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Research article

# Factors influencing ultrasound cardiac output monitor waveform quality in patients admitted to the emergency intensive care unit

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ABSTRACT

*Objective:* The ultrasonic cardiac output monitor (USCOM), an instrument that monitors the evolution of a patient's hemodynamic status and determines the type of shock, has become an important tool for assessing cardiac pathology and predicting changes in disease, but there are some variations in the instrumental findings for different physical conditions of patients. This article examines whether there are differences in the quality of USCOM waveforms measured in different types of critically ill patients based on clinical characteristics and test parameters.
*Methods:* Baseline data, diagnoses, echocardiograms, ventilation patterns, and USCOM results were retrospectively collected from patients in the emergency intensive care unit. Waveform quality was quantified using the Fremantle score to determine the extent to which age, body mass index (BMI), chronic obstructive pulmonary disease (COPD), respiratory failure, cardiac enlargement, valvular heart disease, and ventilation pattern influenced USCOM waveform quality.
*Results:* Age, body mass index, chronic obstructive pulmonary disease, respiratory failure, right and left heart enlargement, aortic valve disease (excluding aortic stenosis), and ventilation mode did not have a significant effect on USCOM waveform quality in critically ill patients ($P > 0.05$).
*Conclusions:* Various physical conditions of critically ill patients may have limited effect on the quality of the USCOM waveform, potentially rendering USCOM suitable for early assessment of hemodynamic status during ICU admission.

## 1. Introduction

The Ultrasonic Cardiac Output Monitor (USCOM™ Pty Ltd, Cofs Harbour, NSW, Australia) is a non-invasive instrument used to measure haemodynamic parameters in patients. USCOM results compare favorably with those obtained through thermodilution, pulmonary artery catheterization, echocardiography, and transesophageal ultrasound. [1–4], and is especially suitable for predicting haemodynamic changes and assessing the shock type in severely ill patients [5,6]. It is easy to use, has rapid operation, is portable, cost effective, and has few potential complications [7]. Therefore, USCOM is suitable for early prediction of the trend of the intensive care unit (ICU) patients' condition, facilitating decision-making regarding shock treatment.

USCOM uses continuous-wave Doppler technology to detect the aortic outflow tract through the thoracic entrance (or pulmonary outflow tract through the anterior chest wall) and displays the patient's Doppler flow profile in real time [8]. Calculation of the area of

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each flow profile through the five-point polygon touch-screen method gives the velocity time integral (VTI). The machine estimates the cross-sectional area (CSA) by extrapolating from the input measurements of height and weight, as outlined in the method previously described by Nidorf et al. [9]. The heart rate (HR) is obtained by measuring the interval between continuous curves. The following formula is used to measure the cardiac output (CO) and other parameters of patients, and the average value of three consecutive cardiac outputs is considered the result [10].

$$CO = VTI \times CSA \times HR$$

According to the working principle of USCOM, a clear Doppler blood flow image is the key to calculating VTI, HR. Previous studies have suggested that factors such as age, hyperinflated lungs, emaciation, and dyspnoea may affect the quality of Doppler blood flow images [11–13], suggesting that USCOMs may not be useful for all patients. Therefore, this study aims to analyze patient clinical data collected from the Emergency Intensive Care Unit (EICU) to investigate the impact of various factors on the quality of USCOM waveforms. The study intends to provide preliminary insights, potentially aid clinicians in forming a foundational understanding of USCOM results. Further research is essential to more definitively determine the applicability and reliability of USCOM in the assessment of hemodynamic status.

## 2. Methods

### *2.1. Patients*

The inclusion criteria were: 1) Patients who were hospitalised in the EICU of XX Hospital between April 2020 and November 2021, 2) patients who underwent USCOM examination within 24 h of admission, and 3) aged ≥18 years.

The exclusion criteria were: 1) patients who refused to undergo USCOM examination and 2) patients who were diagnosed with aortic valve stenosis previously or during hospitalisation.

### *2.2. Experimental procedures*

The following data were collected by reviewing the hospital discharge medical record: sex, age, height, weight, basic disease, diagnosis, echocardiography results, including heart enlargement and aortic valve disease (AVD), waveform image examined by USCOM, and ventilation mode during the USCOM examination. If a patient stayed in the EICU several times during the study period, only the data of the first admission were included.

All USCOM operators in this experiment had >3 years of experience and performed ≥60 operations per year. This study was approved by the Ethics Committee of the Affiliated Hospital of Binzhou Medical College (approval no.: 2023LW-42).

### *2.3. Influencing factors*

The enrolled patients were grouped according to the following principles:

a. Patients were divided into Groups based on age: ≤50 years Group, 51–60 years Group, 61–70 years Group, 71–80 years Group, and ≥81 years Group.
b. Patients were divided into Groups based on BMI: ≤18.4 Group, 18.5–23.9 Group, 24.0–27.9 Group, and ≥28.0 Group [14].
c. Patients were divided into a COPD (Chronic Obstructive Pulmonary Disease) group and a non-COPD group based on their history of COPD or diagnosis of COPD during hospitalisation. There are also some imaging examination signs, such as the presence of obvious pulmonary expansion, which are also criteria for the diagnosis and grouping of COPD patients.
d. Patients were divided into an RF (Respiratory failure) group and a non-RF group based on blood gas analysis results within 24 h of admission. The diagnostic criteria for RF included arterial partial oxygen pressure ($PaO_2$) < 60 mmHg at sea level, resting state, and respiratory air conditions, or an oxygenation index ($PaO_2/FiO_2$) < 300 mmHg.
e. Patients were divided into an AVD (Aortic valve disease) group and a non-AVD group based on their history of AVD or diagnosis of AVD through echocardiography during hospitalisation.

**Table 1**
Freemantle criteria for Doppler flow quality assessment.

| Freemantle criteria | Score |
|---|---|
| Well-defined profile base[a] | 0/1 |
| Well-defined profile peak[a] | 0/1 |
| Well-defined commencement of flow or heart sound[a] | 0/1 |
| Well-defined cessation of flow or heart sound[a] | 0/1 |
| Appropriate scale used on screen | 0/1 |
| Minimal acoustic interference | 0/1 |
| Total | 0/6 |

[a] Must be present on three or more Doppler flow profile complexes.

f. Patients were divided into a heart enlargement group and a non-heart enlargement group based on their history of heart enlargement or diagnosis via echocardiography during hospitalisation.
g. According to the ventilation mode during the USCOM examination, patients were divided into the spontaneous ventilation group, NPPV (Non-invasive positive pressure ventilation) group, and IPPV (Intermittent positive pressure ventilation) group.

### 2.4. Primary outcome

The primary outcome was the waveform score of the USCOM examination image. USCOM waveform images were scored according to the Fremantle scoring criteria (Table 1) by two investigators, blinded to patient information and not involved in data collection (a Fremantle scoring on USCOM waveform images is shown in Fig. 1) [12]. The average of the two scores was considered the USCOM waveform score for each patient.

### 2.5. Statistics

Statistical analysis was conducted using SPSS 27.0, beginning with exploratory analysis for normality assessment. Measurement data are presented as mean ± standard deviation. The independent sample *t*-test or ANOVA was applied for normally distributed data, with Levene's test ensuring homogeneity of variances. Where normality or homogeneity assumptions were violated, non-parametric tests were utilized. The partial correlation coefficient was calculated to assess correlations between measurements, controlling for confounders. Statistical power analysis aimed for at least 80 % power at a 0.05 alpha level.

## 3. Results

### 3.1. Baseline clinical characteristics

During the study period, 674 patients were admitted to the EICU, of whom 576 were included in the study. The baseline characteristics of the included patients are presented in Table 2.

### 3.2. Consistency test of fremantle score

A consistency analysis of the Fremantle score of the USCOM image of the enrolled patients was performed by two researchers, and

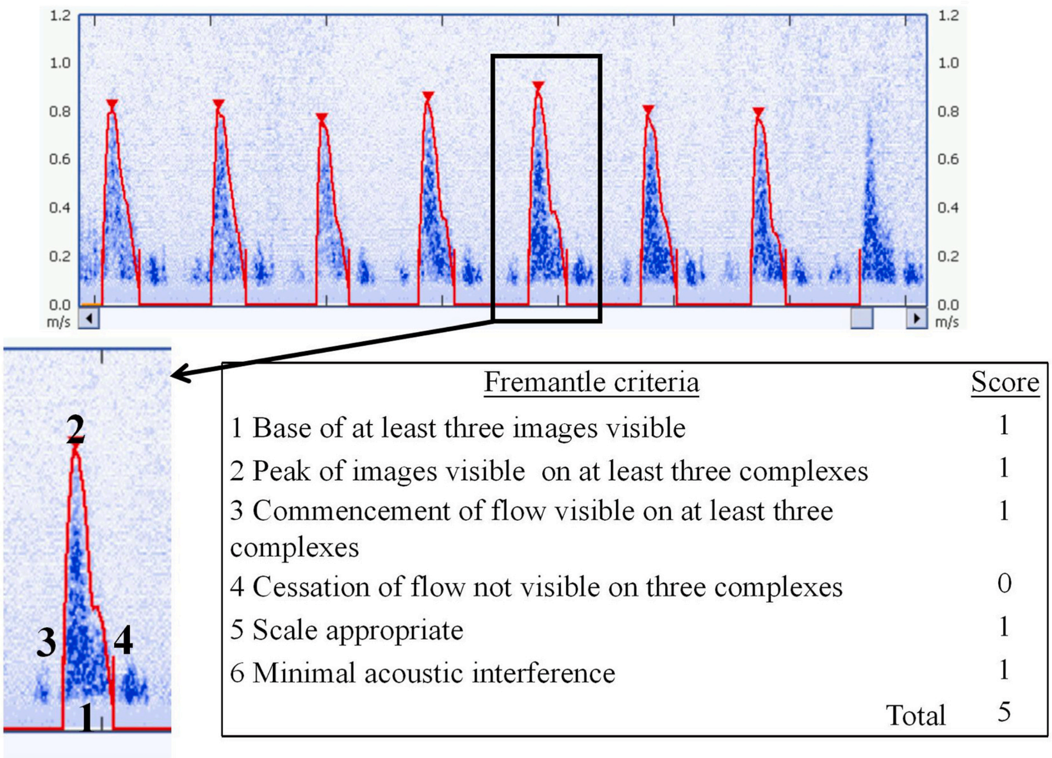


**Fig. 1.** Example of image quality scoring (This image scored 5/6).

**Table 2**
Baseline characteristics of included patients.

| Variable | Median | Frequency | Proportion |
|---|---|---|---|
| Age (years) | 64 | | |
| Height (cm) | 165 | | |
| Weight (kg) | 65 | | |
| Sex | | | |
| Male | | 329 | 57.12 % |
| Female | | 247 | 48.88 % |
| Ventilation | | | |
| IPPV | | 160 | 27.78 % |
| NPPV | | 111 | 19.27 % |
| Spontaneous respiration | | 305 | 52.95 % |
| Main diagnosis | | | |
| Cardiac | | 74 | 12.85 % |
| Respiratory | | 92 | 15.97 % |
| Renal | | 42 | 7.29 % |
| Central nervous | | 65 | 11.28 % |
| After CPR | | 33 | 5.73 % |
| Sepsis/Septic shock | | 42 | 7.29 % |
| Toxic | | 68 | 11.81 % |
| Traumatic | | 69 | 11.98 % |
| Other | | 91 | 15.80 % |

IPPV = intermittent positive pressure ventilation; NPPV = non-invasive positive pressure ventilation; CPR = cardiopulmonary resuscitation.

the Kendall correlation coefficient was calculated as 0.354 ($p < 0.001$), suggesting a significant correlation.

### 3.3. *Effect of age and BMI on USCOM waveform*

The study population was stratified into distinct groups based on age or BMI. Age-wise, the participants were categorized into five groups: those aged 50 years or younger (n = 131), 51–60 years (n = 116), 61–70 years (n = 132), 71–80 years (n = 112), and those aged 81 years or older (n = 85). Regarding BMI, participants were divided into four categories: a BMI of 18.4 or less (n = 48), 18.5–23.9 (n = 247), 24.0–27.9 (n = 206), and a BMI of 28.0 or greater (n = 75). USCOM waveform scores did not statistically significantly differ between patients of different ages ($p > 0.05$) (Fig. 2) or BMIs ($p > 0.05$) (Fig. 3).

### 3.4. *Effect of COPD and RF on USCOM waveform*

The COPD (n = 31) and RF (n = 183) groups did not exhibit statistically significant differences in waveform scores compared with the non-COPD (n = 545) and non-RF groups (n = 393) ($p > 0.05$), respectively (Table 3).

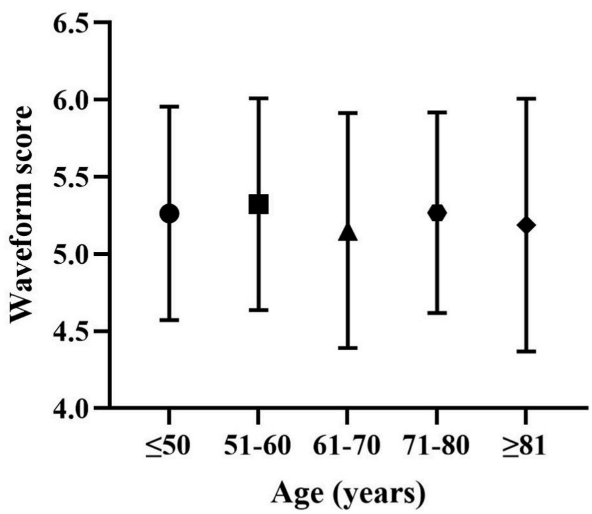


**Fig. 2.** Relationship between age and waveform score.

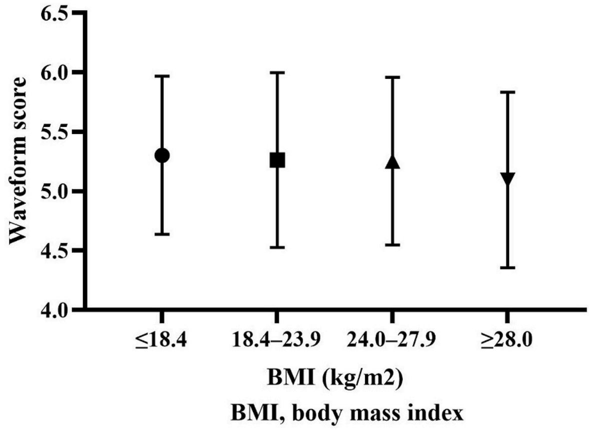


**Fig. 3.** Relationship between BMI and waveform score BMI: body mass index.

### *3.5. Effect of AVD and heart enlargement on USCOM waveform*

Among the patients (n = 542) with waveforms collected via the aortic valve, 260 underwent echocardiography. A total of 143 patients were diagnosed with AVD, among whom 54.6 % had aortic valve degeneration, 6.9 % had aortic regurgitation, 35.7 % had both aortic valve degeneration and regurgitation, and 2.8 % had other pathologies. Moreover, 32.3 % had left heart enlargement and 14.6 % had right heart enlargement [15].

The AVD and heart enlargement groups did not exhibit statistically significant differences in waveform scores compared with the non-AVD and non-heart enlargement groups ($p > 0.05$), respectively (Table 3).

### *3.6. Effect of ventilation mode waveform on USCOM waveform*

Patients were divided into three groups according to the ventilation mode: spontaneous ventilation (n = 305), NPPV (n = 111), and IPPV (n = 160). The statistical results showed that the ventilation mode of patients had no effect on the USCOM waveform score ($p > 0.05$) (Table 4).

## 4. Discussion

### *4.1. Effect of age on USCOM imaging score*

Our results showed no age-related decline in image quality, which is inconsistent with the conclusion drawn by Huang et al. that increasing age has a significant impact on USCOM scan quality and data reliability [11]. In their study, USCOM scan results began to decline in patients aged >50 years, and 50 % of patients aged >65 years had poor USCOM scan results. Moreover, the quality of scans in patients aged >80 years was worse and may have even failed to yield a signal. Huang et al. explained that older age can lead to an elevation of the sternum, elongation and dilation of the aorta, and dilation of the mediastinum, resulting in changes in the position of the heart relative to the aorta [11]. However, other studies suggest that the resting left ventricle ejection fraction, SV, and CO do not change significantly with age, and that left ventricular systolic function remains relatively intact [16–19].

In this study, the median age of the patients was higher (64 years old) than that in the Huang et al. study. Here, 77 % of patients were aged >50 years, and 15 % were aged >85 years, including 13 patients aged >90 years. Moreover, acceptable waveforms were

**Table 3**
Effect of COPD, RF, aortic valve disease, and heart enlargement on waveform score.

| | | | t/F | p |
|---|---|---|---|---|
| COPD | No (n = 545) | 5.242 ± 0.722 | 0.380 | 0.706 |
| | Yes (n = 31) | 5.194 ± 0.692 | | |
| RF | No (n = 393) | 5.241 ± 0.745 | 0.045 | 0.965 |
| | Yes (n = 183) | 5.238 ± 0.665 | | |
| Aortic valve disease | No (n = 117) | 5.303 ± 0.701 | 1.216 | 0.225 |
| | Yes (n = 143) | 5.196 ± 0.717 | | |
| Left heart enlargement | No (n = 176) | 5.253 ± 0.731 | 0.282 | 0.778 |
| | Yes (n = 84) | 5.226 ± 0.670 | | |
| Right heart enlargement | No (n = 222) | 5.246 ± 0.730 | 0.069 | 0.945 |
| | Yes (n = 38) | 5.237 ± 0.590 | | |

COPD, chronic obstructive pulmonary disease; RF, respiratory failure.

**Table 4**
Effect of ventilation mode waveform on waveform score.

| Ventilation mode | | t/F | p |
|---|---|---|---|
| Spontaneous respiration (n = 305) | 5.230 ± 0.739 | 0.657 | 0.519 |
| NPPV (n = 111) | 5.194 ± 0.740 | | |
| IPPV (n = 160) | 5.291 ± 0.670 | | |

NPPV, non-invasive positive pressure ventilation; IPPV, intermittent positive pressure ventilation.

obtained from the older patients. In addition, Huang's study was conducted on perioperative patients. In contrast to previous studies, our research, despite involving an older patient demographic, did not reveal significant differences in USCOM waveform scores among various age groups. Thus, our results suggest that a clear blood flow signal can be acquired by applying USCOM in patients of different ages in the ICU, including patients of advanced age.

### 4.2. Effect of BMI on USCOM imaging score

A previous study by Dey et al. revealed that pronounced emaciation and cachexia in the intercostal space can complicate image acquisition [12]. We discovered no statistically significant differences in waveform scores among patients with different BMIs. The primary purpose of the study by Dey et al. was to assess the reliability and consistency of the results of the examinations by operators with the same training; hence, physicians with no experience with the USCOM instrument were included. In contrast, all operators in the present study were full-time EICU personnel with over 3 years of operational experience. Thus, their operational proficiency may have offset the effect of patient size on image quality. In other words, one of the limitations of our study is the absence of exploration into how the lack of experience among physicians with limited exposure to USCOM affects imaging quality.

### 4.3. Effect of COPD, RF, and heart enlargement on USCOM imaging score

The results indicated no statistically significant difference in waveform scores, regardless of the presence of COPD or RF. Since bedside chest x-rays may not be readily available in critically ill patients, this study investigated whether the presence of pulmonary expansion in patients with COPD impacted the quality of USCOM imaging, utilizing the clinical diagnosis of the disease [20]. The reason why our results are different from those of previous studies [12,13] may be that we used the aortic valve window for waveform acquisition for 94.1 % of patients in this study. Compared to the pulmonary window, more ultrasound waves pass through the mediastinal vessels and thymus during image acquisition via the aortic window than those through the hyperinflated chest; therefore, the effect of gas on the Doppler signal was limited in our study. This suggests that using the aortic valve window for data acquisition is an effective method in patients with pulmonary expansion and patients with respiratory failure.

In addition, it appears that the USCOM waveform quality is unaffected by heart enlargement. This may be since the enlargement of the heart chambers has less of an impact on the positioning of the pulmonary and aortic valves, and detection through ultrasound waves in parallel with blood flow direction through the valves helps reduce error and produces a clear image.

### 4.4. Effect of AVD on USCOM imaging score

The results of the present study suggest that aortic valve lesions (except for aortic stenosis) were not responsible for a decrease in image quality, which to the best of our knowledge, has not been analyzed in any previous study. Based on the imaging principle of USCOM, the orifice area of the aortic valve is derived from height and weight, independent of the presence of valvular pathology. As long as the blood flow velocity through the aortic valve during systole is not affected, the quality of the waveform and the accuracy of the examination are theoretically independent of AVD. It is possible that inclusion of patients with aortic stenosis in the examination of aortic valve pathology in the previous research could increase the bias in USCOM imaging caused by their blood flow velocity.

### 4.5. Effect of ventilation mode on USCOM imaging score

The patient's ventilation mode did not affect the results of USCOM. Compared with spontaneous respiration, during positive pressure ventilation, the systemic and pulmonary venous reflux decrease [21–23], and the functional residual capacity (FRC) increases. This leads to reduction of left ventricular volume [22], which has a certain adverse impact on left ventricular compliance [24]. However, in this study, this series of changes did not affect the position of the aortic or pulmonary valve, and therefore did not significantly affect image quality. It is important to note that acquiring images through the anterior chest wall may result in an increase in gas from the probe to the valve orifice due to an increase in FRC. Therefore, it is necessary to adjust the examination position appropriately and moderately prolong the exam duration to stabilize the airflow at the valve port and reduce the impact on USCOM image quality. Skilled maneuvering techniques and adequate clinical testing experience are required to overcome these challenges.

For patients undergoing IPPV, when obtaining images through the aortic outflow tract (via the thoracic entrance), the ultrasound beam travels through the anterior mediastinum containing fat and thymus in front of the trachea, as well as the ascending aorta, with minimal interference on beam conduction. However, in mechanically ventilated patients, inserting the USCOM probe deep into the suprasternal notch can be challenging due to tracheal intubation, leading to difficulties in image capture. During examination of the pulmonary outflow tract (via the anterior chest wall), an increase in FRC can result in ongoing lung expansion, with gas potentially hindering ultrasound transmission, causing interruptions and weakening, thus impacting image quality. For IPPV patients, both examination areas present their own pros and cons. Therefore, it is crucial to first select the appropriate examination area and, if necessary, extend the examination time to achieve satisfactory waveforms as the primary objective, aiming to minimize the impact of increased gas from the probe on valve opening on image quality. If satisfactory images cannot be obtained after multiple attempts (continuous examination time $>1$ min), it is advisable to discontinue the examination and resort to alternative hemodynamic evaluation methods.

## 5. Limitations

This study had several limitations. First, it was a retrospective study; therefore, the relationship between waveform quality and image acquisition time could not be analyzed. In some cases, the USCOM examination might have been abandoned due to the inability to obtain clear waveforms, which might be one of the reasons for the higher image quality observed in this study. Additionally, we are currently unable to obtain data on how many eligible ICU patients did not undergo USCOM examination, preventing further subgroup analysis of patients who were not examined; Secondly, patients diagnosed with COPD were not graded in this study, as it is difficult for patients in the ICU to cooperate with pulmonary function examination. Patients might have had COPD without obvious pulmonary expansion. Therefore, the impact of COPD on USCOM image quality requires further analysis. Finally, the study only evaluated USCOM results within the first 24 h of admission for different patients. Each patient had only one imaging session and reading during the single USCOM examination within 24 h, thus, further studies are needed to determine whether the quality of the waveform changes with the patient's hemodynamic status.

## 6. Conclusions

This study demonstrate that image quality remains consistent regardless of patient age, body size, COPD, RF, heart enlargement, or ventilation mode. These findings affirm the robustness and adaptability of USCOM in diverse clinical scenarios, highlighting its potential as a reliable diagnostic tool in varied patient populations.

## Ethics approval

This study was approved by the Ethics Committee of the Affiliated Hospital of Binzhou Medical University (approval no.: 2023LW-42).

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## Consent to participate

Written informed consent was obtained from all participants in this study.

## Data availability

The simulation experiment data used to support the findings of this study are available from the corresponding author upon request.

## CRediT authorship contribution statement

**Han Gao:** Conceptualization, Supervision, Writing – original draft, Writing – review & editing. **Tianyi Zhang:** Data curation, Formal analysis. **Lijun Wang:** Formal analysis, Data curation. **Pengbo Hu:** Writing – original draft, Methodology, Investigation. **Songtao Shou:** Writing – review & editing, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## References

[1] Y. Zhang, Y. Wang, D. Ji, J. Qian, J. Xu, J. Shi, Ultrasound cardiac output monitor and thermodilution for cardiac function monitoring in critical patients: a Meta-analysis, Zhonghua Wei Zhong Bing Ji Jiu Yi Xue 31 (2019) 1462–1468.

[2] R.A. Phillips, S.G. Hood, B.M. Jacobson, M.J. West, L. Wan, C.N. May, Pulmonary artery catheter (PAC) accuracy and efficacy compared with flow probe and transcutaneous Doppler (USCOM): an ovine cardiac output validation, Crit. Care Res. Pract. 2012 (2012) 621496.
[3] A. Elgendy, I.M. Seppelt, A.S. Lane, Comparison of continous-wave Doppler ultrasound monitor and echocardiography to assess cardiac output in intensive care patients, Crit. Care Res. 19 (2017) 222–229.
[4] L. Huang, L.A. Critchley, An assessment of two Doppler-based monitors to track cardiac output changes in anaesthetised patients undergoing major surgery, Anaesth. Intensive Care 42 (2014) 631–639.
[5] L.E. Hodgson, R. Venn, L.G. Forni, T.L. Samuels, H.G. Wakeling, Measuring the cardiac output in acute emergency admissions: use of the non-invasive ultrasonic cardiac output monitor (USCOM) with determination of the learning curve and inter-rater reliability, J. Intensive Care Soc. 17 (2) (2016) 122–128.
[6] S.S. Chan, N. Agarwal, S. Narain, M.M. Tse, C.P. Chan, G.Y. Ho, C.A. Graham, T.H. Rainer, Noninvasive Doppler ultrasound cardiac output monitor for the differential diagnosis of shock, Am. J. Emerg. Med. 30 (2012) 629–630.
[7] F.X. Duchateau, T. Gauss, A. Burnod, A. Ricard-Hibon, P. Juvin, J. Mantz, Feasibility of cardiac output estimation by ultrasonic cardiac output monitoring in the prehospital setting, Eur. J. Emerg. Med. 18 (2011) 357–359.
[8] S. Horster, H.J. Stemmler, N. Strecker, F. Brettner, A. Hausmann, J. Cnossen, K.G. Parhofer, T. Nickel, S. Geiger, Cardiac output measurements in septic patients: comparing the accuracy of USCOM to PiCCO, Crit. Care Res. Pract. 2012 (2012) 270631.
[9] S.M. Nidorf, M.H. Picard, M.O. Triulzi, J.D. Thomas, J. Newell, M.E. King, A.E. Weyman, New perspectives in the assessment of cardiac chamber dimensions during development and adulthood, J. Am. Coll. Cardiol. 19 (1992) 983–988.
[10] A. Viruez-Soto, D. Molano-Franco, A. Merino-Luna, A. Bairam, F. Aliaga-Raduán, L. Sanchez, C. Arias-Reyes, J. Soliz, The ultrasound-based cardiac output monitoring is a useful tool to define baseline hemodynamic parameters in healthy permanent residents at high altitude: results of a monocentric pilot study, Front. Physiol. 14 (2024) 1297872.
[11] L. Huang, L.A. Critchley, Study to determine the repeatability of supra-sternal Doppler (ultrasound cardiac output monitor) during general anaesthesia: effects of scan quality, flow volume, and increasing age, Br. J. Anaesth. 111 (2013) 907–915.
[12] I. Dey, P. Sprivulis, Emergency physicians can reliably assess emergency department patient cardiac output using the USCOM continuous wave Doppler cardiac output monitor, Emerg. Med. Australasia (EMA) 17 (2005) 193–199.
[13] L. Huang, L.A. Critchley, R.L. Lok, Y. Liu, Correlation between supra-sternal Doppler cardiac output (USCOM) measurements and chest radiological features, Anaesthesia 68 (2013) 1156–1160.
[14] Chinese Nutrition Society, Dietary Guideline for Chinese Residents: 2022, People's Medical Publishing House, Beijing, 2022.
[15] R.O. Bonow, B.A. Carabello, K. Chatterjee, C.C. de Leon Jr., D.P. Faxon, M.D. Freed, et al., ACC/AHA 2006 guidelines for the management of patients with valvular heart disease: a report of the American College of cardiology/American heart association task force on practice guidelines (writing committee to revise the 1998 guidelines for the management of patients with valvular heart disease) developed in collaboration with the society of cardiovascular anesthesiologists endorsed by the society for cardiovascular angiography and interventions and the society of thoracic surgeons, J. Am. Coll. Cardiol. 48 (2006) e1–e148.
[16] A. Redheuil, W.C. Yu, E. Mousseaux, A.A. Harouni, N. Kachenoura, C.O. Wu, D. Bluemke, J.A. Lima, Age-related changes in aortic arch geometry: relationship with proximal aortic function and left ventricular mass and remodeling, J. Am. Coll. Cardiol. 58 (2011) 1262–1270.
[17] C.H. Chen, M. Nakayama, E. Nevo, B.J. Fetics, W.L. Maughan, D.A. Kass, Coupled systolic-ventricular and vascular stiffening with age: implications for pressure regulation and cardiac reserve in the elderly, J. Am. Coll. Cardiol. 32 (1998) 1221–1227.
[18] C.P. Chan, N. Agarwal, K.K. Sin, S. Narain, B.E. Smith, C.A. Graham, T.H. Rainer, Age-specific non-invasive transcutaneous Doppler ultrasound derived haemodynamic reference ranges in elderly Chinese adults, BBA Clin. 2 (2014) 48–55.
[19] G.N. Cattermole, P.Y. Leung, G.Y. Ho, P.W. Lau, C.P. Chan, S.S. Chan, B.E. Smith, C.A. Graham, T.H. Rainer, The normal ranges of cardiovascular parameters measured using the ultrasonic cardiac output monitor, Phys. Rep. 5 (2017) e13195.
[20] Global strategy for the diagnosis, management and prevention of chronic obstructive pulmonary disease 2022 report.Accessed 15 November 2021. https://goldcopd.org/archived-reports/.
[21] F. Jardin, J.C. Farcot, P. Guéret, J.F. Prost, Y. Ozier, J.P. Bourdarias, Echocardiographic evaluation of ventricles during continuous positive airway pressure breathing, J. Appl. Physiol. Respir. Environ. Exerc. Physiol. 56 (1984) 619–627.
[22] F. Jardin, J.C. Farcot, L. Boisante, N. Curien, A. Margairaz, J.P. Bourdarias, Influence of positive end-expiratory pressure on left ventricular performance, N. Engl. J. Med. 304 (1981) 387–392.
[23] F. Jardin, G. Delorme, A. Hardy, B. Auvert, A. Beauchet, J.P. Bourdarias, Reevaluation of hemodynamic consequences of positive pressure ventilation: emphasis on cyclic right ventricular after loading by mechanical lung inflation, Anesthesiology 72 (1990) 966–970.
[24] J.B. Haynes, S.D. Carson, W.P. Whitney, G.O. Zerbe, T.M. Hyers, P. Steele, Positive end-expiratory pressure shifts left ventricular diastolic pressure-area curves, J. Appl. Physiol. Respir. Environ. Exerc. Physiol. 48 (1980) 670–676.