


# Feasibility of Using a Pocket-Sized Ultrasound Device to Measure the Inferior Vena Cava Diameter of Patients With Heart Failure in the Community Setting: A Pilot Study

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## Abstract

**Background:** The incidence of heart failure as well as its treatment costs and rehospitalization rates are increasing worldwide. Physical assessment of elderly patients with heart failure living in their homes is challenging for community nurses. Pocket-sized echocardiographs will be useful for assessing the condition of the patients with heart failure during home-visit care. **Objectives:** This pilot study aimed to examine the feasibility of measuring the inferior vena cava (IVC) diameter using a pocket-sized ultrasound device. **Methods:** Nursing students were trained to use the pocket-sized ultrasound device (PUSD) for measuring the inferior vena cava diameter of a healthy subject. We evaluated the accuracy and rapidity of the nursing students' measurements compared with those of an expert sonographer. **Results:** In total, 83.3% of the participants accurately visualized the IVC using the PSUD. There was no significant difference in the mean IVC diameter between that measured by the students and the sonographer. In total, 25% of the participants accurately measured the IVC diameter. The mean measurement time was 201 seconds. **Conclusion:** Our training program allowed the participants to accurately visualize the IVC using the PSUD. However, these results on accuracy and measurement time still need to be improved before community nurses can use the PSUD during home visits.

## Keywords

heart failure patients, home-visit care, pocket-sized ultrasound device, training program, Japanese nursing student

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## Introduction

The incidence of heart failure is increasing worldwide, and its treatment costs, rehospitalization, and mortality rates remain markedly high.<sup>1</sup> In a survey of patients with heart failure, 69.3% of whom were aged  $\geq 65$  years, the rehospitalization rate within 1 year after discharge was approximately 34%.<sup>2</sup> In Japan, the number of patients with heart failure aged  $\geq 85$  years is projected to increase rapidly from 91 000 in 2005 to 333 000 in 2040, and the epidemic will be sustained until 2045.<sup>3</sup> Elderly patients with heart failure often live alone and may receive home-visit care services by a community nurse. Cognitive impairment is common in patients with heart failure.<sup>4</sup> Bedside estimates of fluid status such as evidence of edema or pulse rate are notoriously subjective or nonspecific.<sup>5</sup> As such, immediately and continually assessing the health condition of elderly patients with

heart failure living alone in their homes is challenging for community nurses.

## Background and Significance

Pocket-sized ultrasound devices (PSUDs) that can measure inferior vena cava (IVC) diameter will be useful for assessing the condition of patients with heart failure during home-visit care by community nurses. Handheld portable ultrasound examination by nonphysician providers is

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helpful in the management of many health problems, including rheumatic heart disease,<sup>6</sup> maternity care,<sup>7</sup> peripheral intravenous catheter placement,<sup>8</sup> pressure ulcer,<sup>9</sup> and heart failure.<sup>10,11</sup> The IVC diameter and its change with respiratory variation is a marker of right atrial pressure<sup>12</sup> and potentially a significant parameter for assessing temporal changes in the fluid status of a home patient with heart failure. IVC diameter is merely one piece of data that community nurses should employ in assessing the volume status of home-dwelling patients with heart failure. Measurement of IVC diameter using handheld ultrasound devices is easier than that using high-end echocardiography for community nurses who have no prior experience in organ visualization and measurement using ultrasound devices. This approach is more rapid than some parameters, and it allows for accurate visualization-based confirmation of the IVC connected to the right atria.

However, despite the potential benefits of a portable ultrasound device, community nurses with no training and experience using an ultrasound device may have difficulty visualizing and measuring the target organ correctly and rapidly within the limited time frame of a home visit. Therefore, implementation of an effective training program is important. Health care providers identified the lack of training as a primary barrier to the regular use of ultrasound in their practice.<sup>13</sup> We designed an educational training program for IVC ultrasonography for nursing students and community nurses in our area who have similar level of knowledge of ultrasonography and have no prior experience and education in organ visualization and measurements using an ultrasound device.

## Purpose

This pilot study aimed to evaluate our educational program of measuring the IVC diameter using a PSUD. We hypothesized that our educational program will allow for correct visualization of the IVC and rapid and correct measurement of its diameter. Furthermore, in this pilot study, our present educational program will need some necessary improvements before we provide the revised version of this program.

## Methods

### *Participants and Training Program*

This pilot study was approved by the ethics committee of Ishikawa Prefectural Nursing University. The study was conducted in accordance with the international ethical guidelines and of the Declaration of Helsinki. Informed written consent was obtained from each participant after explaining the aim and concerns of the study. The data were collected in August 2017. Fourth-year nursing students from a Japanese university who had no ultrasonography

experience were eligible. The research assistant contacted eligible participants and recruited 10 to 14 participants per study class and conducted investigation for 2 consecutive days. All participants provided written informed consent before inclusion in the study.

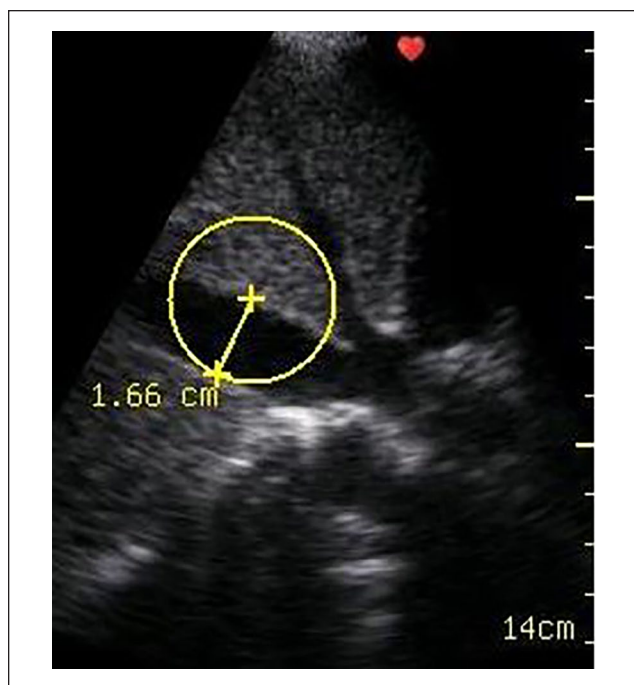
The participants attended a training program on IVC diameter measurement using a PSUD (Vscan, General Electric Healthcare). A previous study showed that the Vscan displayed an image quality that was interchangeable with that from a high-end echocardiography equipment.<sup>14</sup> This program consisted of 2 sessions. The first was a 2-hour didactic session on the heart and IVC anatomy, relationship between heart failure and IVC, principles of ultrasound and ultrasound imaging, and visualization methods. The second was a 1.5-hour skill practice on visualizing the IVC and measuring its diameter using the ultrasonic image acquired by freeze and little-loop functions on a Vscan. An ultrasound simulation model and healthy subjects were involved in this session. Particularly, the model was a simulator that facilitates learning cardiac, lung, abdominal, and OB/GYN ultrasound in a common platform (Vimedix, CAE Healthcare). The practice instructors were registered clinical sonographers with at least 20 years of experience in echocardiography.

### *Data Collection*

The investigation was conducted the day after the training program. Participants measured the IVC diameter of healthy subjects by using a 2-dimensional mode in the long-axis view. This healthy subject was different from those used in the training program. If the participants felt they had failed to correctly visualize and measure the IVC diameter, the procedures could be repeated. Subsequently, the research assistant stored the ultrasound image data. The measurement time was then determined by the research assistant, with the start and end times set as the time when the participant placed the probe of the PSUD on the skin of the chest and the time when the IVC diameter measurement was completed, respectively. Then, the clinical sonographer measured the IVC diameter of the same healthy subject 22 times using the PSUD.

### *Statistical Analysis*

The data were entered into a JMP 9.0 data file (SAS Institute, Inc) for statistical analysis. The first outcome was the participant's success rate of IVC visualization and imaging. Two clinical sonographers determined and agreed whether the target used for the measurement in ultrasound imaging was the IVC. The second outcome was the difference in the mean IVC diameter between the 2 groups (ie, participants and clinical sonographers) determined using the *t* test.  $P < .05$  was considered statistically significant. The third outcome was the percentage of participants who



**Figure 1.** Ultrasound image in the longitudinal orientation for measurement of the inferior vena cava diameter.

measured the IVC diameter within the reference interval.<sup>15</sup> This was a range of 2 standard deviations across the mean IVC diameter of 20 measurements, excluding the first and last, by the clinical sonographer. The result was defined as in or out if the participant's measured IVC diameter was within or outside this reference interval, respectively. Finally, we investigated the minimum and the maximum measurement time values, mean measurement time, and the most frequent measurement time for rapidity.

## Results

Of the 83 eligible participants, 12 participants aged 22 to 23 years were included in this study. The healthy subject was a 20-year-old man. The  $D_{\min}$  during inspiration and the  $D_{\max}$  during expiration of the healthy subject were 6 and 15.7 mm, respectively.

### Accuracy

The success rates in imaging the IVC using the PSUD was 83.3% (10/12) (Figures 1 and 2). There was no significant difference in the mean IVC diameter measured by the sonographer and the participants ( $14.8 \pm 0.6$  vs  $14.8 \pm 1.8$  mm) ( $P = .99$ ). The reference interval calculated from the sonographer's measurements was 14.2 to 15.4 mm. In total, 3 of 10 participants who successfully visualized the IVC were within this reference interval (Figure 2). Furthermore, 25% of the participants properly visualized and imaged the

IVC of the healthy subject and correctly measured the IVC diameter using the PSUD.

### Rapidity

The mean measurement time was 201 seconds ( $\pm 129$ ; range 74-433 seconds). The duration of measurement was equally distributed (Figure 3) and could be roughly classified into within 179 seconds ( $n = 6$  participants) and others ( $n = 6$  participants). The sonographer's measurement times were all within 30 seconds.

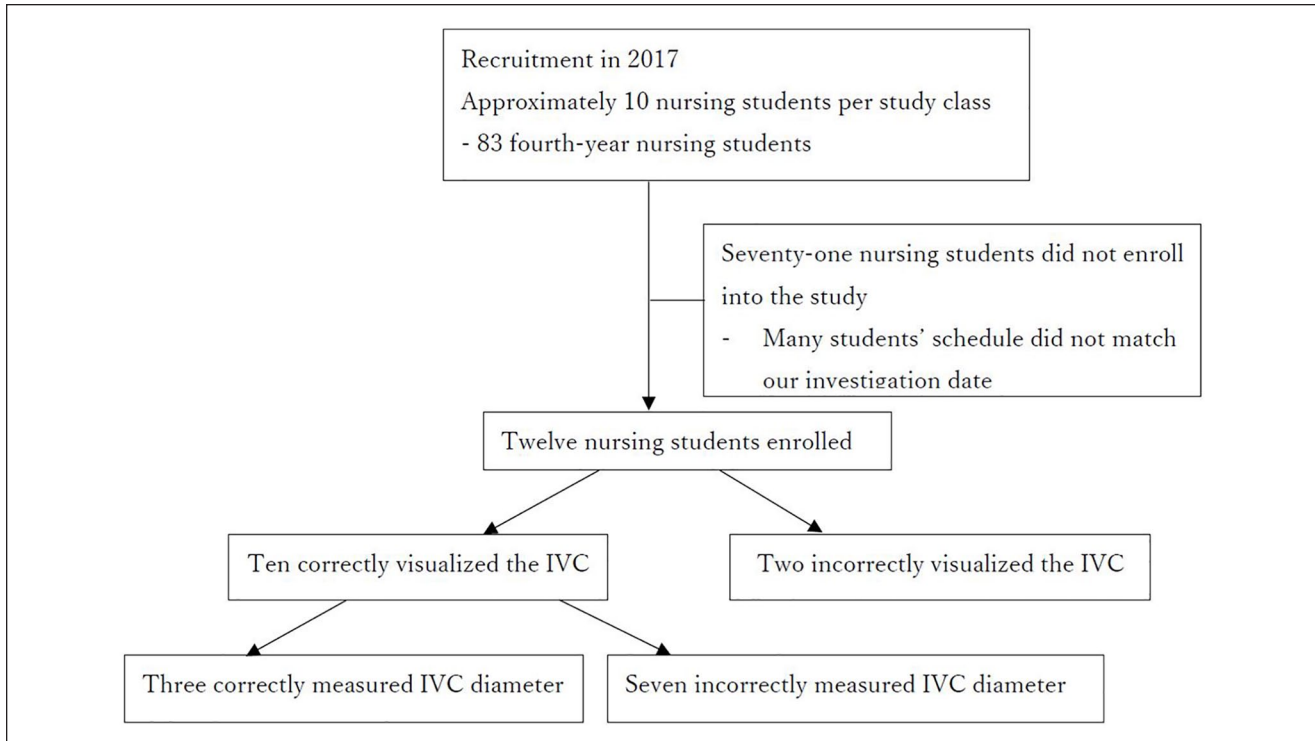
## Discussion

This pilot study for nursing students was conducted to evaluate the accuracy and rapidity of measuring the IVC diameter using a PSUD in the community setting after a short training program. In total, 83.3% of the participants accurately visualized the IVC using the PSUD, and 25% accurately measured the IVC diameter. The mean measurement time was 201 seconds. This pilot study identified key problems to improve the training program for using a PSUD and make it applicable for community nurses who conduct home visits.

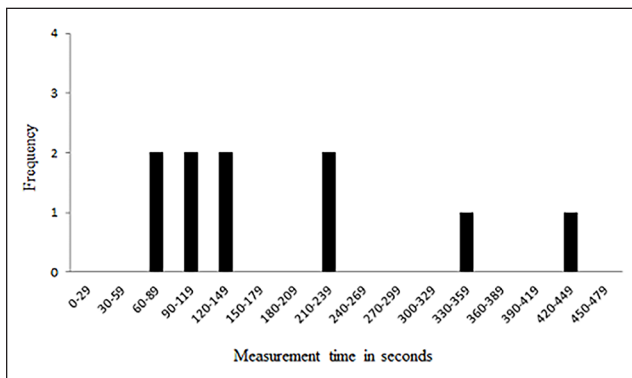
Considering that the participants had no experience in ultrasound imaging, the success rate in IVC visualization in this study was high. The participants easily visualized the IVC with ultrasound imaging. Using anatomical landmarks, the participants were able to easily identify the IVC in both the short-axis view (round shape of IVC) and the long-axis view (continuous contraction and relaxation of the right atrium, which is connected to the IVC). Moreover, the blood vessels appear black or anechoic,<sup>16</sup> while the organs were hypoechoic, and thus, the participants easily differentiated the boundary between the blood vessels and surrounding organs. Failure of some participants to visualize the IVC may be because they perceived the abdominal aorta as the IVC, as was found in the previous study.<sup>10</sup>

With regard to accuracy of IVC measurement, there was no significant difference in the mean IVC diameter between the participants and the sonographer. These findings are consistent with those of a previous study in which the mean difference between the IVC diameter measured by the nurses and experts was only 0.11 cm.<sup>10</sup> However, only 25% of the participants were able to measure the IVC correctly within this reference interval. Even if the participants properly visualized and imaged the IVC, only a few of them measured its diameter correctly. Collectively, these results show that the measurement accuracy was low.

There are several methods to evaluate the accuracy of IVC measurement. A previous study used kappa statistics to calculate the interrater reproducibility of IVC diameter measured using a pocket-mobile echocardiographic and standard transthoracic echo with IVC size judged as



**Figure 2.** Study flow diagram.



**Figure 3.** Distribution of the measurement time.

“normal” or “enlarged.”<sup>17</sup> Meanwhile, other studies used Spearman’s rank correlation coefficient to evaluate the correlation between graded IVC diameter measured using pocket-mobile echocardiographic and standard transthoracic echocardiography.<sup>18</sup> It was also used to identify the sensitivity and specificity of nurse-performed ultrasound for detecting anomalies. The accuracy in these previous studies was higher than that in the current study. The reference interval used in this study is one of the most stringent and accurate criteria for evaluation. The reference interval based on IVC diameter measurement by the sonographer is substantially narrow.

Acquiring adequate skills to correctly measure the IVC diameter was more difficult than we expected. Consequently, we considered four reasons for the failure of the participants to correctly measure the IVC diameter. The first reason was the IVC respiratory fluctuations. Previous studies have reported that the mean IVC diameter was affected by deep breathing<sup>19</sup> and was associated with respiratory fluctuations,<sup>20</sup> probe direction,<sup>21</sup> and measurement formulas.<sup>22</sup> However, the optimal measurement method is yet to be determined. In this study, the IVC diameter measured by the expert sonographer under the presence of respiratory fluctuations ranged from 6 to 15.7 mm. Accordingly, 70% (7/10) of the participant measurements were within this range. We instructed the participants to measure the IVC diameter 1 cm away from the right atrium when the IVC became the largest diameter, but the training was insufficient to achieve the optimal timing. The second reason was that the participants had difficulty operating the probe, particularly with regard to probe direction and pressure adjustment. To measure the IVC diameter accurately, the probe should be directed according to the IVC location, but it can be difficult to adjust the probe in both mediolateral and craniocaudal directions.<sup>21</sup> Some participants pressed the ultrasound equipment probe strongly onto the skin, which consequently changed the IVC shape from circular to oval. The third reason was the lack of practice with the biological models. Some participants wished to practice with more healthy subjects. The success rate of ultrasound-guided

peripheral intravenous catheter placement depends on the learner's experience, with the rate increasing with the number of procedures performed.<sup>8</sup> Practicing with the training simulator models helps beginners learn and improve their technical skills in using the ultrasound equipment.<sup>23</sup> However, it was not possible to simulate IVC respiratory fluctuations and determine the extent of probe pressure with the simulator model as they do not present real-life IVC movement affected by respiratory fluctuations and have no elastic skin and subcutaneous tissue.

The fastest and slowest measurement time in this study was 74 and 433 seconds, respectively, and the measurement duration was evenly distributed. Thus, we divided the participants into 2 groups: those with measurement times less than and greater than 180 seconds. In Japan, the time allocated for a single home-visit care session is around 30 minutes, within which time the community nurses assess the patient's health condition and provide medications and individualized care. In consideration of this time, approximately <3 minutes would be reasonable to perform the examination. The results of our study showed that the measurement time for the majority of the participants in the home-visit care was too long. According to a previous study, the focus-assessed transthoracic echocardiography included 6 images obtained within approximately 70 seconds using a Vscan.<sup>14</sup> In other studies investigating the feasibility of using a Vscan, it took a mean time of 17 minutes with 12 examination elements for bedside cardiovascular screening,<sup>18</sup> 9 minutes with 6 images for the examination of fluid imbalance in patients with heart failure,<sup>10</sup> and 3 to 5 minutes with 7 prespecified measurements for transthoracic echocardiography in in- and outpatients.<sup>17</sup> In the case of the IVC diameter, not only the image but also the measurements are required for assessment. Some participants remeasured the IVC diameter because of the incorrect measurement operations, even after correctly identifying the IVC with ultrasound imaging. Almost all the participants said they were nervous when they investigated the IVC. Thus, the lack of practice with healthy subjects impacted not only the accuracy but also rapidity.

### Limitations

This pilot study has some limitations. First, the reference interval used in this study, as a gold standard, was based on the fact that one sonographer measured the same subject's IVC diameter repeatedly with one ultrasound device. Second, measurement time was the participant's first effort after training. Finally, the sonographer measured the IVC diameter continuously. Because the next measurement was made after knowing the previous measurement value, the previous measurement value may possibly be biased.

### Conclusion

Our training program allowed the participants to accurately visualize the IVC using the PSUD, but the accuracy of measurement of the IVC diameter needs to be improved. Furthermore, the measurement time was long. Our present training program needs to be longer, mainly focusing on differentiating IVC from the abdominal aorta and enabling familiarization with the IVC respiratory fluctuations, adjustment of the probe direction and pressure, and a smooth equipment measurement operation for capturing the ultrasonic image of the largest IVC diameter using a PSUD.

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