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Accuracy and precision of USCOM versus transthoracic echocardiography before and during pregnancy

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ABSTRACT

Objective: Monitoring hemodynamic status throughout pregnancy may help in identifying women with maladaptation predisposing to hypertensive complications. The Ultrasonic Cardiac Output Monitor (USCOM) is an easy-to-operate device for measuring cardiac output (CO) quickly. Our aim was to assess agreement between USCOM and transthoracic echocardiography (TTE) in: 1) non-pregnant women to correct for possible sources of discrepancy; 2) women longitudinally over the course of the pregnancy.
Study design: High-risk women admitted for cardiovascular risk factor evaluation before pregnancy and multiple times during pregnancy, were included. CO was measured by TTE directly followed by USCOM measurements.
Main outcome measures: Bias, limits of agreement (LOA) and percentage error between the two methods by Bland-Altman analysis.
Results: Despite comparable non-pregnant CO levels (4.6 L/min), LOA and percentage error between the two methods improved moderately by optimizing the measurements using only the highest quality USCOM recordings in 132 non-pregnant women (percentage error of 39% and 30%, respectively). During pregnancy, in total 83, 106, 96 and 77 measurements were evaluated at respectively 12, 16, 20 and 30 weeks gestational age. Mean CO in USCOM was about 0.6 L/min higher compared to TTE in all trimesters; percentage error ranged from 35% to 45%. Linear mixed model analysis showed no association between bias and moment of measurement.
Conclusion: Agreement between USCOM and TTE in pregnancy was outside our a priori determined level of acceptability and therefore absolute values of USCOM and TTE cannot be used interchangeably. Future research should focus on the agreement of USCOM and TTE in clinical decision-making.

1. Introduction

During pregnancy, the maternal cardiovascular system undergoes major changes, including increases in blood volume, stroke volume (SV) and heart rate (HR), and an accompanying increase in cardiac output (CO) [1–3]. During pregnancy, hypertensive complications and foetal growth restriction are often preceded by deviant hemodynamic adaptation [4]. Women who develop gestational hypertension often have a higher CO accompanied by low peripheral vascular resistance early in pregnancy, while in early onset preeclampsia, low first trimester CO and elevated peripheral vascular resistance is seen [5–8]. In the case of impaired foetal growth, a limited initial increase in maternal CO parallel to a restricted fall in peripheral resistance is often observed [9,10]. Therefore, determining hemodynamic status early in pregnancy may be helpful in identifying women at risk for complications [11,12]. It may improve our intervention and prevention possibilities, thereby reducing the high maternal and foetal morbidity and mortality of hypertensive disorders and impaired foetal growth [13]. Moreover, classifying maternal hemodynamic parameters when gestational hypertensive complications occur may indicate corrective measures, directed to a more tailored choice in antihypertensive medication [14,15].

The gold standard for CO measurement is the pulmonary artery catheter method. However, the invasiveness of the procedure and

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associated risks of injury and infection make longitudinal and outpatient use impossible. Transthoracic echocardiography (TTE) is a non-invasive alternative that has been widely used in regular practice. In pregnant populations, TTE can be used as a reference method for the validation of CO measuring techniques [16]. Although many specialized centres optimised their accessibility to TTE, it is still not standardly available in all obstetrics departments. Moreover, this method is labour-intensive, expertise-dependent and results are not readily available. The Ultrasonic Cardiac Output Monitor (USCOM) is a non-invasive method using continuous wave Doppler ultrasound to determine CO. No additional costs are incurred after purchase, and the device is compact and portable, making it possible to measure CO at the bedside with results immediately available. The skills required to perform measurements with USCOM are quickly acquired when compared to TTE.

Previous studies have shown poor agreement between USCOM and TTE in non-pregnant and postpartum individuals [17,18]. In the study by Nguyen et al., increased discrepancy between the two methods could have been introduced by including both adults and children [17]. Estimated valve area based on height, as is applied in the USCOM device, could be a contributing source of error. For CO monitoring purposes, it might be profitable to measure valve diameter once by TTE, and use it for subsequent efficient USCOM follow-up measurements [19].

Two studies have cross-sectionally determined the accuracy of USCOM compared to TTE in pregnant women [18,20]. Both studies report higher CO values when measured by USCOM, and only in the third trimester, agreement between the two methods was close to the proposed level for clinical acceptability when comparing CO monitors [21]. The cross-sectional study design did not allow to check whether the difference in readings of two methods is consistent when measured multiple times during pregnancy.

In this study, we aimed to quantify the accuracy and precision of TTE and USCOM for measuring CO in: 1) non-pregnant women to correct for possible sources of discrepancy; and 2) pregnant women over the course of pregnancy, measured longitudinally at defined time points of gestational age.

2. Methods

The hospital medical ethical committee of the Maastricht University Medical Centre (MUMC) approved the study protocol (MEC azM/UM 14-4-118). Individually informed consent related to the use of clinically acquired data for scientific analysis was obtained, as is customary in the MUMC. Participants were recruited from a standard monitoring programme that has been running since 2014 at the Department of Obstetrics. In this ongoing programme, high-risk non-pregnant women structurally undergo cardiovascular measurements in a single assessment, and again during their subsequent pregnancy around 12, 16, 20 and 30 weeks (± 1 week) of gestational age. High risk is defined as having pre-existent hypertension, diabetes mellitus, an auto-immune disease or a previous pregnancy complicated by hypertension, pre-eclampsia, HELLP syndrome, eclampsia and/or related foetal complications, including delivery of a small for gestational age (SGA) neonate, stillbirth or placental abruption. The aim of the preconception assessment is to determine underlying disorders and risk factors that contribute to the development of pregnancy complications and cardiovascular disease, and to advise on preventive measures. The aim of the assessments during pregnancy is to monitor cardiovascular adaptation to pregnancy and to adjust maladaptation with medication in order to the reduce risk of complications. Data on obstetric outcomes of pregnancies were obtained from medical files after delivery. The effect of pharmaceutical correction of maladaptation as intervention was not the scope of this study. Women with congenital or acquired heart valve disease were excluded from the analysis.

Measurements of hemodynamic parameters were performed in one morning session and USCOM measurements parallel to TTE measurements were introduced in the period July 2015 through to December 2017. Arterial blood pressure was measured in sitting position on the left arm at a 3-minute interval by a semiautomatic oscillometric device (Dinamap Vital Signs Monitor 1846; Critikon, Tampa, FL). The median value of 11 measurements was reported. TTE was performed in all women, directly followed by USCOM measurements in triplicate. These examinations were performed by a single experienced cardiac sonographer (J.O.) to assure accuracy and consistency, and to avoid inter-observer variation.

TTE was performed according to the American Society of Echocardiography guidelines using a commercially available phased-array echocardiographic Doppler system (iE33 system with S5-1 or X5-1 transducers, Philips Medical Systems, Best, the Netherlands) [22]. As per recommendations, all images were acquired in left lateral position, after 10 min of rest to ensure stable hemodynamic variables and timed at the end of expiration. Images were recorded as ECG-gated digital loops and stored for offline analysis. Data on hemodynamic parameters were collected and analysed offline using specific software (Xcelera, Philips, Best, the Netherlands) after completing all measurements. Outflow tract diameter (OTD) and velocity time integrals (VTI) were measured at the level of the aortic annulus. HR was calculated by measuring the time interval between two consecutive R peaks on the ECG. SV was calculated using the following formula: $SV = \pi (OTD/2)^2 * VTI$; three VTI traces were used to determine SV. CO was calculated as CO = HR*SV. TTE measurements with low image quality were excluded for the analysis. To determine reproducibility, images on CO were acquired in duplicate for 24 women, with a few minutes rest in left lateral position in between.

USCOM (Ultrasonic Cardiac Output Monitor, USCOM Ltd, Sydney, Australia) measurements were performed standardized in supine position. Hemodynamic parameters were determined by placing the 3.3-MHz transducer in the suprasternal notch directing caudally towards the aortic valve where blood flow through the valve can be measured. According to the manufacturer's instructions, the systolic Doppler profile was optimized through small angulations of the probe in order to achieve the highest velocity and greatest spectral intensity with a clear systolic beginning and end, full systolic timing, and sharp peaks. All measurements were displayed and analysed in the flow trace modus, including all VTI complexes displayed on the screen. Singular flows that were traced inadequately were deselected offline. All measurements with USCOM were individually scored by a single researcher (S.B.), blinded to the TTE measurements, using the Fremantle criteria, a 6-point score system to assess the quality of images [23]. The first collected image per subject with a Fremantle score of ≥ 4 was included in the analysis. To determine reproducibility, multiple measurements of women with a Fremantle score of ≥ 4 were analysed. Overall, the first twenty examinations whereof aim was to gain assessment competence were excluded from analysis, as proposed by Dey et al. [23].

3. Statistical analyses

In both groups of women, agreement between USCOM and TTE was determined by using the Bland-Altman method, as it measures the extent of deviation from the line of complete agreement between the two methods [24]. The Bland-Altman graph was constructed by plotting the difference of USCOM and TTE values for each subject against the average of both measurements. Moreover, for CO and each component that defines CO -including SV, OTD, VTI and HR- mean difference (bias), precision (SD of mean difference), limits of agreement (LOA, bias ± 1.96SD) and the percentage of error (100 * 1.96SD / mean value) were determined. As suggested by Critchley et al., a threshold of $< 30\%$ for percentage error was defined as acceptable [21]. In order to detect potential proportional bias (i.e. the mean difference related to the magnitude of measurement), the difference of the two methods was regressed on the average of the two methods.

In non-pregnant women, we repeated the analysis with only high-

quality USCOM measurements (Fremantle score > 5), and incorporated the measured OTD in the USCOM formula for CO to assess whether better agreement was obtained by minimizing the influence of an estimated OTD. For the longitudinal data of the pregnant women, a linear mixed-effects regression analysis was performed to assess the association between the average difference in CO measured by the two methods and the moment of measurement. The linear mixed-effects regression accounts for the clustering of multiple measures within each patient (i.e., the longitudinal measurements). Reliability of both TTE and USCOM was assessed by scatterplots and by calculating the intra-class correlation coefficient for repeated measurements. IBM SPSS version 21.0 was used for calculations and statistical analysis.

4. Results

4.1. Non-pregnant participants

A total of 172 eligible non-pregnant women were enrolled in this study. Eight participants (4.7%) were excluded from analysis due to inadequate TTE measurements and 32 women (18.6%) due to poor USCOM image quality (Fremantle score < 4). Consequently, data from 132 non-pregnant participants were suitable for analysis. Baseline characteristics of non-pregnant women are presented in Table 1. Fig. 1 shows the Bland-Altman plot for CO in the non-pregnant group. We observed no systematic bias (mean difference = 0.0), and the LOA were −1.8 to 1.8 L/min. However, the percentage error was 39%. No proportional bias was detected in the group of non-pregnant women. Replacing the estimated OTD by the measured OTD in USCOM calculations for CO, a bias (LOA) of −0.3 (−1.9 to 1.3) L/min was found with a lower percentage error of 36%. In a subgroup consisting only of participants with a Fremantle score ≥5 (n = 103), a bias (LOA) of 0.1 (−1.5 to 1.7) L/min was seen. Participants with a Fremantle score of 6 (n = 52) showed a bias (LOA) of 0.2 (−1.2 to 1.6) L/min. Percentage error for image qualities scoring ≥5 and 6 were respectively 34% and 30% (Table 2).

4.2. Pregnant participants

139 pregnant women were included, of whom 20 (14%) were measured once, 27 (19%) were measured twice, 54 (39%) were measured three times, and 38 (27%) were measured four times during pregnancy. The number of pregnant women measured at 12, 16, 20 and 30 weeks of gestational age was respectively 87, 111, 104, and 86.

Table 1
Baseline characteristics of non-pregnant women and obstetric outcomes of pregnant women.

	Non-pregnant women n = 132
Age, y	39 (9.3)
Height, cm	168 (7)
Weight, kg	73 (12)
Parity	2 [1]
Systolic blood pressure, mmHg	114 (12)
Diastolic blood pressure, mmHg	71 (8)
Mean arterial pressure, mmHg	88 (9)
	Pregnant women n = 139
Gestational age at delivery, w	38[2] [13]
Preterm birth < 37 w, n (%)	15 (11)
Birth weight	3095 [749]
Birth percentile	35 [47]
SGA neonate, n (%)	19 (14)
Preeclampsia, n (%)	10 (7)
Stillbirth, n (%)	2 (1)
Neonatal death, n (%)	1 (1)

Data are presented as mean (standard deviation) or as median [interquartile range]. w, weeks; y, years; cm, centimetres; kg, kilogrammes; mmHg, millimetre of mercury; SGA, small for gestational age.

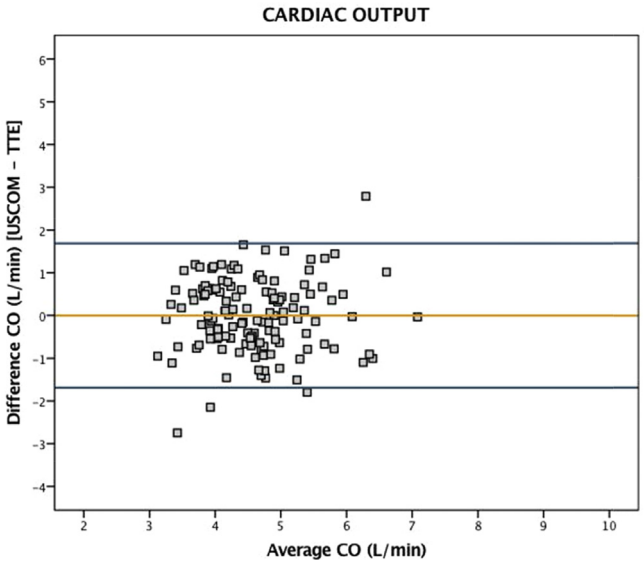


Fig. 1. Bland-Altman plot presenting agreement between USCOM and echocardiography (TTE) for cardiac output (CO) in non-pregnant women. The centred line (yellow) presents bias between two methods, and upper and lower lines (blue) indicate the limits of agreement. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Obstetric outcomes of pregnant women are presented in Table 1. Women who developed complications during pregnancy were included in the analysis. In all four gestational age groups, one woman was excluded due to poor image quality obtained by TTE. Additionally, due to poor USCOM quality (Fremantle scores < 4), we excluded three women (3.4%) at 12 weeks of gestation, five women (4.5%) at 16 weeks of gestation, seven women (6.7%) at 20 weeks of gestation, and eight women (9.3%) at 30 weeks of gestation. There was no difference in the number of poor USCOM quality measurements between groups at different gestational ages ($P = 0.356$). For the comparison between USCOM and TTE, we analysed respectively 83, 105, 96, and 77 women at the gestational age of 12, 16, 20 and 30 weeks.

Bland-Altman plots for CO measured at 12, 16, 20 and 30 weeks of gestational age are shown in Fig. 2. Results on bias, LOA and percentage error of the variables are presented in Table 3. During pregnancy, CO measured by USCOM was at about 0.6 L/min higher compared to CO measurement by TTE. Percentage error of CO varied between 35% and 45%, being lowest at 12 weeks of pregnancy, and highest at 16 weeks of pregnancy. Regression analysis showed proportional bias at all gestational age groups, indicating a tendency for USCOM to overestimate higher CO values and underestimate lower CO values.

This table is supplemented with mean values and Bland-Altman analysis for variables that determine CO, namely SV, HR, OTD and VTI. Bland-Altman analysis of SV shows similar results as compared to CO, with an overestimation when measured with USCOM, and lowest percentage error found early in pregnancy. HR measured with USCOM was on average lower compared to TTE. Linear mixed-effects regression showed no evidence of an association between the difference in CO by the two methods and moment of measurement ($P = 0.874$).

4.3. Method characteristics

TTE measurements in duplicate showed an intra-class correlation coefficient of 0.86 (95% CI 0.71–0.94; $P < 0.001$), and 0.93 (95% CI 0.90–0.95; $P < 0.001$) for USCOM.

Table 2
Agreement of CO between USCOM and TTE in non-pregnant women with proceedings to optimize measurements.

		All measurements n = 132	Measured OTD n = 132	Fremantle score ≥5 n = 103	Fremantle score = 6 n = 52
CO (L/min)	USCOM	4.6 (0.9)	4.3 (1.0)	4.7 (0.9)	4.7 (± 0.8)
	TTE	4.6 (0.9)	4.6 (0.9)	4.6 (0.9)	4.6 (± 0.9)
	Bias	0.0	−0.3	0.1	0.2
	Precision	0.9	0.8	0.8	0.7
	Limits of agreement	−1.8 to 1.8	−1.9 to 1.3	−1.5 to 1.7	−1.2 to 1.6
	Percentage error	39%	36%	34%	30%

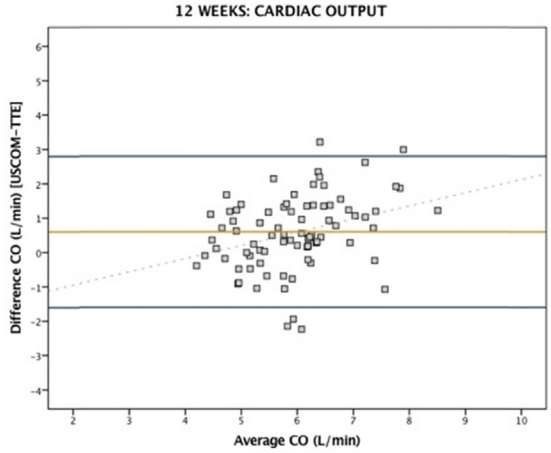
Data are presented as mean (standard deviation). OTD, outflow tract diameter; CO, cardiac output; USCOM, Ultrasonic Cardiac Output Monitor; TTE, transthoracic echocardiography.

5. Discussion

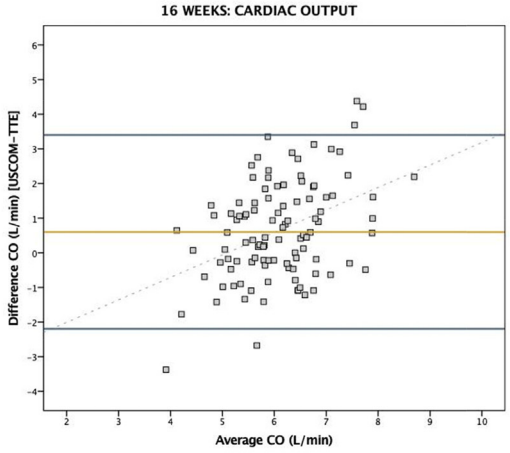
The aim of this study was to assess accuracy and precision of CO measured with USCOM and TTE before and during pregnancy. Optimizing measurements in non-pregnant women only moderately improved agreement between the methods. Therefore, only unrefined data of pregnant women were used in further analysis. Bland-Altman analyses revealed similar results of bias in pregnant women over the course of the pregnancy, being 0.6 L/min higher when measured with USCOM, however, percentage error in all trimesters was higher than clinical acceptability of 30%.

First, we determined whether agreement between the two methods could be improved by optimizing measurements in the non-pregnant population. Estimated OTD based on height by USCOM was replaced by measured OTD by TTE, which could be useful for monitoring purposes. This procedure barely improved percentage error, and precision decreased slightly. Therefore, we would not recommend this procedure to optimize agreement. Similar results of only small improvements in

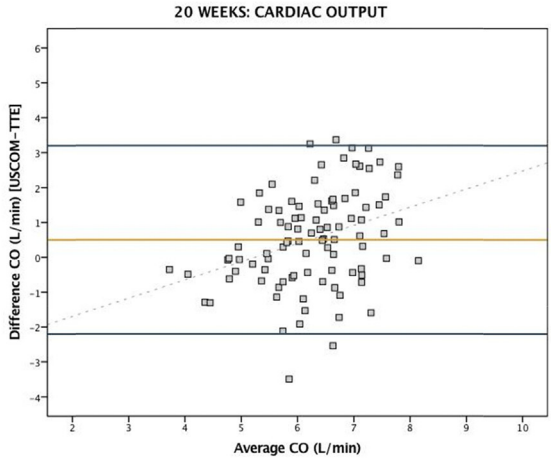
(A) Bland-Altman plot in pregnant women at 12 weeks of gestational age.



(B) Bland-Altman plot in pregnant women at 16 weeks of gestational age.



(C) Bland-Altman plot in pregnant women at 20 weeks of gestational age.



(D) Bland-Altman plot in pregnant women at 30 weeks of gestational age.

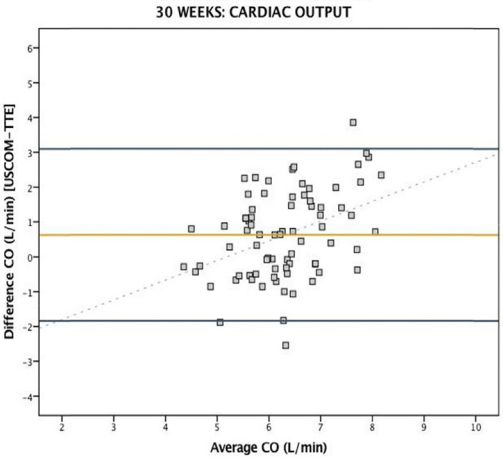


Fig. 2. (A-D): Bland-Altman plots presenting agreement between USCOM and transthoracic echocardiography (TTE) for cardiac output (CO) in pregnant women over the course of pregnancy. The centred line (yellow) presents bias between two methods, and upper and lower lines (blue) indicate the limits of agreement. The dotted lines indicate significant proportional bias. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 3
Agreement between USCOM and TTE of cardiac output, and variables that determine cardiac output during pregnancy.

		12 weeks n = 83	16 weeks n = 105	20 weeks n = 96	30 weeks n = 77
	GA age at measurement	12[3] [5]	16[3] [5]	20[1] [4]	30[1] [4]
	Height, cm	166 (6)	166 (6)	167 (6)	167 (6)
	Weight, kg	72 (14)	73 (14)	75 (13)	79 (14)
CO (L/min)	USCOM	6.2 (1.2)	6.4 (1.3)	6.5 (1.3)	6.6 (1.3)
	TTE	5.7 (0.9)	5.8 (0.9)	6.0 (0.9)	6.0 (0.9)
	Bias	0.6	0.6	0.5	0.6
	Precision	1.1	1.4	1.4	1.3
	Limits of agreement	−1.5 to 2.7	−2.2 to 3.4	−2.2 to 3.2	−1.8 to 3.1
	Percentage error	35%	45%	43%	39%
SV (ml)	USCOM	85 (15)	88 (17)	89 (17)	84 (15)
	TTE	75 (10)	77 (12)	79 (12)	72 (11)
	Bias	9	11	10	11
	Precision	15	18	18	15
	Limits of agreement	−21 to 39	−24 to 46	−25 to 45	−19 to 41
	Percentage error	37%	43%	42%	39%
HR (bpm)	USCOM	74 (10)	73 (9)	74 (9)	80 (9)
	TTE	76 (11)	75 (9)	77 (11)	83 (10)
	Bias	−2	−2	−3	−4
	Precision	7	6	6	6
	Limits of agreement	−15 to 11	−14 to 10	−16 to 10	−15 to 8
	Percentage error	17%	17%	17%	14%
OTD (cm)	USCOM	1.91 (0.06)	1.91 (0.06)	1.92 (0.06)	1.92 (0.06)
	TTE	1.90 (0.12)	1.90 (0.11)	1.91 (0.11)	1.93 (0.13)
	Bias	0.02	0.02	0.00	−0.02
	Precision	0.12	0.11	0.11	0.13
	Limits of agreement	−0.22 to 0.25	−0.20 to 0.24	−0.21 to 0.21	−0.27 to 0.24
	Percentage error	12%	11%	11%	13%
VTI (cm)	USCOM	29.6 (4.7)	30.6 (5.4)	30.7 (5.4)	28.9 (4.9)
	TTE	26.7 (3.3)	27.5 (4.0)	27.8 (4.4)	24.9 (3.5)
	Bias	2.9	3.1	2.9	4.1
	Precision	4.0	5.1	5.6	4.5
	Limits of agreement	−4.9 to 10.7	−6.9 to 13.1	−8.0 to 13.8	−4.8 to 12.9
	Percentage error	28%	35%	37%	33%

Data are presented as mean (standard deviation) or as median [interquartile range]. USCOM, Ultrasonic Cardiac Output Monitor; TTE, transthoracic echocardiography; GA, gestational age; y, years; cm, centimetres; kg, kilograms; CO, cardiac output; L/min, litres per minute; SV, stroke volume; ml, millilitres; HR, heart rate; bpm, beats per minute; OTD, outflow tract diameter; VTI, velocity time integral.

agreement when estimated OTD was replaced was found in a study comparing USCOM with Cardiac Magnetic Resonance and in a study comparing USCOM with thermodilution [19,25]. Selecting only high-quality USCOM images (Fremantle score = 6) improved percentage error up to 30%, reaching approximately the clinical level of acceptability. Since only 52 of the 132 measurements (40%) had this Fremantle score, in clinical practice, this restriction is not feasible.

Percentages of error in pregnant women in our study varied between 35% and 45%, which is higher compared to McNamara et al. (percentage of error 33%) and Vinayagam et al. (percentage of error between 29% and 38%) [18,20]. This might be explained by difference in measurement position. McNamara et al. performed both measurements in left lateral position, while women in our study were shifted from left lateral (TTE) to supine position (USCOM), in compliance with manufacturer's instructions. The difference in position in itself and shifting may have induced changes in CO, especially in the third trimester, when the enlarged uterus may compress the inferior vena cava and affect cardiac preload, filling and SV [26]. Another explanation for the difference in percentage error could be the higher mean CO measured in women by Vinayagam et al. Percentage error is calculated by dividing precision by mean CO, and lower percentages of error could be expected in high CO states. This difference was most pronounced in advanced gestation. All determinants of CO (i.e. SV calculated from VTI and OTD, and HR) had some degree of disagreement. In contrast to McNamara et al. the percentage error of SV was comparable to the percentage error of CO, and we would not recommend assessing this as an independent variable [20].

This is the first study reporting the difference between TTE and USCOM measurements longitudinally during pregnancy. For valid measures of CO during pregnancy, it is important that bias is independent from the moment of measurement during pregnancy. We found no evidence that the bias in CO increases or decreases over the course of pregnancy, taking repeated measurement within individuals into account.

Insight in hemodynamic status early in pregnancy may be helpful in identifying women with deviant adaptation to pregnancy, who are at risk for hypertensive complications and or growth restriction [10,11]. Also, information on maternal hemodynamic parameters when hypertensive problems arise may result in a tailored choice of antihypertensive medication [14,15]. A "point-of-care" device such as USCOM should be efficient, cheap and easy to operate. USCOM is portable and results are immediately readable. We showed good intra-observer correlations for USCOM measurements, and good inter-observer correlations have been reported previously [27]. However, utility in clinical practice greatly depends on useful results, and acceptable quality measurements. In USCOM, only 80% of the images were of a good quality in the non-pregnant women in our population, which is a significant limitation of the measure. This study showed that exact values of USCOM and TTE cannot be used interchangeably. Biological fluctuations in CO that result from respiration and baroreceptor-mediated cardiac responses might have moderately contributed to the discrepancy between the two methods. Even though measurements with TTE were timed at the end of expiration, a deviation of 20% of the averaged CO during a complete respiratory cycle cannot be ruled out [28]. USCOM measurements were not timed within the respiratory cycle. Previous research has shown that repeated CO measurements with thermodilution randomly at different phases of the respiratory cycle substantially affected variation (range of 1.50 L/min) compared to timed repeated measurements (range of 0.47 L/min at end-exhalation) [29].

Compared to TTE, CO in USCOM is based on more heartbeats and velocity time integral complexes, averaging hemodynamic fluctuations. Ideally, when comparing methods, CO should be measured during a similar period, using many more, but at least a comparable amount of cardiac cycles to enable a more accurate comparison. Lastly, as extensively explained by Cecconi et al., fulfilling the 30% criteria of clinical acceptability greatly depends on the precision of the reference technique, which appeared to be moderate for TTE [30]. With a lower precision of the reference measurement, it is more difficult to reach the limit of clinical acceptability for a newly introduced method.

The main strength of our study is the comparison of a new method with a reference method in non-pregnant women, and a broad range of gestational ages in the same women. The possible self-induced biological CO fluctuation through a change in the assessment position was a limitation of our study, as were the untimed USCOM measurements in the respiratory cycle. Moreover, our high-risk population is more likely to have deviant hemodynamic adaptation to pregnancy. Due to the present proportional bias, indicating that CO is underestimated by USCOM in low CO values, and overestimated in high CO values, agreement might be more acceptable within the normal range of CO. However, especially women with deviant adaptation to pregnancy might benefit from CO determination, and a method that replaces echocardiography should be able to accurately identify both a limited as well as a marked increase in CO. We would therefore not recommend

to study agreement of these methods solely in a low-risk population. Taken the proportional bias into account, USCOM provides a rough estimate of CO (low, moderate, high), only allowing to identify women at higher risk of complications.

6. Conclusion

Agreement between USCOM and TTE in pregnancy was outside our a priori determined level of acceptability and absolute values of TTE and USCOM should not be used interchangeably. Optimizing USCOM measurements resulted only in limited improvement in agreement between the two methods. Future research should focus on the clinical consequences and decision-making of the measured CO for the separate techniques.

7. Declarations of interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.preghy.2019.04.003.

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