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Can a renal nurse assess fluid status using ultrasound on the inferior vena cava? A cross-sectional interrater study: Ultrasound on the inferior vena cava

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Can a renal nurse assess fluid status using ultrasound on the inferior vena cava? A cross-sectional interrater study

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Conflict of interest

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Abstract

Introduction

Ultrasound of the inferior vena cava (IVC-US) has been used to estimate intravascular volume status and fluid removal during a haemodialysis session. Usually, renal nurses rely on other, imprecise methods to determine ultrafiltration. To date, no study has examined whether renal nurses can reliably perform ultrasound for volume assessment and for potential prevention of intradialytic hypotension. This pilot study aimed to determine if a renal nurse could master the skill of performing and correctly interpreting Point of Care Ultrasound (POCUS) on patients receiving haemodialysis.

Methods

After receiving theoretical training and performing 100 training scans, a renal nurse performed 60 ultrasound scans on 10 patients. These were categorized by the nurse into hypovolemic, euvolemic or hypervolemic through measurement of the maximal diameter and degree of collapse of the inferior vena cava (IVC). Scans were subsequently assessed for adequacy and quality by two sonologists, who were blinded to each other's and the nurse's results.

Findings

The interrater reliability of 60 scans was good, with intraclass correlation 0.79 (95% confidence interval (CI) =0.63 to 0.87) and with a good interrater agreement for the following estimation of intravascular volume (Cohen's weighted Kappa $\kappa_w = 0.62$), when comparing the nurse to an expert sonographer.

Discussion

A renal nurse can reliably perform ultrasound of the IVC in haemodialysis patients, obtaining high quality scans for volume assessment of haemodialysis patients. This novel approach could be more routinely applied by other renal nurses to obtain objective measures of patient volume status in the dialysis setting.

Keyword list

haemodialysis, inferior vena cava, interrater reliability, intravascular volume status, renal nurses, point of care ultrasound

Summary of the study

The diameter and respiratory variability of the inferior vena cava usually reflects intravascular volume status. Knowledge of volume status is helpful for a renal nurse when assessing a haemodialysis patient. This study showed that a renal nurse can reliably perform ultrasound on the inferior vena cava obtaining high quality scans for volume assessment of haemodialysis patients. Assessment of the scans on adequacy, quality and volume status showed good interrater agreement when comparing the nurse to an expert sonologist.

Introduction

Intradialytic hypotension (IDH) is still the most frequent adverse event amongst patients receiving maintenance haemodialysis ([1, 2]). These authors report that episodes of hypotension can occur in as much as 31% of all treatments. This indicates that the renal community is yet to find a gold standard assessment tool for the recognition and prevention of IDH. Intradialytic hypotension remains under recognized despite the advancement and availability of various technical devices for intradialytic surveillance of haemodialysis patients. The high prevalence of intradialytic hypotension demonstrates that accurate clinical assessment of fluid balance prior to and during treatment remains extremely difficult. Sinha ([3]) argues that clinical examinations determining ideal body weight are poorly performed in comparison to objective methods and suggests assistive technologies may be helpful for improving subjective clinical methods. There is some evidence that ultrasound of the inferior vena cava (IVC-US) offers opportunity to objectively and reliably assess the intravascular volume status in outpatient haemodialysis clinics by health professionals with minimal experience in using Point of Care Ultrasound (POCUS) ([4]). Good predictability of volume status was achieved with expert sonographers performing this ([5]). Renal nurses spend a significant amount of time with their patients during haemodialysis, but are generally not empowered to use objective fluid or volume assessment measures other than systemic blood pressure or weight assessments before and after treatment. Developing skills and knowledge to use more objective parameters when assessing volume status may help when deciding treatment goals, potentially decreasing the frequency of intradialytic hypotension. This is especially important as experienced sonographers are not readily available in satellite haemodialysis clinics.

Evidence shows that nephrologists can successfully perform this ultrasound on haemodialysis patients ([6]) and other studies confirm that emergency department nurses without prior experience of ultrasonography were also successfully able to learn IVC-US ([7]). However, no studies have shown whether renal nurses can reliably perform this form of ultrasound([8]). In this study, we aimed to determine if a renal nurse, after receiving training, can master the skills required to perform IVC-US and interpret those images to form a correct clinical conclusion regarding volume status from the measurements.

Materials and Methods

In a euvolaemic patient the diameter of the inferior vena cava varies throughout the respiratory cycle. It is necessary to obtain an ultrasound measurement of the IVC during inspiration when it collapses (IVC_{min}) and a second on expiration when the IVC is at its largest diameter (IVC_{max}). The IVC collapsibility index (IVCCI) is calculated from these two measurements $[(IVC_{max} - IVC_{min})/ IVC_{max}] \times 100$ (Figure 1) and shows a good correlation with the central venous pressure ([9]). The indexed vena cava diameter (VCDi) is calculated by dividing IVC_{max} (in mm) by the body surface area in m^2 according to Cheriex, Leunissen ([10]) These two derived measurements give a good point approximation of the patient's intravascular volume status, though some debate remains as to exactly what IVC measurements and collapsibility are significant. Muniz Pazeli, Fagundes Vidigal ([6])

emphasized that “small millimetric differences in the measurements may change the classification”. The current ‘Guidelines for the Echocardiographic Assessment of the Right Heart in Adults’ ([11]) suggest that a diameter > 2.1 cm and collapsibility <50% represents hypervolaemia correlating with central venous pressure. The reference values for IVCCI and VCDi are shown in Tables 1+2 of the supplemental section.

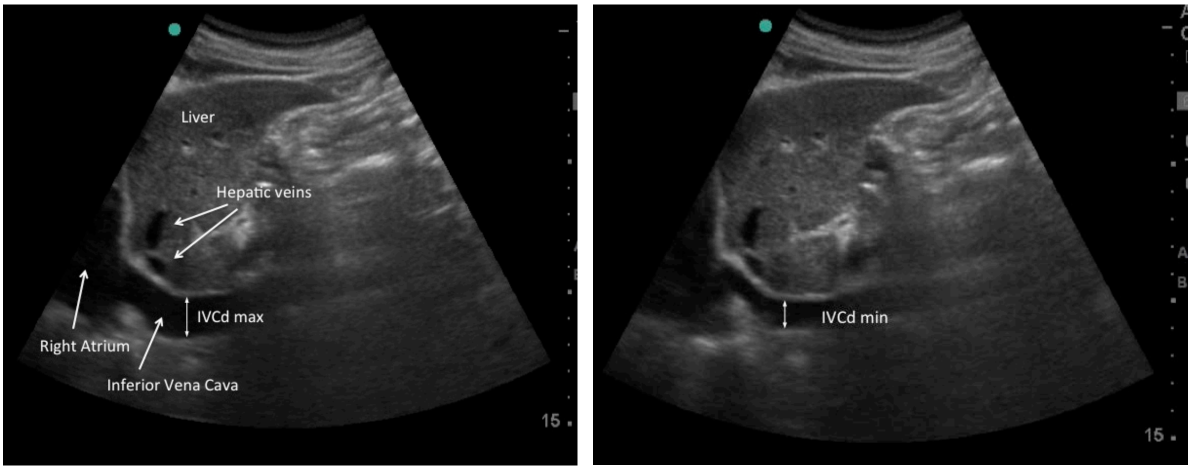

Figure1. IVC longitudinal view – maximum diameter (IVCdmax) at expiration and minimum diameter (IVCdmin) at inspiration

Study design

A cross-sectional study design examined the ultrasound agreement (IVCCI and VCDi) and clinical conclusions between a renal nurse with no prior formal training and two blinded expert sonologists.

Setting, sample and data collection

This study was conducted in a satellite haemodialysis clinic in Western Australia without radiology services on-site. A convenience sample of 10 randomly selected haemodialysis participants were recruited for this study. Prior to consenting, patients received written information about the study and protocols were explained in detail. A renal nurse with limited experience and no formal training in the use of a POCUS received four hours of didactic training covering the theory of IVC ultrasound. This included relevant anatomy and physiology, the clinical relationship between central venous pressure and IVC diameter (IVCd) as well as effects of variation in intrathoracic pressure throughout the respiratory cycle. It also covered the fundamentals of ultrasound, how to use an ultrasound machine and take measurements. A further four hours of practical ultrasound education followed the theory, guided by an expert sonologist. The renal nurse then subsequently performed 100 self-directed training ultrasound scans on randomly selected patients to refine the technique and gain confidence in the skill. Video clips of scans were retrospectively reviewed by an expert sonologist after 15, 50 and 100 scans with appropriate feedback given.

Thereafter for this study, the renal nurse performed and recorded 60 abdominal scans focused on the IVC of the 10 recruits, but purposefully did not perform the haemodialysis treatment or calculate any ultrafiltration goals. Further, no clinical data were observed or recorded, so the renal nurse was not biased to any other clinical parameters. Scans were conducted at commencement, half way, and at the end of the dialysis session. All scans were paired, with both longitudinal and transverse views of the IVC at each time point, resulting in 30 sets of paired scans.

The POCUS used in this study was the SonoSite M Turbo (FUJIFILM SonoSite Australasia) with a C60n probe (5-2MHz), a 60mm broadband curved array transducer suitable for abdominal ultrasound. Each scan consisted of a 6-second loop, ensuring capture of one full respiratory cycle to display the maximum and minimum diameter of the IVC.

The initial scan was performed with the patient supine after a five-minute rest on the treatment chair. For scan 1 the probe was placed in the subxyphoid position, in the long axis below the diaphragm, obtaining a longitudinal view of the IVC. Scan 2 aimed to obtain a transverse view of the IVC after a 90-degree rotation of the probe. Using the liver as an acoustic window the IVC was visualized and its diameter was measured in the anteroposterior dimension, just distal to the hepatic vein junction or approximately 0.5 to 3 cm distal from the right atrium. This is in accordance with the "Guidelines of the American Society of Echocardiography" ([11]).

The paired clips were anonymized, their order randomized and assessed by the nurse and the two expert sonologists. All three raters were blinded to each others' measurements and interpretation of the scans. Raters reviewed the same de-identified and randomized scans, measured the maximum IVC diameter on the computer display whilst scrolling through the scan clips and made a clinical decision on the intravascular volume status based on those longitudinal and transverse views of the IVC. The experts first rated the scans on adequacy and quality, then independently measured IVC_{max} and IVC_{min}, calculating the IVC collapsibility index and finally allocated each set of the transverse and longitudinal views into hypovolemic, euvolemic or hypervolemic categories.

The Bland-Altman plot was used for graphical representation of the interrater agreement of the VCDi measurement means of the expert raters (ER) and the non-expert (renal nurse). An interrater reliability (IRR) analysis of the volume status using the weighted Kappa statistic (κ_w) was performed to determine consistency among raters for the categorical data variable "volume status". Statistical analyses were performed by using SPSS version 22.

Study population

Fifty per cent (n=5) were male. With a mean age of 69 years, none of the patients were classified as underweight, but 60% were either overweight or obese. The mean duration of dialysis was 29 months, and the main causes of chronic kidney disease were hypertensive nephrosclerosis (40%) and diabetic nephropathy (30%), outlined in Table 1.

Table 1. Demographic and clinical characteristics of patients (n = 10)

Male gender, N (%)	5 (50%)
Age, years, (mean ± sd)	68.6 ±14
Body mass index	25.9 ±5
<18.5	0 (0%)
18.6 - 24.9	4 (40%)
25 – 29.9	4 (40%)
>30	2 (20%)
Duration of dialysis, months	29 (2 - 105)
Chronic kidney disease etiology	
Hypertensive nephrosclerosis	4 (40%)
Diabetic nephropathy	3 (30%)
Other	2 (20%)
Chronic Glomerulonephritis	1 (10%)

Results

Sixty nurse-performed scans of the IVC were completed, comprising 30 paired examinations: each included a longitudinal view (LV) (see Figure 1) and a transverse view (TV) (see supplemental section Figures 2 and 3). All 30 LVs were judged as adequate by both expert raters. Four of 30 TVs were considered to be inadequate. These were taken above the hepatic vein junction and represented the right atrium rather than the IVC.

Quality of scans

The quality rating of each scan was rated on a continuous 10 step scale (0= poor and 10=excellent), LV was rated with a mean value of 5.66 by expert rater 1 (ER1) and 5.86 by expert rater 2 (ER2). Ratings for TV were similar with a mean of 5.51 by ER1 and 5.74 by ER2.

30 paired (LV+TV) scans

All paired scans were reviewed and measured by each ER individually in a post-hoc analysis. Each scan comprised a 6-second video which was looped and paused appropriately to measure the minimum and maximum diameter of the IVC through the respiratory cycle. From these two measurements conclusions regarding the volume status were made. Minimum and maximum diameter of the IVC are on a ratio scale, therefore two-way mixed model intraclass correlation coefficients (ICCs) were calculated to measure the level of IRR. When assessing the minimum IVC diameter (IVC_{min}), the average ICC was 0.92 ($F(55,55) = 12.23$, $p<.001$, 95% CI: 0.86 - 0.95) for ER1 and the nurse which indicates excellent reliability. Similarly, the ICC resulted in 0.89 ($F(55,55) = 8.83$, $p<.001$, 95% CI: 0.81 - 0.93) for ER2 and the nurse, indicating good reliability. These results indicate good agreement amongst the nurse and both experts, when assessing for minimum IVC diameter (Table 2).

Table 2. Cohen's weighted Kappa κ_w on intravascular volume status and Intraclass correlation **(**ICC) values for IVC Minimum and IVC Maximum diameter

Cohen's weighted Kappa κ_w on intravascular volume status	renal nurse vs ER 1	renal nurse vs ER 2	ER 1 vs ER 2
Cohen's weighted Kappa κ_w (95% CI)	0.61 (0.41-0.8)	0.63 (0.45-0.81)	0.91 (0.82-0.99)
p - value	<0.001	<0.001	<0.001
Intraclass correlation (ICC) values for IVC Minimum			
Intraclass correlation (ICC) (95% CI)	0.92 (0.86-0.95)	0.89 (0.81-0.93)	0.88 (0.8-0.93)
p - value	<0.001	<0.001	<0.001
Intraclass correlation (ICC) values for IVC Maximum			
Intraclass correlation (ICC) (95% CI)	0.92 (0.86-0.95)	0.94 (0.9-0.96)	0.93 (0.88-0.96)
p - value	<0.001	<0.001	<0.001

Data represent means; ICC = intraclass correlation coefficient; ER 1 = Expert rater 1; ER 2 = Expert rater 2

Almost identical ICC's were obtained when the raters judged the maximum diameter of the IVC (IVC_{max}) in LV and TV (Table 4). The ICC resulted in 0.92 $F(55,55) = 12.34$, $p<.001$, 95% CI: 0.86 - 0.95) between the nurse and ER1 and 0.94 ($F(55,55) = 16.46$, $p<.001$, 95%

CI: 0.9 - 0.96) between ER 2 and the nurse. The comparison of IVC maximum diameter again resulted in an almost perfect agreement among the nurse and both experts (Table 2).

Table3. Comparison of mean values of indexed vena cava diameter (VCDi) and inferior vena cava collapsibility index (IVCCI) amongst 3 raters (2 experts and 1 renal nurse)

	renal nurse	expert rater 1 (ER1)	expert rater 2 (ER2)
Indexed vena cava diameter corrected for body surface area (VCDi)	6.8 ± 3.1	6.92 ± 3.22	7.85 ± 3.08
Inferior vena cava collapsibility index (IVCCI)	40.88 ± 25.24	50.85 ± 27.06	53.39 ± 22.53
IVCCI median	39.05	50	53.94
IVCCI interquartile range (IQR)	30	30.19	35.63

Data represent means ± standard deviations (SD) or medians or interquartile ranges (IQR)

VCDi and IVCCI parameters

The mean VCDi parameters for each rater ranged from 6.57 (nurse) to 6.92 (ER1) or 7.85 (ER2) respectively (Table 3). These values demonstrate that all three raters had similar means with almost identical standard deviations. The nurse also had a VCDi mean result comparable to that of ER1. However, there was a better agreement between ER1 and ER2 when comparing the mean values for IVCCI. The mean IVCCI for ER1 (51.97) and for ER2 (52.49) showed a strong correlation, while the mean IVCCI of the nurse was lower (41.75). The individual comparison of VCDi values between the nurse and the experts are presented in Figures 4-6 of the supplemental section, and confirming the findings of VCDi means.

Sixty scans assessed for volume status

Comparing intravascular volume assessment by ER1 to the renal nurse resulted in a Cohen's weighted Kappa of κ_w=0.61 ($p<0.001$, 95% CI: 0.41 - 0.8), which reflects a good interrater agreement (Table 4). Similar to this outcome, the comparison between ER2 and the nurse yielded κ_w=0.63 (p<0.001, 95% CI: 0.45 - 0.81), which also reflects substantial agreement amongst expert and non-expert. Comparison between both experts (ER1 and ER2) resulted in κ_w = 0.91 (p<0.001, 95% CI: 0.82 - 0.99), indicating extremely good agreement (Table 2).

The Bland-Altman plot

The Bland-Altman plot of all VCDi measurement means showed good interrater agreement when comparing each expert rater with the nurse (Figure 2) (see also Figure 6 in the supplemental section), as all means were found close to the central axis. The Bland-Altman plot comparing ER1 with ER2 illustrated similar results (Figure 7 in the supplemental section).

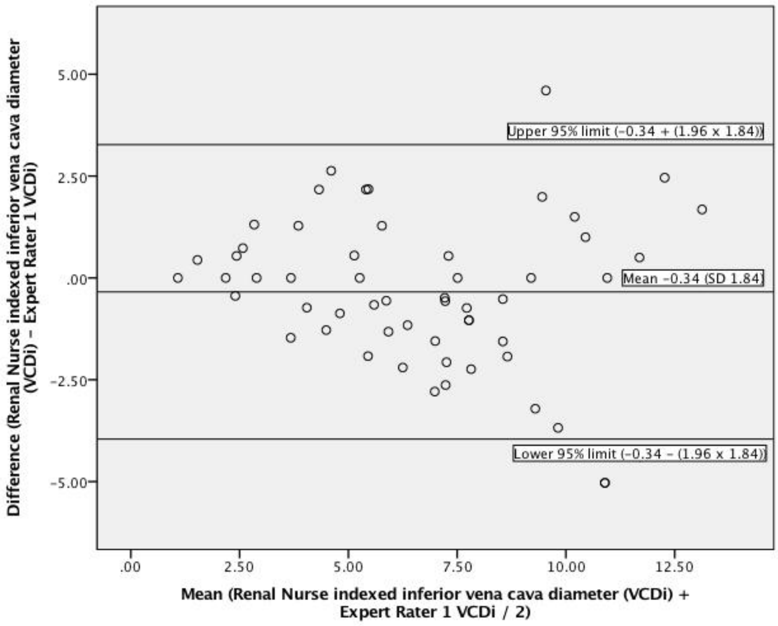

Figure 2. The Bland-Altman graph comparing means of Renal Nurse indexed inferior vena cava diameter (VCDi with Expert Rater 1

Discussion

This is the first study confirming that, given adequate training and resources, a renal nurse can develop the skills required to perform IVC-US and can correctly interpret the results. Should ultrasound be shown to predict which patients are more prone to intradialytic hypotension, enabling prevention, and if IVC measurements can be used to guide decisions regarding ultrafiltration goals for dialysis, this skill may well become an essential part of the renal nurse's skill set.

However, there were several phases to learning how to perform focused ultrasound examinations. The first included a general understanding of the nature of ultrasound, how it works and understanding the appearance of different structures. This was followed by understanding and attaining the skills required to use the ultrasound probe and machine to gain and optimize images. The next phase involved specific ultrasound knowledge required for a focused scan, i.e. understanding the normal anatomy and physiology of the region targeted, and understanding specific maneuvers and methods to optimize images in that area. The final phase involved understanding the pathology and interpreting its ultrasound appearance to make a valid clinical conclusion.

If an individual is a complete ultrasound novice, the road to competence is significantly longer than if one already has a solid ultrasound knowledge foundation and just learning a new type of focused scan. Hence, multiple preliminary self-directed scans performed by the nurse, retrospectively reviewed, appears essential for attaining the desired learning outcome. Quantitating the amount of training is where opinions and results vary and the literature confirms this.

Bowra, Uwagboe (12) found poor agreement amongst ultrasound measurements from an expert and a novice when assessing IVCd and IVCCI. This significant difference might have originated from the short initial training of the learner, only 2 hours combined didactic and practical training prior to commencement of the study. The authors recommended "a minimum level of training…before an operator can be considered competent in performing and interpreting IVC ultrasound" (p.298). Fields, Lee ([13]) showed that for emergency physicians who had previously performed more than 150 general ultrasound examinations, they still required at least 15 IVC-US, of which 10 should be supervised to reach a level of excellent accuracy and good IRR. Emergency physicians usually learn aortic ultrasound very early in their practice and adapting this to IVC-US, a similar approach, appeared easy considering the relatively few scans required to reach competence in this group. Interestingly, one study by Muniz Pazeli, Fagundes Vidigal ([6]) did demonstrate a strong correlation between a nephrologist without formal ultrasound training and a cardiologist despite only receiving focused IVC-US training of 30 minutes and performing six supervised IVC-US measurements prior to the study. These authors did report the nephrologist had "only limited echocardiographic exposure", but did not quantify the amount of exposure so a degree of prior expertise may also be assumed.

These studies compared the IRR of emergency physicians, a nephrologist and a trainee doctor in emergency medicine with an expert. Studies comparing nurses with an expert have shown similar results. In all these studies the authors stressed the importance of adequate and sufficient training in ultrasound before IRR assessment formally occurs. The prospective study by Dalen, Gundersen ([14]) which investigated the IRR between two nurses specialized in cardiovascular nursing and a cardiologist found good agreement. These nurses had previously performed more than 200 focused ultrasound scans. In a study by De Lorenzo and Holbrook-

Emmons ([7]), fourteen emergency department nurses with no prior experience in formal ultrasonography, received structured training of 3.5 hrs. They were able to identify and measure IVCd “with reasonable accuracy and reliability”. These authors reported a nurse-expert correlation coefficient (*R* value) for the longitudinal orientation of 0.68 and 0.59 for the transverse orientation. Their nurses performed better in achieving adequate images of the IVC in the longitudinal orientation, which correlates with the results of our study, where all 100% of the LV scans were rated as adequate by both expert raters, whereas 87% of TV scans were rated as adequate. In another study by Gustafsson, Alehagen ([15]) four nurses in a heart failure clinic without prior ultrasound experience received 4 hrs training before they performed scans on 104 patients. During this study, the nurses performed ultrasound scans not only on the IVC, but also on the chest, back and abdomen to investigate pleural effusions and comet tail artefacts to assess for pulmonary congestion. Comparison of the IVC scans of the nurses with those of a cardiologist, showed only fair agreement with a Kappa value of 0.39. The authors concluded that the ability to reliably examine the IVC requires more than four hours basic training for a non-expert. As we also found early in the training period, they reported that occasionally the nurses mistook the aorta for the IVC.

In our study the renal nurse was a novice and received 8 hours of intensive training, then performed 100 scans with three summative assessments, where scans were reviewed and discussed along the way. This study shows that for this individual, after this period, their scans were reliable. It may be reasonable to assume that renal nurses with pre-existing ultrasound expertise – for example in vascular access or fistula assessment – may gain the required skill in slightly less time. Specific areas in which the nurse encountered initial difficulty included ensuring correct probe orientation, differentiating the aorta from the IVC, negotiating and minimising the effect of bowel gas, ensuring optimal midline visualisation of the tubular IVC in the longitudinal plane, and even after 100 scans, difficulty in determining the correct level of the IVC to scan when in the transverse plane. These are all fairly fundamental errors that are encountered regularly by ultrasound educators as they teach novice practitioners ([15]).

It may be critical to choose the correct moment for measurements, as previous studies have cautioned against measurements of the IVC for dry weight assessment at treatment cessation, as they may be incorrect due to plasma refilling([16]).

When performing IVC-US, we strongly feel that a combination of both longitudinal and transverse views of the IVC is necessary. This ensures the user can build a more accurate 3-dimensional picture of the IVC in their mind. The longitudinal view is useful in measuring the IVC in the anteroposterior plane, and ensuring the measurement is taken at the correct site, just distal to the hepatic veins. The disadvantage is, that it is easy to be off axis, and take a measurement of the IVC off its midline. The transverse view enables clear differentiation from the aorta, and gives a cross sectional view of IVC enabling a very accurate visual assessment of the IVC size through the respiratory cycle. One view confirms the accuracy of the other.

Our study has demonstrated that an ultrasound naive renal nurse can successfully learn and apply the skills required for IVC-US for the purpose of volume assessment in dialysis patients. Analyzing metric (ratio) and categorical data with a variety of different IRR analyses resulted consistently in good interrater agreement across all methods.

Although ultrasound with a vascular (linear array) transducer is commonly used in haemodialysis satellite units for the visualization of arteriovenous fistulas, abdominal (curved array) transducers might not always be available, although they would be essential for the visualisation of the IVC with ultrasound. If they were present, sufficient didactic theoretical and practical training provided to the nurses would enable them to learn this critical and valuable skill.

Future research might reveal if upskilling of a larger group of renal nurses with the technique of IVC-US is feasible and whether this may lead to improved volume assessment and outcomes of haemodialysis patients.

Limitations

As this is a pilot study, only one renal nurse was chosen to perform IVC-US, whereas future research should be undertaken to investigate if the skill IVC-US can be mastered by a greater number of renal nurses. The sample size in this study was small, using only 10 individual patients – although each had multiple scans. A larger number of participants could potentially also mean more variety in individual anatomical differences within a specific cohort of haemodialysis patients. Measuring central venous pressure may be influenced by a variety of cardiovascular conditions such as pulmonary hypertension, right heart failure and triscuspid regurgitation and results may vary from healthy volunteers. Patients with these conditions could be potentially falsely assessed as ‘hypervolemic’ when using ultrasound as a solitary method. Therefore, we propose that the results of the ultrasound scan should always be seen in the clinical context of other objective volume indicating parameters, especially in those patients. In this exploratory study, we did not specifically exclude participants with a history of cardiovascular disease, as it aimed only at assessing the ability of a renal nurse to learn the technique and to interpret it, and not to determine whether ultrasound of the IVC was useful. This should be further investigated in another prospective study.

Conclusion

An ultrasound naïve renal nurse can be successfully taught how to acquire, measure and interpret ultrasound images of the inferior vena cava. Although a non-expert, multiple repeated performances of IVC-US in the same anatomical area can add a valuable, non-invasive practical skill to the renal nurse. This study showed that the nurse gained confidence and could reliably perform the skill independent from the expert. Visualization of intravascular volume status might be a helpful addition to the information used by renal nurses in their decision-making process regarding fluid removal during haemodialysis. Furthermore, IVC-US holds a major advantage in that it could be applied at any stage before, during or after the haemodialysis session, providing an objective picture of the intravascular volume status. This might elicit critical information for the treating nurse, and in combination with other clinical parameters like blood pressure and heart rate, could lead to a more holistic approach when assessing volume status and treatment goals.

Applying IVC-US on a broader scale would potentially allow for another clinical dimension when assessing for volume status, upskilling of renal nurses with another objective and non-invasive volume assessment skill that could be particularly beneficial. Renal nurses with improved skills for objective volume assessment are more likely to better understand underlying anatomical conditions and are more inclined to deliver a less troublesome treatment to patients.

An ultrasound naïve renal nurse can be successfully taught how to acquire, measure and interpret ultrasound images of the inferior vena cava. We suggest future research studies should investigate on a larger scale if IVC-US used by several renal nurses prior and during a haemodialysis session correlates with other volume indicating clinical parameters such as bioimpedance measurements and intradialytic blood pressure trends.

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