

Teaching Jugular Venous Pressure (JVP) Ultrasound: Methods That Improved Medical Students' Knowledge and Confidence in Performing JVP Assessment

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Purpose: Jugular venous pressure ultrasound (JVP US) augments the physical examination by allowing direct visualization of the jugular vein. While JVP US offers diagnostic advantages, there is limited literature describing methods for teaching JVP US to medical students. We describe methods by which medical students were trained to use JVP US as part of volume status assessment. We aimed to increase student knowledge as well as demonstrate students' ability to apply bedside JVP US skills through this workshop.

Patients and Methods: Ninety-one medical students completing a sub-internship in internal medicine participated in this study. All students received a brief didactic workshop on dyspnea, an overview of JVP US, and then a hands-on bedside practice session with JVP US on two volunteer patients. Students participated in the study by completing a pre-survey and post-survey which aimed to assess both knowledge and confidence.

Results: After completing the JVP US training program, students demonstrated increased knowledge in multiple assessed survey questions. Additionally, they were more confident in their ability to distinguish the jugular vein from the carotid artery using color and pulse wave doppler (Pre- 2.67 to Post- 4.62; $p < 0.001$). Finally, students believed that JVP US added confidence to their estimation of JVP when added to the physical examination (Pre- 3.88 to Post- 4.64; $p < 0.001$).

Conclusion: In this single-arm, non-randomized study, after a didactic workshop and structured bedside JVP US practice session, student surveys showed an increase in knowledge and self-reported confidence in the usage of JVP US as a complement to the physical examination for patients with dyspnea.

Keywords: ultrasound, jugular venous pressure, medical education, bedside teaching, dyspnea, volunteer patients

Introduction

Dyspnea is one of the most frequent reasons patients present to the hospital for evaluation.¹ Identification of the underlying cause of dyspnea is crucial because management depends on the underlying etiology. This requires incorporation of multiple pieces of data, including a comprehensive assessment of patient presentation, physical examination, laboratory, and imaging findings.

When evaluating patients with shortness of breath, an elevated jugular venous pressure (JVP) can suggest a cardiovascular etiology for their dyspnea.² Bedside identification of an elevated JVP correlates with invasive hemodynamics² and has prognostic implications.³⁻⁵ However, bedside physical examination of the jugular vein can be difficult due to factors such as a patient's specific neck anatomy,⁶ inter-observer variability,^{6,7} and misidentification with the nearby carotid artery.⁸ Recent work has shown that point-of-care ultrasound (POCUS) improves the evaluation of patients with dyspnea.^{9,10} Jugular venous pressure ultrasound (JVP US) augments the physical examination by allowing

direct visualization of the jugular vein and thus providing a more accurate estimate of the central venous pressure than physical examination alone.^{11–15}

While the diagnostic advantages of JVP US are well documented, there is limited literature describing methods for teaching JVP US to medical students. Pettit et al¹⁶ described using a brief training in JVP US to a mixed population of sixteen medical students and residents to improve JVP measurement in obese patients. Beyond this, data on implementation of JVP US teaching for medical students is limited. Our group previously reported the results of a study evaluating whether medical students learned POCUS skills for the evaluation of hypotension and shock differently through the usage of a manikin simulator or on real patients.¹⁷ However, the best methods for the implementation of JVP US teaching are not currently known. A recent position paper evaluating POCUS curricula from the American College of Physicians described growing recognition that POCUS broadly is an important skillset that should be widely adopted at a national level, including methods in JVP US.¹⁸ This work details a framework for instructional methods that are effective for teaching POCUS skills, and their findings can inform the design of POCUS curricula.¹⁸

We report the results of a prospective study that extends Pettit et al's¹⁶ observations and offers detailed methods that can be used to implement JVP US teaching. In our study, sub-internship medical students were trained to use JVP US as part of volume status assessment using a structured skills session in a simulation laboratory followed by hands-on practice at the bedside. We hypothesized that JVP US teaching would increase medical students' confidence and knowledge in their bedside assessment of the JVP, as well as complement their physical examination assessment of volume status. Using Miller's pyramid as an educational framework,¹⁹ we aimed to increase knowledge (Level 1: Knows) as well as demonstrate students' ability to apply bedside JVP US skills through this workshop (Level 2: Knows How).

Methods

Institutional Review Board Approval

Institutional review board approval for this study was obtained from the Mass General Brigham Institutional Review Board as an amendment to a previously approved protocol (Protocol #2021P001881, AME 2) and the Harvard Medical School Program in Medical Education's Executive Committee in 2022. Our study complies with the Declaration of Helsinki. Verbal consent was all that was required of the Volunteer Patients by our Ethical Review Board because protected patient information, including patient names or medical record numbers, was not recorded at any time. Both the Mass General Brigham Institutional Review Board and Harvard Medical School Program in Medical Education's Executive Committee agreed that volunteering for a jugular venous pressure ultrasound was a low-risk volunteer examination and that verbal consent was deemed sufficient for patient participation. To date, no patient adverse reactions or complaints have been received from any patients who volunteered with verbal consent. The IRB approval process and study design was modeled after our prior study¹⁷ conducted and published by our group, which received similar IRB approval from both Mass General Brigham Institutional Review Board and Harvard Medical School's Program in Medical Education.

Student Participants

Following successful completion of core clerkships, all Harvard Medical Students (HMS) students are required to complete the internal medicine sub-internship, a four-week intensive clinical rotation at one of five hospital affiliate sites in Boston. The JVP US training program was implemented and evaluated in the medicine sub-internship at Brigham and Women's Hospital (BWH), a large urban academic medical center. Approximately 50 HMS students complete their medicine sub-internship at BWH each year. Prior to our study's implementation, there was no formal instruction in JVP US in the medicine clerkship or the sub-internship at BWH. All Harvard Medical Students participated in an educational workshop and individual ultrasound practice sessions as required components of their clinical clerkship. Prior to the workshop, students received an information sheet ([Supplementary Material 1](#)) informing them of their voluntary participation in this study through completion of optional surveys. This included information informing the students the purpose of the study, the voluntary nature of the study, and the consent process. Students also received information about this study in person prior to the start of the educational workshop in the presence of an attending physician (HMS)

who was available to answer any questions about the study. Completion of the approved anonymous study surveys was voluntary. Because the internal medicine sub-internship is a month-long required clerkship at HMS and does not sub-select for medical students by student performance or intended medical specialty, including those specialties that have high utilization of ultrasound in their clinical practice, the risk of selection bias in participants was deemed to be low.

Study Design

The study was conducted from January to August 2023 and January to August 2024. All Harvard Medical School students enrolled in the Internal Medicine Sub-Internship at Brigham and Women's Hospital during the study period participated in a two-part structured training: a JVP US didactic workshop/skills session and a bedside JVP US practice session. The JVP US didactic workshop consisted of a thirty-minute skills session on assessing JVP by physical examination and by JVP US. The bedside JVP US practice session was a one-hour practice session at the bedside of volunteer patients. Student participation was required as part of the sub-internship course. Students completed voluntary study surveys before the didactic workshop (Pre-Survey, [Supplementary Material 2](#)) and after the completion of both the workshop and bedside practice session (Post-Survey, [Supplementary Material 3](#)).

All faculty members and supervising residents had formal education in POCUS, including JVP US. This included attending formal education didactic lectures in POCUS and completing hands-on training and/or clinical usage of POCUS with patients.

Structured JVP Ultrasound Teaching Sessions for Each Sub-Intern

JVP Ultrasound Didactic Workshop Skills Session (30 Minutes)

All students participated in a didactic workshop that reviewed the pathophysiology of dyspnea, the physical examination of the JVP, and introduced the JVP US examination. During this thirty-minute workshop, students were placed in groups of 3–5 students.

To teach the physical examination of the JVP, students were asked to demonstrate an examination of the JVP on volunteer teaching faculty, supervising residents, or fellow volunteer students. After visual identification of the meniscus of the JVP, a ruler and index card were used to measure the height of this point above the sternal angle. An additional 5 centimeters was added to this measurement to estimate the JVP. A JVP of less than 8 cm H₂O was defined as normal.

After the physical examination, students were taught a four-step structured protocol to identify the jugular vein and then estimate the JVP using POCUS. This protocol was based upon previously established methods for performing JVP US.^{11,12,14,20} Ultrasound was performed using either the SonoSite X-Porte (FUJIFILM SonoSite Inc., Bothell, Washington) in 2023 or Philips Lumify Hand-held portable probe and attached tablet (Philips Ultrasound Machines, Andover, Massachusetts) in 2024. The ultrasound probe was placed at the base of the neck on the right side above the clavicle with the indicator marker oriented toward the patient's right shoulder. The internal jugular vein and carotid artery were first identified using visual features. Students were then taught to utilize four steps to confirm the anatomy, including 1) compressibility of the vein; 2) augmentation of venous filling using Valsalva maneuver or flat positioning; 3) using color doppler to visually contrast pulsatile arterial flow from continuous venous flow and aiding in directional assessment of flow; and 4) using pulse wave doppler to distinguish arterial from venous waveforms. Upon confirmation of the venous structure, using minimal applied pressure, the vein was scanned until a point of tapering was identified. This point was confirmed in the longitudinal view demonstrating the Steeple Sign.¹² The height of the JVP column was measured at this point aided by a ruler and index card as previously performed for the physical examination. This served as an estimation of the JVP from the sternal angle. From this measurement, 5 centimeters was added to account for the average distance between the sternal angle and right atrium. As previously noted, a JVP of less than 8 cm H₂O was defined as normal. Students received a color handout indicating these key steps and an overview of ultrasound images used to perform a JVP US examination ([Supplementary Material 4](#)).

Bedside JVP Ultrasound Practice Session

All students participated in a hands-on bedside session in which they were provided three opportunities to practice JVP US: first with the volunteer faculty member/teaching resident, and then with two volunteer inpatients. The majority of

medical students were precepted at the bedside individually by a single faculty member. In a minority of cases, medical students completed these sessions in groups of two students with one faculty member.

Patient Recruitment

Patients admitted to the Internal Medicine or Cardiology inpatient services at BWH were recruited by the study faculty (HXC, HMS) or teaching resident (BP, EER) following a floor nurse's recommendation that the patient would be a good model for the JVP US bedside practice session. Patients provided verbal consent to participate, and participation was voluntary ([Supplementary Material 5](#)).

Equipment Utilized

The equipment used at the bedside session included the following:

1. Philips Lumify handheld portable probe (Philips Ultrasound Machines, Andover, Massachusetts)
2. Rulers and index cards
3. Hospital bed with head of bed elevated to a 30–45 degree angle
4. Individual ultrasound gel packets, towels to cover the gown to protect the patient's gown from ultrasound gel
5. Clean chuks, gloves, alcohol wipes as well as sanitizing anti-bacterial wipes for the probe and tablet.

Faculty or Supervising Resident Practice of JVP Ultrasound (15 Minutes)

Prior to examining two volunteer patients at the bedside, all students received a supplemental packet of reference handouts on how to perform the JVP US examination on a patient.^{12,20} Each student then reviewed the steps of the physical examination of the jugular vein, as well as the steps for JVP US with the supervising faculty member or supervising resident. These were the same structured steps detailed in the previous JVP Ultrasound Didactic Skills Session and detailed in [Supplementary Material 4](#). Each student then performed the JVP US on the supervising faculty member and were given immediate feedback on technique before heading to the patients' bedsides.

Two Volunteer Patient JVP Ultrasound Examinations (30 Minutes)

Each volunteer patient was laid recumbent with their head elevated between 30 and 45 degrees. A physical examination of the jugular venous pulsation was first performed. An estimation of the JVP was made using a ruler and index card to measure the height of the venous column from the sternal angle. A handheld ultrasound probe was then used to identify the jugular vein and carotid artery in the transverse view ([Figure 1](#)). Identification of the vein was confirmed using visual

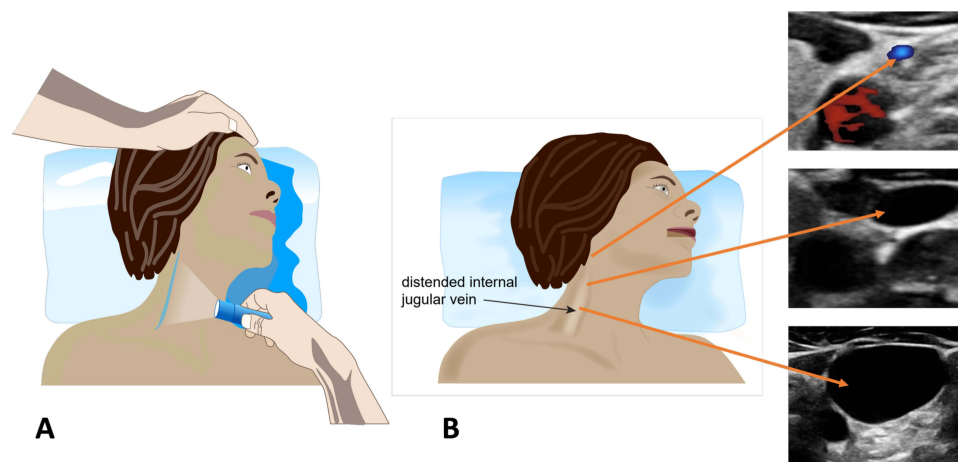


Figure 1 Method of Assessing Jugular Venous Pressure. With the patient's head of bed positioned between 30 to 45 degrees, the patient is instructed to look to their left exposing the sternocleidomastoid muscle. A flashlight is used to aid in visualizing the jugular venous pulsations (**A**). The height of the jugular venous column is marked, and this point is measured from the sternal angle. An additional 5 cm is added to this measurement to estimate the jugular venous pressure. This jugular venous pressure height is then confirmed using JVP US (**B**). The Orange arrows illustrate corresponding JVP US images at successively increasing heights along the jugular vein column.

features (thin walled, not muscular nor circular in contrast to the carotid artery), compressibility, augmentation with Valsalva, color flow doppler, and pulse wave doppler. Using minimal applied pressure, the vein was scanned until a point of tapering was identified. This point was confirmed in the longitudinal view demonstrating the Steeple Sign.¹² The height of the JVP column was measured at this point with a ruler and index card and served as an estimation of the JVP from the sternal angle. Five centimeters was added to this measurement to serve as the average distance between the sternal angle and right atrium. A JVP of less than 8 cm H₂O was defined as normal. Following the exam, all equipment was cleaned and new equipment was utilized for separate patients such as index cards.

Each student performed both of these physical examinations and JVP US examinations to estimate the JVP under the supervision of the teaching faculty member or resident. Individual feedback was provided to each student in real time and included hands-on suggestions for improving technique.

Study Survey Completion (5 Minutes)

The JVP US training program was evaluated using pre- and post-surveys that assessed students' knowledge and confidence. Surveys were completed immediately before the JVP Ultrasound didactic skills session (Pre-Survey, [Supplementary Material 2](#)) and immediately after the JVP ultrasound bedside practice sessions (Post-Survey, [Supplementary Material 3](#)). To accommodate scheduling needs, several students completed the individual ultrasound bedside practice session prior to the didactic workshop; these students were asked to complete the Pre-Survey before receiving any educational instruction. The Post-Survey was administered immediately after completing all educational instruction at the didactic session and bedside practice session, with total time course between Pre-Survey and Post-Survey ranging from 1 to 3 weeks based upon the students' clerkship schedules.

Statistical Analysis

Survey data were analyzed using IBM SPSS Statistics v.28 predictive analytics software. Knowledge-based questions were recoded into dichotomous (correct/incorrect) variables in which correct answers were coded "1" and incorrect ones "0". Given the small numbers of incorrect responses in our 2 by 2 tables, knowledge items were analyzed using Fisher's Exact Test and p-values which are reported in [Table 1](#).

Likert-style self-perceived confidence items were recorded using a 1 to 5 scale (1 = Strongly Disagree and 5 = Strongly Agree). Total scores, pre- and post-intervention, were calculated and are detailed in [Table 2](#). These data,

Table 1 Results of Knowledge-Based Questions Pre- and Post-Workshop and JVP US Session

Question	Pre Workshop n (%)	Post Workshop n (%)	Fisher's Exact p value
Which of the following physical examination signs are consistent with volume overload? <i>All of the above</i>	88 (98)	89 (99)	1.00
Which of the following structures is identified by the orange arrow? <i>Carotid Artery</i>	86 (96)	90 (100)	0.12
You identify the jugular vein meniscus at 4 centimeters above the sternal angle on a patient lying at a 30-degree angle. What is their approximate central venous pressure? <i>9 cm H₂O</i>	80 (89)	89 (99)	0.01
Which of the following structures is identified by the white arrow? <i>Internal Jugular Vein</i>	83 (92)	90 (100)	0.01
Each of the following are ultrasound features of jugular vein except: <i>Round, thick muscular wall</i>	90 (100)	90 (100)	1.0

Notes: Knowledge scores presented are the number of students reporting the correct answer with the percentage listed in parentheses. A p-value of 0.05 was used as the threshold for statistical significance and is indicated in bold.

Table 2 Results of Student Confidence Questions Pre- and Post-Workshop and JVP US Session

	n	Mean	Std. Dev.	95% CI	p-value	Cohen's d
<i>I feel confident in identifying the jugular venous pressure using my physical examination without ultrasound</i>						
Pre	90	2.73	0.91	1.03 to 1.57	<0.001	1.41
Post	90	4.03	1.03			
<i>I feel confident recognizing ultrasound images of the jugular vein</i>						
Pre	89	3.27	1.04	1.19 to 1.67	<0.001	1.76
Post	89	4.70	0.49			
<i>I feel confident in obtaining images of the jugular vein using bedside ultrasound</i>						
Pre	90	2.61	1.17	1.61 to 2.16	<0.001	2.03
Post	90	4.49	0.53			
<i>I feel confident using Color and Pulse Wave Doppler to distinguish the jugular vein from the carotid artery</i>						
Pre	90	2.67	1.13	1.69 to 2.22	<0.001	2.18
Post	90	4.62	0.57			
<i>Jugular vein ultrasound adds confidence to my physical examination of a patient's jugular venous pressure</i>						
Pre	90	3.88	0.83	0.57 to .97	<0.001	1.13
Post	90	4.64	0.48			

Notes: Confidence scores presented are mean ratings where 5 = Strongly Agree and 1 = Strongly Disagree. A p-value of 0.05 was used as the threshold for statistical significance using the Wilcoxon Signed Rank Test and is indicated in bold.

both pre- and post-intervention, are non-normally distributed and therefore were analyzed using the Wilcoxon Signed Rank Test. The distribution of responses to the confidence questions, both pre- and post-intervention, is skewed and therefore total score means were analyzed using Wilcoxon Signed Rank Test. Means, p-values and appropriate effect size calculations are reported in [Table 2](#).

Student response to the clinical impact question was recoded into dichotomous (yes/no) variables in which yes was coded "1" and no was coded "0". This was analyzed using Fisher's Exact Test and p-values which are reported in [Table 3](#).

Likert-style attitudinal questions were recoded, creating a 1 to 5 scale (1 = Strongly Disagree and 5 = Strongly Agree) for each item. Mean scores for each item, pre- and post-survey, were analyzed using Wilcoxon's Signed Rank Test. Means, p-values and appropriate effect size calculations are reported in [Box 1](#).

Table 3 Result of Clinical Impact Question

Could You Identify a Patient for Whom Jugular Venous Pressure Ultrasound Could be Helpful?	Pre Workshop n (%)	Post Workshop n (%)	Fisher's Exact p value
Yes	78 (86.7)	90 (100)	<0.001
No	12 (13.3)	0	

Notes: Student responses are presented in a yes/no format with corresponding percentages listed. A p-value of 0.05 was used as the threshold for statistical significance and is indicated in bold.

Box I Results of Student Evaluations and Feedback Comments

	Excellent n (%)	Very Good n (%)	Good n (%)	Fair n (%)	Poor n (%)	Mean
Please rate your overall experience during the workshop	72 (81.8)	13 (14.8)	3 (3.4)	0	0	4.78
Please rate the workshop and in-hospital hands-on jugular venous pressure ultrasound practice	73 (82.0)	16 (18.0)	0	0	0	4.82
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Mean
The workshop was a helpful review of the pathophysiology and differential diagnosis of dyspnea	71 (78.9)	17 (18.9)	0	0	0	4.81
If offered, I would attend a similar simulation and ultrasound workshop in the future	71 (79.8)	17 (19.1)	1 (1.1)	0	0	4.79

Please provide any feedback you have regarding the workshop and the in-hospital hands-on jugular venous pressure ultrasound practice session (Optional) (n = 21 / 90; 23%):

- *Awesome session! Highly recommend to future medical students!*
- *Awesome!*
- *Excellent workshop. Really glad to have had this opportunity*
- *Great experience; will employ techniques learned.*
- *Great Session! Learned a lot & Practical skills were very helpful. Good correlation to clinical knowledge*
- *Great teaching! Really appreciated the systematic approach to dyspnea ddx and the group UIS session followed by one-on-one practice.*
- *I have always (in med school) wanted an opportunity to learn how to use the US better. Having 1:1 Experience in addition to quality teaching is a dream come true! Thank you for putting this together and I hope the program expands to offer opportunity to everyone at HMS!*
- *In hospital was very helpful – rarely do you get to practice on pts of varying difficulties and anatomies*
- *It was very efficient. Perfect use of time. Effective, Efficient, Excellent, and concise. Great to have had back-to-back scan sessions. Learned a skill I did not have before these sessions, and now I have after*
- *Lots of strong feedback surrounding the flow for our JVP ultrasound teaching. Our direct visual JVP teaching followed by ultrasound teaching was “extremely effective” and “much better” than a similar session due to its “straightforward, clear explanations and instructions,” breakdown into four steps for confirmation, and “amount of time” hands-on with the probe*
- *The structure of the workshop day was very well organized, flowed well, and each portion built on the last*
- *PLEASE! More of This. Sessions like this are spectacular. They should be spread through our curriculum. It will be fantastic. ABD POCUS, LENIs... we should practice doing it all! Thank you so much!*
- *Thank you very much! This is a great tool.*
- *Thank you! Incredible learning. Great teacher*
- *Thanks for all of the time and energy put into this!*
- *The dyspnea etiology table was a very helpful resource*
- *The hands-on learning with ultrasound was super helpful! One more practice session for visual ID of JVP at bedside would be great!*
- *V. helpful, thanks!*
- *Very helpful for medical students. Especially since POCUS is changing how we are practicing medicine.*
- *Very helpful! Thanks.*

Notes: Scores presented are mean ratings where 5 = Excellent and 1 = Poor OR 5 = Strongly Agree and 1 = Strongly Disagree.

Results

Participation and Survey Response Rates

Ninety-one sub-interns participated in the JVP US training sessions over two academic years from January 2023 to August 2024. 90/91 students (99%) completed the associated voluntary study surveys.

Knowledge-Based Question Survey Responses

Two of the five associated knowledge questions showed statistically significant increases in correct responses between the pre- and post-survey time points (Table 1). After completing the JVP US training program, significantly more students correctly calculated estimated central venous pressure when provided the height of an example JVP column (Question 3, 89% Pre- to 99% Post; $p = 0.009$) and correctly identified the internal jugular vein on an ultrasound image (Question 4, 92% Pre- to 100% Post; $p = 0.014$) as compared to pre-survey responses.

Confidence-Based Question Survey Responses

After completing the JVP US training program, students demonstrated increased confidence in several domains (Table 2). These included identifying the JVP by physical examination (Pre- 2.73 to Post- 4.03; $p < 0.001$) and recognizing (Pre- 3.27 to Post- 4.70; $p < 0.001$) and obtaining images of the jugular vein using JVP US (Pre- 2.61 to Post- 4.49; $p < 0.001$). Students were also more confident in their ability to distinguish the jugular vein from the carotid artery using color and pulse wave doppler (Pre- 2.67 to Post- 4.62; $p < 0.001$). Finally, students believed that JVP US added confidence to their estimation of JVP when added to the physical examination (Pre- 3.88 to Post- 4.64; $p < 0.001$).

All students reported they could identify a patient for whom JVP US could be clinically helpful (Pre- 86.7% to Post- 100%; $p < 0.001$) (Table 3). In addition, the workshop and individual practice sessions were well received with positive comments from students in their anonymous evaluations (Box 1).

Discussion

In this single-arm, non-randomized prospective pilot study, we aimed to increase knowledge and demonstrate medical students' ability to apply bedside JVP US skills through this workshop. Using Miller's pyramid as an educational framework for evaluation,¹⁹ these aims achieved Level 1 ("Knows") and Level 2 ("Knows How").

We outline teaching methods for JVP US consisting of a didactic workshop and a bedside practice session. These were feasible, well-received, and associated with increases in students' knowledge and confidence in JVP assessment.

Our findings extend prior work showing that JVP ultrasound skills can be taught efficiently and effectively to medical students. Building on Pettit et al's work,¹⁶ we demonstrate similar results in a larger cohort of third and fourth year medical students taught JVP US within a short time period.

In our study, medical students felt that utilization of JVP US increased their confidence in estimating JVP and complemented the standard physical examination. Prior literature has noted that among components of the physical examination, medical students and trainees self-ranked examination of the JVP among their three least confident physical exam skills.²¹ Following our intervention, students felt more confident in identifying the jugular vein and were less likely to misidentify the jugular vein with the nearby carotid artery by using color doppler and pulse wave doppler techniques. This builds upon the prior literature that has demonstrated the efficacy of JVP US by its ability to directly visualize the internal jugular vein^{11–16} and its ability to significantly improve specificity of the JVP examination.²² Our work extends these findings to a larger group of medical students.

Our study has several strengths. Our study design incorporated multiple spaced opportunities to practice JVP ultrasound, consistent with adult learning principles²³ and previous literature demonstrating benefits of skill-based repetition in learning physical examination over time.²⁴ The individual JVP US practice sessions were less than one hour in length and provided a high-yield educational session for one to two students at a time. We believe that the one-on-one bedside supervision and teaching facilitated learning through deliberate practice with individualized feedback occurring within an authentic clinical context.²⁵ Additionally, our data align with a recent article in *The New England Journal of Medicine*, which identifies usage of POCUS as one strategy to "reinvigorate the bedside clinical encounter".²⁶ The *American College of Physicians* recently published a position paper, which highlighted POCUS skills, teaching methods, and evaluation strategies.¹⁸ Our study incorporates several of their suggested teaching methods including interactive case-based POCUS didactic instruction, usage of quizzes for learning, discussion on the pitfalls during image acquisition and interpretation, and supervised scanning of hospitalized patients by the POCUS educator.¹⁸ Finally, although we did not directly assess clinical outcomes, all students reported they could identify patients for whom JVP US would be helpful.

Our study has a number of limitations. First, it is a prospective, non-randomized study without a control arm. Second, we did not directly assess students' ability to perform a JVP US after completing the training program. Third, although student confidence in JVP US significantly increased during our study, student knowledge only increased in two out of the five studied questions. However, one explanation for this finding is that our students had a high baseline level of knowledge demonstrated by the students' responses to these knowledge questions in the pre-survey. This may have led to a "ceiling effect" in which the designed knowledge questions were not at a level of difficulty in which differences could be readily detected.²⁷ Alternatively, this may suggest that in future work in this topic, students could go directly toward hands-on practice and may not need a separate didactic review of JVP US. Additionally, due to multiple diverse aspects of implemented educational interventions in our study based on the nature of its design, it is not apparent which components of our implemented interventions were associated with resulting positive effects on student knowledge and confidence. It is unclear whether the didactic component, or the hands-on ultrasound practice session, or a combination of the two were drivers of our results. Alternatively, it is also possible that students were motivated to independently study and practice after our workshops, which could also have contributed to our findings. Finally, our students were only surveyed immediately following our intervention, and longitudinal outcomes were not assessed during this initial study.

Future directions can include evaluating students' ability to incorporate JVP US into their physical examination of the JVP and usage of this skillset in clinical practice. This could occur through methods such as longitudinal follow-up of participating students to assess whether students report using JVP US in subsequent clinical rotations or in their future residency practice.

Conclusion

Our single-arm, non-randomized prospective study demonstrates that structured teaching of JVP US – consisting of a didactic workshop and hands-on bedside practice paired with immediate feedback – was a helpful approach for teaching medical students how to incorporate JVP US into their physical examination. In the survey data, students showed increased knowledge and self-reported confidence in JVP assessment after completing the teaching sessions. Medical students felt that usage of JVP US significantly complemented their physical examination. Our study offers a practical model for structured teaching of JVP ultrasound to medical students that institutions may consider as they design integration of POCUS into physical exam instruction.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically

reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Disclosure

The authors have no financial disclosures or conflicts of interest to report.

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