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Machine Learning Models for Point-of-care Ultrasound Education and Training: National Cost Savings and Expert Time Reduction

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Abstract

Point-of-care ultrasound (POCUS) serves as a valuable diagnostic tool for healthcare providers. It enhances diagnostic accuracy and patient outcomes while reducing Emergency department (ED) length-of-stay and expenses. Nonetheless, barriers such as access to instructors and the costs of training novices impede widespread POCUS implementation. One alternative is artificial intelligence (AI) guided image acquisition tools. This study explores the potential national cost savings of employing AI acquisition software to teach POCUS to residents. A Monte Carlo simulation estimated the hours and costs of attending physician time needed for traditional versus AI-guided ultrasound education. The findings suggest that incorporating AI-guidance in ED resident ultrasound education could save $5.3 million annually in costs nation-wide. This cost-effective method holds the potential to maintain or even enhance quality of education while alleviating financial constraints. Investing in AI technology for medical education has the potential for improved patient care and streamlined workflows in healthcare environments.

Keywords: point-of-care ultrasound (POCUS), artificial intelligence (AI), machine learning, ultrasound education, cost savings, medical imaging

1. Introduction

Point-of-care ultrasound (POCUS) has emerged as a powerful imaging tool for diagnosing various acute conditions, enhancing speed, accuracy, and patient outcomes (Hashim et al., 2021). Using POCUS over alternative advanced imaging modalities has been proven to reduce Emergency Department (ED) length-of-stay, save costs, and improve patient outcomes (Brower et al., 2022; Zieleśkiewicz et al., 2021).

Traditionally, trainees have learned ultrasound through didactic sessions and hands-on practice under expert guidance. However, significant barriers associated with POCUS training scalability such as limited access to expert instructors have hindered POCUS implementation in clinical care (Wong et al., 2020; Russell et al., 2021; Smith et al., 2021). To achieve competency, trainees need extensive didactic instruction from ultrasound-trained physicians and must complete a series of supervised scans to demonstrate proficiency (ACEP, 2016). This process incurs considerable costs associated with paying attending physicians and procuring ultrasound equipment and supplies (ACEP Now, 2020).

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Various initiatives have attempted to address these challenges surrounding ultrasound education accessibility. Research has shown that automated artificial intelligence (AI)-guidance software enables ultrasound novices to acquire images comparable in quality to those obtained by experts. For instance, Schneider et al. investigate the performance of a machine learning algorithm in supporting ultrasound-naïve novices in acquiring diagnostic echocardiography loops. Their study shows that the algorithm helps novices obtain accurate diagnostic images and provides reliable estimation of left ventricular ejection fraction (Schneider et al., 2021).

Narang et al. further underscores the potential of AI-guided systems in helping novices obtain high-quality images (Narang et al., 2021), while Chiu et al. demonstrate that the implementation of AI effectively facilitated novice acquisition of high-quality diagnostic images in Morrison's pouch. AI guidance resulted in significantly improved diagnostic quality scores and higher rates of acceptable clips (Chiu et al., 2023).

Implementing this software in clinical teaching settings has the potential to decrease training time and costs for novice learners, while also improving access to ultrasound nationwide. Our study focuses on quantifying the national cost savings associated with using AI guidance to train learners in acquiring cardiac POCUS images. By incorporating AI technology into the training process, we aim to demonstrate the significant benefits and financial implications of this approach.

2. Methods

To estimate potential national cost savings from adopting machine learning (ML)-based tools for automated image acquisition teaching, we conducted a Monte Carlo simulation comprising 1,000 trials using the Oracle Crystal Ball application (Oracle Corporation, 2023). Presently, Emergency medicine residents require a number of scans to attain competence in each POCUS modality, and these scans require a significant amount of faculty time and supervision (Figure 1).

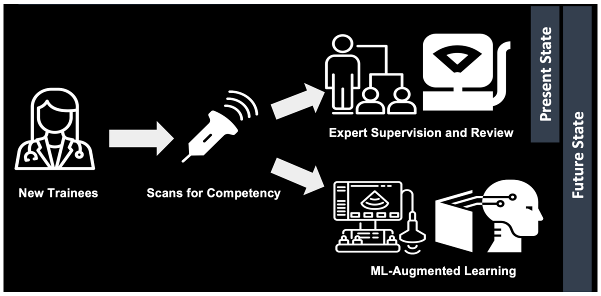

Figure 1. Current and future state of resident POCUS education.

Thus, the study population consisted of incoming Emergency Medicine trainees matching into accredited residency programs. It is assumed that these trainees have minimal prior training in POCUS and thus will require targeted training to achieve competency as is outlined in the American College of Emergency Physician (ACEP) training guidelines (ACEP, 2016). In our simulation, we estimated that the number of new EM residents per year is approximately 2,581 with a standard deviation of 221 based on the ACEP Joint Statement on the Results of the 2022 Residency Match (ACEP, 2022).

In our simulation, we made certain assumptions regarding the training requirements for incoming residents in ultrasound, as well as the costs associated with faculty time and AI technology. Specifically, per ACEP 2016 Ultrasound Guidelines, residents need to perform 25-50 scans to achieve competency in ultrasound, and we assumed approximately 30-50% of these scans would be directly supervised by ultrasound EM faculty (ACEP, 2016).

To calculate the cost of faculty time, we estimated that each supervised scan would require 15 minutes of faculty input, while each retrospective scan review would require 5 minutes. We further utilized an hourly salary of $287 for faculty, including fringe benefits, which was quoted by ACEP Now in their 2019-2020 Emergency Physician Compensation Report (ACEP Now, 2020).

In addition to faculty costs, we considered the expenses associated with AI technology. On February 7th, 2020, the Food and Drug Administration (FDA) authorized Caption Health's AI-guided ultrasound acquisition software for clinical echocardiography. This software is used with handheld POCUS probes connected to an iOS capable device. This tool assists users in obtaining diagnostic-quality POCUS echocardiogram images by providing real-time feedback on ultrasound probe placement and positioning (Caption Health, 2020). The annual cost of this AI software was estimated to be \$3,650 (Caption Health, 2022).

We also factored in the number of probes per program, assuming an average of 4 handheld probes (ranging between 3-5) would be required. There is a fixed cost of \$2,399 per AI-compatible probe. We assumed each probe would have a lifespan of 7.5 years (with a range of 5-10 years), and the cost was distributed evenly over the lifetime of the probe (Butterfly Network, personal communication, 2022). Furthermore, the annual subscription cost of an AI-compatible probe subscription was assumed to be \$420 (Butterfly Network, personal communication, 2022).

Additionally, our model assumed that trainees would require 30 minutes of image acquisition training with ML-based POCUS from faculty. This estimation was based on data adopted from the first FDA-approved ML-based POCUS tool, Caption Health (Caption Health, 2020)

These assumptions were incorporated into our simulation model to estimate the potential cost savings and financial implications of adopting AI technology for ultrasound training (Table 1, Table 3). It is important to note that the actual costs and specific circumstances may vary across institutions and programs.

Model outputs (Table 2) included the annual expert scanning/review hours for cardiac POCUS resident training, annual expert scanning/review cost for cardiac POCUS resident training, annual expert scanning/review hours for cardiac POCUS averted with AI, and annual expert scanning/review cost for cardiac POCUS resident training averted with AI (Table 2).

By running the Monte Carlo simulation, we were able to assess the potential impact of ML-based tools on faculty time and associated costs, providing insights into the potential cost savings that could be achieved through the adoption of AI-guided ultrasound acquisition.

Table 1. Model Inputs.

A	Annual Number of New EM Trainees
B	Number of Supervised Scans to Achieve Competency
C	Number of Unsupervised Scans to Achieve Competency
E	Expert Time per Supervised Scan (Hours)
F	Expert Review Time per Unsupervised Scan (Hours)
G	Estimated Expert Hourly Cost (Average EM Hourly Salary + 30% Fringe Benefit Rate)
H	Expert Time for Scanning with AI Software per Trainee (Hours)
I	Number of ACGME EM Residency Programs
J	Annual Cost of AI Software (Caption Health)
K	Number of AI-Compatible Probes per Program
L	Annual Cost of AI-Compatible Probe Subscription per Probe (Butterfly)
M	Fixed Cost of AI-Compatible Probes (Butterfly)
N	Lifespan of AI-Compatible Probes (Butterfly, Years)

Table 2. Model Outputs.

O1	Annual Expert Scanning/Review Hours for Cardiac POCUS Resident Training	$A * [(B * E) + (C * F)]$
O2	Annual Cost of Expert Scanning/Review Time for Cardiac POCUS Resident Training	$A * [(B * E) + (C * F)] * G$
O3	Annual Expert Scanning/Review Hours for Cardiac POCUS Averted with Caption Health AI	$A * [(B * E) + (C * F) – H]$
O4	Annual Cost of Expert Scanning/Review Time for Cardiac POCUS Averted with Caption Health AI	$\{A * [(B * E) + (C * F) – H] * G\} – \{I * [J + K * (L + M / N)]\}$

3. Results

Our Monte Carlo simulation model revealed that the training of emergency medicine residents in cardiac point-of-care ultrasound requires approximately 19,300 hours (±2,100 hours) of attending physician time annually to adequately educate new trainees in cardiac POCUS. In monetary terms, this significant investment in faculty time corresponds to an estimated cost of $5.6 million (±$590K).

The implementation of AI-guided POCUS tools for the cardiac modality has the potential to lead to approximately 18,000 (±2,000) hours reduction of faculty time, equivalent to a cost reduction of around $3.4 million (±569K). If 30% of these estimated savings were realized, this would still result in cost savings amounting to around $1.1 million (±170K) and 5,400 hours (±600) of ultrasound faculty time saved. These findings demonstrate the potential of AI-based tools to address the financial and logistical challenges associated with POCUS education.

4. Discussion

Numerous studies have provided evidence supporting the beneficial impact of ED-based POCUS, which can lead to improved diagnostic accuracy and patient outcomes (Zieleśkiewicz et al., 2021; Hashim et al., 2021). However, widespread POCUS implementation faces barriers such as limited access to expert ultrasound instructors for efficient training and education (Wong et al., 2020; Russell et al., 2021; Smith et al., 2021). Teaching POCUS to novices is labor-intensive and financially costly, thus, given the recent expansion of POCUS worldwide, scalable approaches to POCUS education must be identified (Russell et al., 2021; Brower et al., 2022; Zieleśkiewicz et al., 2021).

Recently developed AI-guided software supporting POCUS image acquisition provides real-time feedback and assists users in obtaining diagnostic-quality images regardless of prior skill level. Use of these tools results in improved diagnostic quality scores and higher rates of acceptable-quality clips acquired by novice users (Schneider et al., 2021; Narang et al., 2021; Chiu et al., 2023). We show that utilization of AI-guided POCUS tools can save up to approximately 18,000 (±2,000) faculty hours, translating to a substantial annual cost reduction for a single POCUS indication. We predict these savings can extend across multiple POCUS indications beyond cardiac POCUS (e.g. to lung, soft tissue, vascular POCUS, etc), thereby amplifying the overall financial benefits if widely adopted.

While AI-based image acquisition tools can guide novice users to obtain expert-quality images, for AI-based tools to be successfully incorporated into medical education, ensuring comparable levels of competency are achieved with AI-based approaches compared to training via traditional approaches is needed. Current standard practice for assessing POCUS competency is often based on subjective measures such as expert observations of learner performance or correlation between expert and learner scanning technique. Such assessment approaches will need to be validated for AI-trained learners to be able to truly compare competency achieved from AI-based training vs traditional approaches. Alternatively, developing and applying objective competency metrics may be helpful in evaluating the full effect of AI-driven software in medical education.

In addition to imparting savings associated with lower training costs, it is possible that incorporating AI-based tools into POCUS education may offer additional benefits such as improved ED workflow efficiency. By automating time-intensive, introductory-level tasks, AI-based training could allow faculty physicians to prioritize higher-level educational tasks such as complex POCUS image interpretation or other patient care. Improved workflows secondary to AI-based tools have been demonstrated in Radiology departments, where these tools can efficiently prioritize worklists to triage time-sensitive studies (Winkel et al., 2019). Similar to the potential impact of AI-based tools in the field of EM-based POCUS, the potential for AI-assisted education to revolutionize residency training and practice for radiologists has also been highlighted (Tajmir et al., 2018). Specifically, AI-based educational tools have a role in facilitating the integration of learning into the daily routines of radiologists (Tajmir et al., 2018). This may also be true for POCUS education in EM. The potential streamlined workflows and optimized educational resource allocation may improve medical training, healthcare delivery and outcomes.

While there is evidence that images obtained via AI guidance are non-inferior, further studies are needed to examine whether AI-educated residents possess similar knowledge, skills, and confidence as those who received traditional education. Further studies are required to assess the proficiency and efficacy of AI-guided ultrasound education compared to conventional methods.

8. Limitations

The primary focus of our study was to estimate the potential cost savings associated with AI technology in training resident physicians in cardiac POCUS image acquisition. Consequently, a comprehensive evaluation of other skills associated with POCUS mastery including image interpretation, clinical application, and confidence levels of residents who received ultrasound training through AI-based tools was beyond the scope of our research. While there are studies showing that AI-guided image acquisition is non-inferior, it is not clear whether better images correlates to more effective learning for residents. Such research studies would provide a more complete understanding of the impact and efficacy of AI-assisted ultrasound education on the overall professional development and proficiency of residents. Further investigation is needed to conduct a thorough assessment of the educational outcomes and benefits derived from the incorporation of these advanced technological tools into POCUS training programs.

Our findings support a role for AI-based technology in aiding POCUS image acquisition for clinical staff who are novice users. It is possible that some trainees may have pre-existing POCUS experience and would therefore require less training at the residency level. However, we anticipate our findings would conceptually extend to POCUS training at any level and across medical specialities beyond emergency medicine

The assumptions associated with the cost of AI technology used in this study are derived from a single manufacturer device. This device was selected for this work as it was the first FDA-approved AI-driven technology for acute care POCUS indications. While variable costs associated with alternative manufactures may alter the scope of our findings, we predict the trend of identifying potential national cost savings by incorporating novel AI-driven technologies into POCUS education will still be valid. Further analyses with additional tools and products as well as with additional POCUS exam types are needed to corroborate these findings.

Procedural guidance has become a critical use for POCUS in an array of healthcare settings. While this work focused on POCUS image acquisition, it is unclear how our findings may apply to incorporating AI-drive technologies into education for POCUS-guided procedural training. In addition to image acquisition guidance, additional skills such as needle guidance or anatomy identification are critical for procedural competency. As additional AI-driven tools become available that can assist with POCUS-guided procedural tasks, additional studies regarding the potential impact and cost savings of such tools in procedural education will be needed.

9. Conclusion

Our work demonstrates the significant potential financial impact of incorporating AI-guided POCUS in medical education. AI technology can be a cost-effective and efficient alternative to traditional attending physician-led ultrasound education for residents. Future studies should explore alternative workflows for AI-guided POCUS training in various healthcare settings. Continued research and investment in AI-based technology for medical education may unlock its full potential, leading to improved training and patient care. As the field of AI continues to evolve, it holds promise for transforming medical education and enhancing patient care.

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Table 3. Model Inputs.

	Input Assumption	Estimate	SD or Range	Lower Bound	Upper Bound	Distribution Type	Notes	Reference
A	**Annual Number of New EM Trainees**	2,581	221	NA	NA	Normal		ACEP, 2022.
B	**Number of Supervised Scans to Achieve Competency**	20	15-25	15	25	BetaPERT	ACEP Policy requires 25-50 scans for competency	ACEP, 2016.
C	**Number of Unsupervised Scans to Achieve Competency**	30	25-35	25	35	BetaPERT	ACEP Policy requires 25-50 scans for competency	ACEP, 2016.
E	**Expert Time per Supervised Scan (Hours)**	0.25	NA	NA	NA	NA	Assumes each supervised scan requires ~15 minutes of expert time	
F	**Expert Review Time per Unsupervised Scan (Hours)**	0.08	NA	NA	NA	NA	Assumes each unsupervised scan requires ~5 minutes of expert time for retrospective review	
G	**Estimated Expert Hourly Cost (Average EM Hourly Salary + 30% Fringe Benefit Rate)**	$287.30	NA	NA	NA	NA	Assumes national hourly salary of $221 (based on a 2019-2020 ACEP report, most recent available) plus a fringe benefit rate of 30% (based on data from the Bureau of Labor Statistics)	ACEP Now, 2020.
H	**Expert Time for Scanning with AI Software per Trainee (Hours)**	0.5	NA	NA	NA	NA	Assumes each trainee requires ~30 minutes of expert time for hands-on training and orientation with AI scanning	Schneider et al., 2021.
I	**Number of ACGME EM Residency Programs**	273	NA	NA	NA	NA		EMRA Match, 2022.
J	**Annual Cost of AI Software (Caption Health)**	$1,200	NA	NA	NA	NA	Assumes various annual costs for Caption Health AI software per program as follows: Educational Program ($2,500 per year)	Caption Health, personal communication, 2022.
K	**Number of AI-Compatible Probes per Program**	4	3-5	3	5	BetaPERT	Assumes each residency program requires a total of 3-5 probes for training residents	
L	**Annual Cost of AI-Compatible Probe Subscription per Probe (Butterfly)**	$420	NA	NA	NA	NA	Assumes annual cost of $420.00 per probe for Butterfly IQ software at a program-level	Butterfly, personal communication, 2022.
M	**Fixed Cost of AI-Compatible Probes (Butterfly)**	$2,399	NA	NA	NA	NA	Assumes each probe costs $2,399.00 with the cost of the probe spread evenly over its average lifespan (see variable M below)	Butterfly, personal communication, 2022.
N	**Lifespan of AI-Compatible Probes (Butterfly, Years)**	7.5	5-10	5	10	BetaPERT	Assumes probes need to be replaced every 5-10 years with the fixed cost of the probe spread evenly over this time period	