$). Similarly, the baseline image interpretation scores for both groups were comparable, with the ST group scoring 79.0% ± 20.8% and the FC group scoring 79.0% ± 14.2% ($p = 0.63$).

Following the intervention, both groups demonstrated significant improvement in overall mean scores from baseline. The ST group showed an 11.0% increase (95% CI: 6.0%–17.0%; $p = 0.02$), while the FC group demonstrated a 7.3% increase (95% CI: 2.35%–10.98%; $p = 0.03$). When comparing overall performance, the post-intervention assessment revealed no statistically significant difference between the ST and FC groups (75.3% ± 20.1% vs. 72.3% ± 21.4%; $p = 0.65$). In terms of knowledge assessment, both groups achieved similar mean scores (63.6% ± 20.2% vs. 70.3% ± 21.0%), with no statistically significant difference ($p = 0.32$). Similarly, post-intervention image interpretation scores remained comparable between groups (88.6% ± 10.0% vs. 84.8% ± 15.2%; $p = 0.60$) (Table 3).

The post-intervention assessment of POCUS themes demonstrated varying improvements between the FC and ST groups. Both groups showed improvement in the recognition of a hyperdynamic left ventricle (13.3% vs. 13.3%). The identification of acute right ventricular strain

Table 4 Comparison of knowledge and image interpretation results across POCUS themes between FC & ST models ($n=30$)

Characteristics	FC Pre-test ($n=15$)		FC Post-test ($n=15$)		% Diff Post-Pre-test (FC) with 95% CI
	n %	95% CI	*n* %	95% CI	
Hyperdynamic LV	10 (66.6%)	42.8%- 90.5%	12 (80.0%)	59.8%-100.0%	13.3% (-30.0%-51.2%)
Acute RV Strain	10 (66.6%)	42.8%- 90.5%	12 (80.0%)	59.8%-100.0%	13.3% (7.50%-30.0%)
IVC dilation	14 (93.3%)	80.7%-100.0%	14 (93.3%)	80.7%-100.0%	0.0% (0.0%-28.6%)
Chronic RV Strain	06 (40.0%)	15.2%-64.8%	08 (53.3%)	28.1%-78.6%	13.3% (-30.0%-51.2%)

Characteristics	ST Pre-test ($n=15$)		ST Post-test ($n=15$)		% Diff Post-Pre-test (ST) with 95% CI	% diff between percentages difference of pre-post-test ST-FC with 95% CI
	n %	95% CI	*n* %	95% CI		
Hyperdynamic LV	10 (66.7%)	42.8%-90.5%	12 (80.0%)	59.8%-100.0%	13.3% (-30.0%-51.2%)	0.0%
Acute RV Strain	10 (66.7%)	42.8%-90.5%	11 (73.3%)	51.0%-95.7%	6.6% (0.0%-12.5%)	-6.7% (-24.59%-11.19%)
IVC dilation	12 (80.0%)	59.8%-100.0%	14 (93.3%)	80.7%-100.0%	13.3% (0.0%-34.1%)	13.3% (-4.59%-31.19%)
Chronic RV Strain	06 (40.0%)	15.2%-64.8%	08 (53.3%)	28.1%-78.6%	13.3% (-30.0%-51.2%)	0.0%

showed greater improvement in the FC group compared to the ST group (13.3% vs. 6.6%). Conversely, the detection of inferior vena cava (IVC) dilation improved significantly in the ST group (13.3%) compared to no change in the FC group (0%). Both groups showed equal improvement in recognizing chronic RV strain (13.3% vs. 13.3%) (Table 4).

Discussion

The study highlights the effectiveness of FC and ST methods in improving knowledge and image interpretation skills related to the use of POCUS for diagnosing high-risk pulmonary embolism. While the FC model was hypothesized to be superior based on its learner-centered design, the observed improvements were comparable across both groups, without statistically significant differences. These findings suggest that while both approaches are effective, the choice of teaching model should be based on practical considerations, such as learner preferences, time constraints, and resource availability.

The flipped classroom teaching model has gained popularity in medical education as an innovative method that provides active, learner-centered teaching. Unlike traditional didactic teaching methodology, the FC model delivers the theoretical content through pre-class preparation, allowing in-person sessions to focus more on interactive discussions, case-based learning, and hands-on practice [11]. By shifting content delivery to pre-class learning, FC allows participants to engage with the material at their own pace, reducing cognitive overload during hands-on sessions. Several studies have demonstrated positive outcomes of the FC model in various educational settings, including POCUS, resulting in increased engagement, retention, and application of knowledge [8, 9].

In our study, a significant portion of participants (56.67%) reported basic POCUS experience, and about 60.0% were certified as independent practitioners by the Canadian Point of Care Ultrasound Society (CPOCUS). Despite these credentials, most participants (80.0%) expressed low confidence in identifying signs of high-risk PE with POCUS. This reveals a gap between theoretical certification and practical application, aligning with previous studies that emphasize the need for regular, hands-on POCUS training to build confidence and competence in clinical practice [12, 13]. Lack of training and time limitations were identified as the primary barriers to POCUS use in clinical settings, consistent with challenges reported in earlier emergency medicine research [14, 15]. These results underscore the importance of targeted strategies to overcome these barriers.

Although the baseline scores between the FC and ST groups were similar, the post-intervention assessment showed improvements in both knowledge and image interpretation skills across both groups, with no significant difference between them. This finding suggests that both teaching methods are effective in developing image-based skills. While traditional instructor-led teaching is often considered beneficial for immediate feedback and guided supervision, the comparable performance of the FC group highlights that structured pre-class learning, combined with hands-on practice, can effectively support both conceptual understanding and skill acquisition. This reinforces the idea that the FC model can serve as a viable alternative to traditional teaching methods without compromising learning outcomes.

The subgroup analysis of different POCUS themes further highlights the effects of both teaching strategies. The FC group showed greater improvement in identifying acute right ventricular strain, a dynamic finding that requires the integration of multiple cardiac ultrasound features. This improvement may reflect the advantage of self-paced pre-class learning, which allows learners to repeatedly review complex material before hands-on practice [16, 17]. On the other hand, the ST group demonstrated significantly better performance in detecting IVC dilation, a more straightforward anatomical finding. This finding supports the view that traditional didactic methods can still be highly effective for delivering structured knowledge, particularly for learners who benefit from direct instruction. Despite these differences, both the FC and ST groups showed significant improvement in the recognition of hyperdynamic left ventricle and chronic right ventricular strain, with no statistically significant difference between the two methods. These finding highlights that both teaching approaches can be effective in improving POCUS skills when delivered within a structured curriculum. The lack of a significant difference in overall performance may indicate that the choice of educational model should be guided by the specific learning objectives and skill complexity rather than a one-size-fits-all approach [18].

The study has several limitations. It was conducted at a single institution; therefore, the findings might not capture differences in educational practices, learner profiles, or resource availability across other settings. The knowledge assessment focused on one-month post-intervention outcomes, leaving long-term knowledge retention and the practical application of POCUS in real-world scenarios unexamined. We did not assess differences in image acquisition skills; only knowledge and image interpretation were evaluated. This omission limits the comprehensiveness of our findings, as improved interpretation skills may not directly translate into bedside scanning proficiency. Future studies are needed that incorporate real-world scan acquisition to determine the impact of training on this skill. The exclusion of qualitative feedback further limits insight into participants' experiences and perceptions regarding the teaching methods. Additionally, the study did not reach the target sample size of 32 participants due to recruitment challenges, which may have slightly reduced the statistical power to detect smaller differences between groups. Further studies with larger, more diverse samples, multi-institutional involvement, and a focus on evaluating practical skills and their long-term impact are needed to overcome these limitations.

Conclusion

This study suggests that both flipped classroom and standard teaching methods are effective educational strategies for POCUS education, particularly in enhancing advanced interpretative skills essential for diagnosing high-risk PE. The study found no statistically significant difference in overall performance, suggesting that both approaches can be successfully implemented in POCUS education. However, the FC model offers distinct potential advantages in terms of flexibility, learner autonomy, and time efficiency, making it a practical alternative to traditional lecture-based teaching. A hybrid educational approach that combines pre-class self-directed learning with in-class supervised hands-on training may provide the most comprehensive framework for POCUS education. Future research should investigate the long-term retention of skills and explore the applicability of FC-based learning across different POCUS applications.

Abbreviations

PE	Pulmonary embolism
POCUS	Point of care Ultrasound
FC	Flipped classroom
ST	Standard teaching
CPOCUS	Canadian Point of Care Ultrasound Society

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

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JC- Conceptualization & Supervision. NA & AT- Data Curation, Writing, Reviewing, and Editing. SS- Methodology, Data Analysis and Writing, Reviewing and Editing. DS & RS- Writing, Reviewing, and Editing. All authors reviewed and approved the final manuscript.

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Data availability
Data will be available on a reasonable request to the corresponding author.

Declarations

Ethical approval and consent to participate
The study was approved by the Institutional Review Board of Sunnybrook Health Sciences Centre (Project ID: 6043). Informed written consent was obtained from all the participants.

Competing interests
The authors declare no competing interests.

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