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ORIGINAL RESEARCH / *ÖZGÜN ARAŞTIRMA*

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Comparison of USCOM and PiCCO Cardiac Output Measurements in Intensive Care Unit

Yoğun Bakım Ünitesinde USCOM ve PiCCO ile Kalp Debisi Ölçümlerinin Karşılaştırılması

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ABSTRACT *Objective:* In the management of haemodynamically unstable patients, cardiac output (CO) measurement provides clinicians with important data on organ tissue perfusion. This measurement can be performed by pulse-induced contour cardiac output (PiCCO) using thermodilution method, which is a less invasive method, and ultrasonic cardiac output monitoring (USCOM), which is completely non-invasive. The aim of this study was to investigate the clinical relevance of CO and cardiac index measurements obtained by USCOM in patient's with sepsis and septic shock by comparing them with the PiCCO technique, which has been used as a reference measurement method in recent years.
Materials and Methods: In this prospective study, 36 patient's with sepsis and septic shock ventilated with 8-10 mL/kg tidal volume without respiratory effort were included. Patient's with arrhythmia, known heart failure or pulmonary embolism were excluded.
Results: After averaging the PiCCO and USCOM measurements performed by different clinicians, the heart rate was found to be 3.23 L/min/m^2 with PiCCO and 2.24 L/min/m^2 with USCOM. When the two results were compared, the difference was statistically significant (p=0.01). Stroke volume variation was 15.80% with PiCCO and 52.89% with USCOM. When the two results were compared, the difference was statistically significant (p=0.01).
Conclusion: There was no agreement between USCOM and PiCCO measurements in sepsis patient's. In our opinion, more studies are needed for USCOM reliability.
Keywords: PiCCO, USCOM, cardiac output

ÖZ *Amaç:* Hemodinamik olarak stabil olmayan hastaların yönetiminde, kardiyak output (CO) ölçümü klinisyenlere organ doku perfüzyonu hakkında önemli veriler sağlar. Bu ölçüm daha az invaziv bir yöntem olan termodilüsyon yöntemi kullanılarak PiCCO (pulse-induced contour cardiac output) ve tamamen non-invaziv olan ultrasonik kardiyak output monitörizasyonu (USCOM) ile yapılabilmektedir. Bu çalışmanın amacı, sepsis ve septik şok hastalarında USCOM ile elde edilen CO ve kardiyak indeks ölçümlerinin, son yıllarda referans ölçüm yöntemi olarak kullanılan PiCCO tekniği ile karşılaştırılarak klinik anlamlılığının araştırılmasıdır.
Gereç ve Yöntem: Bu prospektif çalışmaya, solunum eforu olmadan 8-10 mL/kg tidal volüm ile ventile edilen 36 sepsis ve septik şok hastası dahil edildi. Aritmisi, bilinen kalp yetmezliği veya pulmoner embolisi olan hastalar çalışma dışı bırakıldı.
Bulgular: Farklı klinisyenler tarafından yapılan PiCCO ve USCOM ölçümlerinin ortalaması alındıktan sonra, kalp atım hızı PiCCO ile 3,23 L/dk/m^2 ve USCOM ile 2,24 L/dk/m^2 olarak bulundu. İki sonuç karşılaştırıldığında aradaki fark istatistiksel olarak anlamlı bulunmuştur (p=0,01). İnme hacmi değişimi PiCCO ile %15,80 ve USCOM ile %52,89 idi. İki sonuç karşılaştırıldığında aradaki fark istatistiksel olarak anlamlıydı (p=0,01).
Sonuç: Sepsis hastalarında USCOM ve PiCCO ölçümleri arasında uyum yoktu. USCOM güvenilirliği için daha fazla çalışmaya ihtiyaç olduğunu düşünüyoruz.
Anahtar Kelimeler: PiCCO, USCOM, kardiyak output

Introduction

In order to make the most accurate decision in the management of hemodynamically unstable patients, the use of many physiological parameters at the same time will minimize the margin of error. In addition to parameters such as blood pressure (BP), heart rate (HR), central venous pressure (CVP) and blood lactate level, cardiac output (CO) measurement provides clinicians with important data about organ tissue perfusion in patients followed and treated in the intensive care unit.

Although the use of a pulmonary artery catheter (PAC) for CO measurement is considered the gold standard, its use is gradually decreasing due to some risks. Instead of this invasive technique, measurement of CO with devices such as pulse-induced contour cardiac output (PiCCO), which uses the thermodilution method and is less invasive, is coming to the fore. Ultrasonic cardiac output monitoring (USCOM) is a device that performs CO measurement completely non-invasively by the continuous-wave Doppler method and provides rapid and economical cardiac measurements. The aim of this study was to investigate the clinical relevance of USCOM in patients with sepsis and septic shock by comparing the cardiac index (CI) measurements obtained by USCOM with the PiCCO technique, which is the most commonly used measurement method in recent years.

Materials and Methods

Ethics Committee Approval

This study was conducted in the Anaesthesiology and Reanimation Intensive Care Unit of Akdeniz University Faculty of Medicine Hospital. Approval from the Akdeniz University Faculty of Medicine Clinical Research Ethics Committee was obtained before the commencement of the study (decision no: 299, decision date: 18.06.2014). The study was conducted in accordance with the principles stated in the Declaration of Helsinki. Patients and their relatives were informed and their consent was obtained for this prospective study.

Patients

In this prospective study, 37 patients with sepsis and septic shock hospitalized in the Department of Anaesthesiology and Reanimation, Intensive Care Unit of Akdeniz University Faculty of Medicine Hospital were included. One patient was excluded from the study because the PiCCO measurement could not be performed due to a technical error. All patients were followed up on mechanical ventilators. None of the patients had arrhythmia, valvular heart disease or previously known heart failure. We excluded patients diagnosed with pulmonary embolism from the study.

Method

The ultrasonic heart monitor (USCOM Pty Ltd., Coffs Harbour, NSW, Australia) is a non-invasive bedside measurement device. The USCOM records the blood Doppler flow curve through the aortic or pulmonary valve and calculates the CO by multiplying the stroke volume (SV) and HR. The USCOM software uses an algorithm based on the patient's height to determine the aortic valve area. Here, SV is the product of the velocity time integral (VTI) and the cross-sectional area (CSA) of the selected valve. An algorithmic result is obtained from the height and gender data previously recorded for each patient (1,2).

CO : SV x HR

In the measurements, a Doppler flow curve with a maximum blood flow characterized by a well-defined waveform is recorded and displayed on the monitor as a time velocity curve. After recording patient data (height, sex), the optimum flow profile is frozen. CO is calculated based on SV and HR (calculated with the device software using the SV time rate curve and measured valve CSA values) (3). Initially, the operator placed the ultrasound probe at the suprasternal angle (aortic valve view) and manipulated it to obtain the best waveform and audible signal. In the study, the USCOM was used to measure the CI in the direction of the aortic valve axis from the jugular notch three times and the mean of these measurements was taken as the basis.

PiCCO Pulsion Medical Systems, Feldkirchen, Germany is a way to check blood flow that combines both steady and changing blood flow information with pulse contour analysis and transcardiopulmonary thermodilution (3,4). It is a less invasive hemodynamic monitor that does not require pulmonary artery catheterization, requires only a central venous catheter and femoral artery catheter, and measures continuous CO (5). The principle of operation is based on transpulmonary thermodilution and pulse contour technology. The PiCCO catheter injects a known amount of cold liquid at a known temperature through a central catheter. The device measures the change in blood temperature near the tip of

the PiCCO catheter in the artery after injection. The device displays and calculates the curve of the resulting temperature change. As the injected fluid passes through the heart and lungs, the device can also determine parameters such as preload and extra vascular lung fluid. The PiCCO device was the first pulse contour device used for CO measurement in clinical practice. PiCCO provides information about patient preload and systemic vascular resistance, guiding intensive care specialists in planning fluid and inotropic therapy (6).

The study conducted measurements within the first 24 hours after admitting patients to intensive care. For patients measured with PiCCO, we took three measurements from the central catheter (vena jugularis interna or subclavian vein) and simultaneously took three measurements from the jugular notch with USCOM. We then calculated the average of these measurements as the basis. To eliminate observer-based variability and the risk of bias, all USCOM measurements were performed by a single investigator and PiCCO measurements were performed by a separate investigator.

This study was approved by the Akdeniz University Faculty of Medicine Clinical Research Ethics Committee with decision no. 299, dated June 18, 2014. Patients' consent was not obtained due to the prospective design of the research.

Statistical Analysis

In the statistical analysis of data, descriptive statistics were presented with frequency, percentage, mean and standard deviation values. Paired t-test and Wilcoxon signed-rank were used to analyze the difference between the measurement values of the two groups. Bland-Altman analysis confirmed the difference in measurements using the Jamovi program. We applied correlation analysis to determine the relationship between measurement methods and patient scores. In the study, p-values below 0.05 were considered statistically significant. We conducted the analyses using the SPSS 22.0 package program.

Results

Thirty-six patients hospitalized in intensive care and diagnosed with sepsis and septic shock were included in our study. PiCCO device was installed for hemodynamic monitoring of the patients and hemodynamic parameters were evaluated simultaneously with USCOM methods. Table 1 presents the demographic characteristics of the patients.

The distribution of patients administered noradrenalin, dobutamine, dopamine and adrenalin during follow-up is given in Table 2. The results obtained by comparing the CO, CI, SV and SV index (SVI) measurements of the patients in the study according to PiCCO and USCOM devices are given in Table 3 below.

According to the results obtained, it was determined that CO, CI, SV and SVI measurements gave different results according to PICCO and USCOM devices. The CO measurement values obtained in the PICCO device were higher than those measured in USCOM device and the difference was statistically significant.

Table 1. Demographic data	
Gender (n, %)	
Female	10 (27.8)
Male	26 (72.2)
APACHE-II (min-max)	18.86 (5-35)
Age (years, SD)	59.2±18.5
Weight (kg)	76.1±8.5
MAP (mmHg)	79.9±16.6
Sepsis (n, %)	7 (19.4%)
Pneumosepsis	4 (57.1%)
Meningitis	1 (14.3%)
Diabetic foot infection	1 (14.3%)
Abdominal sepsis	1 (14.3%)
Septic shock	29 (80.6%)
Pneumosepsis	16 (55.3%)
Abdominal sepsis	8 (27.6%)
Urosepsis	1 (3.4%)
Diabetic foot infection	2 (6.9%)
Catheter-related sepsis	1 (3.4%)
Necrotizing soft tissue infection	1 (3.4%)

Gender is expressed as number of people and percentage (%), APACHE-II value is expressed as minimum and maximum. Age, weight expressed as mean (standard deviation). MAP: Middle arterial pressure, APACHE-II: acute physiology and chronic health evaluation-II, min-max: minimum-maximum, SD: standard deviation

Table 2. Doses of vasopressors and inotropes used		
Drug	**n (%)**	**Mean drug dose (mcg/kg/min)**
Noradrenaline	23 (63.9%)	0.5
Dobutamine	5 (13.9%)	5.1
Dopamine	1 (2.8%)	6.6
Adrenaline	1 (2.8%)	0.1

Table 3. Comparison of measurements according to PiCCO and USCOM methods (n=36)

Measurement	Method	Mean ± SD	p-value
CO	PiCCO USCOM	5.9±2.2 4.3±1.7	0.01
CI	PiCCO USCOM	3.2±1.1 2.2±0.8	0.01
SV	PiCCO USCOM	64.1±23.8 43.6±15.9	0.01
SVI	PiCCO USCOM	35.1±12.5 22.8±8.1	0.01

PiCCO: Pulse-induced contour cardiac output, USCOM: ultrasonic cardiac output monitoring, CO: cardiac output (L/min), CI: cardiac index (L/min/m^2), SV: stroke volume (mL/beat), SVI: stroke index (mL/beat/m^2)

Discussion

Hemodynamic monitoring plays an indispensable role in intensive care and patient management, but it is important to remember that no monitoring tool can improve patient outcomes on its own (7). The fact that the changes in the CI determined by USCOM correspond very well with the changes measured by PiCCO is of great practical importance, especially in clinical use (8).

We aimed to compare the CI measurements obtained by USCOM with the PiCCO technique, which has been used as a reference measurement method in recent years, to investigate the clinical suitability of USCOM in patients with sepsis and septic shock. According to the data obtained, it was observed that CI measurements gave different results according to PiCCO and USCOM devices, (PiCCO 3.23 L/min/m^2, USCOM 2.24 L/min/m^2). This difference was statistically significant ($p<0.05$). Horster et al. (9) evaluated seventy sepsis patients in their study and found that the results obtained with the USCOM technique were significantly similar to those obtained with PiCCO. A similar comparison was made in a meta-analysis including six studies and there was a consistent and significant relationship between USCOM measurements and PiCCO measurements (10). The poor agreement between USCOM and PiCCO measurements in our study may be due to a number of factors. Although all measurements were made by a single user in our study, we think that instantaneous changes in patient dynamics, the environment factor, and the fact that the appropriate angle for doopler measurement of the patient varies for each patient and cannot be standardized are the reasons for the incompatibility. The quality of CO measurement depends on operator as well as patient factors. Tan et al. (11) reported that 25% of the examinations performed with the patient in the supine position failed to produce a satisfactory Doopler profile, but a change to a left lateral tilt of 15° to 30° provided a satisfactory profile. Phillips et al. (12) found a deviation of 0.6 L/min/m^2 and a mean error percentage of 56% in measurements made with the USCOM technique and the results were discordant. This result showed that USCOM measurements tended to significantly underestimate CI compared with PiCCO measurements. Failure to obtain measurements in 16% of interventions raises questions about the applicability of the USCOM device. There are also studies in the literature comparing CO measurements by USCOM technique and PAC. Jain et al. (13) obtained correlated results with PAC in USCOM measurements in their study. Phillips et al. (14) found poor accuracy and sensitivity between the two methods. Vandenbogaerde et al. (15) found that 22% of the patient population did not have an acceptable aortic flow signal, and they concluded that the transoesophageal approach was more reliable. In addition, mechanical ventilation may cause difficulties in measuring CO with a US-based device. The accuracy of USCOM depends on obtaining appropriate VTI and heart valve area measurements. Appropriate CCA measurement requires a good flow signal. An inappropriate beam alignment in relation to the direction of blood flow may lead to a suboptimal Doppler signal, which may lead to an underestimation of the CO value. The inaccuracy of CO determination, even for Doppler profiles that fulfill the acceptability criteria, shows that factors other than operator-dependent ones also contribute significantly to poor results. Continuous wave Doppler devices have been studied since the early 1980s. The main problems encountered are the inability to obtain acceptable flow signals with a transthoracic approach and the difficulty in measuring the CSA of the flow. Further evaluation of the USCOM device in low and high CO conditions is required (11). This study has several limitations. The study was single-centre and had a limited number of patients.

Hemodynamic monitoring techniques should be able to identify failure and guide personalized hemodynamic treatments when combined with clinical examinations to assess perfusion adequacy. All monitoring will not improve outcomes unless it is combined with appropriate and effective treatment. Hemodynamic monitoring can be invasive or non-invasive. In recent years, we see that

non-invasive monitoring techniques have increased in intensive care units, while invasive methods such as PAC have decreased (16). We would like to remind you that no matter what method is used, it is necessary to consider each patient individually. We summarize the management of intensive care hemodynamics in Figure 1.

The main goal after shock recognition is to guarantee life-sustaining tissue perfusion levels. BP measurement, skin mottling, and capillary refill time inform the progress of resuscitation (17). Utilizing lactate levels for triage is beneficial due to their good predictive value. Repeatedly measuring lactate levels is useful because they tend to decrease in recovered patients and frequently remain elevated, sometimes even rising in cases where septic shock is not properly managed. Lowering lactate levels during resuscitation has been linked to a decrease in hospital mortality (18). Quick echocardiographic analysis can help with hemodynamic assessment (19). Assessing blood lactate levels can help identify tissue perfusion impairments. It may also be helpful to know the difference in carbon dioxide partial pressure (pCO_2) between central venous blood and arterial blood ($Pv\text{-}aCO_2$) and central venous oxygen saturation ($ScvO_2$) when putting in a central venous catheter (20). CVP

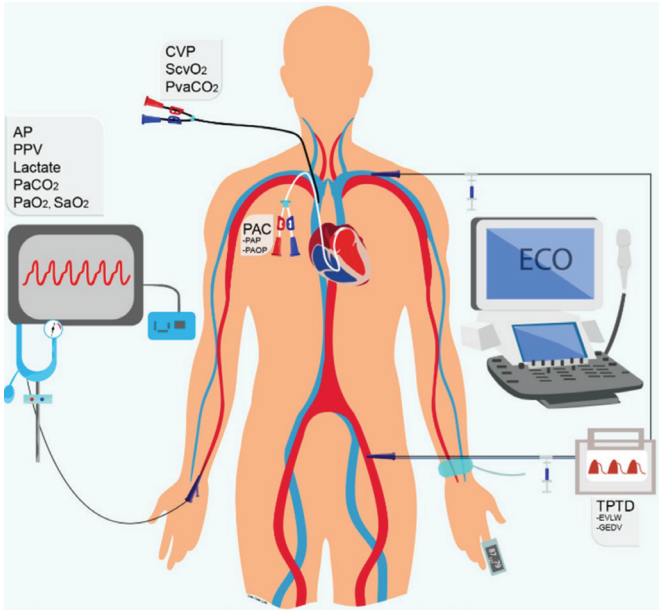

Figure 1. Hemodynamic monitoring in intensive care

PAC: Pulmonary artery catheter, PAP: pulmonary artery pressure, PAOP: pulmonary artery occlusion pressure, TPTD: transpulmonary thermodilution, EVLW: Extravascular lung water, CVP: central venous pressure, PPV: pulse pressure variation, GEDV: global end-diastolic volume, ECO: effective cardiac output

is a complex variable that reflects right ventricular preload and function and is affected by intrathoracic pressure (21). It should be measured in shock even if it is not a reliable indicator of how the patient will react to fluids. Nevertheless, it offers valuable insights about the patient's fluid state and right ventricular reserve (22). In monitoring, more complex patients (based on comorbidities, associated organ dysfunction, or poor evolution) will benefit from the use of transpulmonary thermodilution (TPTD) or eventually a PAC combined with echocardiography when necessary (23). TPTD is used to estimate calibrated measurements of CO, fluid response, static volumetric preload indices, cardiac function indices, extravascular lung water, and vascular permeability. This comprehensive hemodynamic assessment is particularly useful in fluid management as it provides a dynamic assessment of fluid response and an assessment of the risks associated with volume administration (22).

Conclusion

Although USCOM is not a substitute for invasive methods such as PiCCO, its use in patient management under appropriate conditions is debatable. The USCOM device is easy to use and safe as it utilizes ultrasound technology, allowing for repeated measurements to track changes over time. It avoids the complications of pulmonary artery catheterization or central and arterial catheterization procedures in PiCCO or transoesophageal echocardiography. Awake patients can also tolerate it. Apart from all these, USCOM is limited to the measurement of CO because it is unfortunately inadequate to determine variables such as pressure measurements (pulse pressure variation, SV variation, systemic vascular resistance index) or $ScvO_2$.

The poor agreement and failure rate in obtaining an acceptable Doppler profile suggest that this device currently has little clinical utility in intensive care. Further studies are necessary to establish its reliability.

Consequently, the choice of monitoring technique should be based on the patient's condition, local experience and availability, and the expected response to treatment. A phased approach is recommended for the patient in septic shock, evaluated individually.

Ethics

Ethics Committee Approval: This study was approved by the Akdeniz University Faculty of Medicine Clinical Research Ethics Committee with decision no. 299, dated June 18, 2014.

Informed Consent: Patients' consent was not obtained due to the prospective design of the research.

Authorship Contributions

Surgical and Medical practice: Ö.Ç., Concept: A.R., O.H., Design: M.C., Data Collection and Process: H.P., Analysis or Interpretation: Ö.Ç, O.H., Literature Search: M.Y., Writing: Ö.Ç.

Conflict of Interest: No conflict of interest was declared by the authors.

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