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Haemodynamic effects from aortocaval compression at different angles of lateral tilt in non-labouring term pregnant women†‡

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Editor's key points

- The supine position can cause aortocaval compression (ACC) in parturients.
- Among 157 term parturients placed supine, none showed a decrease in systolic arterial pressure (AP) or symptoms of ACC.
- Cardiac output was improved by 15° lateral tilt but not by supine or 7.5° lateral tilt.
- All CO measurements were within the normal range. However, 11 patients showed severe caval compression and one also showed aortic compression.
- Measuring changes in CO from two tilt positions allows determination of optimal tilt for positioning a term parturient.

Background. Aortocaval compression (ACC) can result in haemodynamic disturbances and uteroplacental hypoperfusion in parturients. Its detection is difficult because in most patients, sympathetic compensation results in no signs or symptoms. However, profound hypotension may develop after sympathectomy during regional anaesthesia. In this prospective observational study, we aimed to detect ACC by analysing haemodynamic changes in term parturients who were positioned sequentially at different angles of lateral tilt.

Methods. We studied haemodynamic changes in 157 non-labouring term parturients who were positioned in random order at 0°, 7.5°, 15°, and full left lateral tilt. Cardiac output (CO), stroke volume, and systemic vascular resistance were derived using suprasternal Doppler. Non-invasive arterial pressure (AP) measured in the upper and lower limbs was analysed to detect aortic compression.

Results. CO was on average 5% higher when patients were tilted at $\geq$15° compared with <15°. In a subgroup of patients (n=11), CO decreased by more than 20%, without changes in systolic AP, when they were tilted to <15° which was considered attributable to severe inferior vena caval compression. Only one patient in the supine position had aortic compression with the systolic AP in the upper limb 25 mm Hg higher than the lower limb.

Conclusions. Patients with ACC can be identified by the CO changes from serial measurements between supine, 15°, or full lateral tilt. Our findings suggest that in non-labouring parturients, ACC is asymptomatic and can be effectively minimized by the use of a left lateral tilt of 15° or greater.

Keywords: haemodynamics, cardiac output; patient positioning; pregnancy, term birth; ultrasonography, Doppler

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Aortocaval compression (ACC) occurs when the gravid uterus compresses the maternal abdominal aorta and inferior vena cava (IVC). Compression of the IVC impedes venous return which decreases cardiac output (CO), and compression of the aorta may reduce uteroplacental perfusion which may result in fetal acidosis.[1–3] It is recommended that the ACC be avoided by applying lateral uterine displacement. This can be achieved by tilting the operating table, although the effectiveness of this manoeuvre is unclear and the optimal degree of tilt is unknown.

The majority of patients who have ACC are clinically asymptomatic,[4 5] and supine hypotension develops only if ACC is severe, in ~8% of the patients.[6] Patients who are asymptomatic with 'concealed' ACC are able to maintain their arterial pressure (AP), despite a reduction in CO by compensatory mechanisms such as an increased systemic vascular resistance (SVR).[7] However, these patients may develop severe hypotension as a result of sympathetic blockade during spinal anaesthesia.

Previously, ACC was demonstrated in parturients undergoing Caesarean section using radiological angiographic studies.[8 9] However, the invasive nature of this technique makes it impractical for routine use and thus a simple non-invasive method for identifying patients with ACC would be

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useful. Conventional monitoring of AP or heart rate (HR) changes lacks the necessary specificity. Since a direct effect of IVC compression is a decrease in CO,[10] we hypothesized that serial measurements of CO at different degrees of operating table tilt would enable us to identify the presence of IVC compression.

The objective of this study was to measure and analyse changes in CO and other haemodynamic parameters as indicators of the presence of ACC when term parturients are positioned with different degrees of lateral tilt.

Methods

This study received approval from the Clinical Research Ethics committee of the Chinese University of Hong Kong (CREC number CRE-2005.053) and all patients gave written informed consent. The study was conducted over a 20-month period from June 2006 until February 2008. ASA physical status I–II non-labouring term parturients presenting for elective Caesarean section were screened at the antenatal ward and recruited after anaesthetic evaluation the day before surgery. Patients with cardiovascular or cerebrovascular disease, pre-existing or pregnancy-induced hypertension, preeclampsia, or known fetal abnormality were excluded.

Premedication of famotidine 20 mg orally was given the night before and on the morning of surgery. The study was performed in a fully equipped room located in the labour ward before surgery. On arrival, patients were positioned on an operating table that was tilted at 15° to the left. Standard monitoring was applied, including non-invasive AP (NIAP) at 1 min intervals on the left arm, electrocardiography, pulse oximetry, and continuous cardiotocography. A 16 G cannula was inserted into a forearm vein under local anaesthesia. A midwife was present throughout the study to monitor fetal well-being and an obstetrician was available immediately for consultation or emergency intervention. For the purpose of detecting aortic compression, a second NIAP cuff was placed on the patient's left calf for measuring the lower limb AP. Intermittent measurements of CO, stroke volume (SV), and SVR were taken using suprasternal Doppler ultrasound (USCOM® cardiac output monitor, USCOM PTY. Ltd, Sydney, NSW, Australia). This method measures beat-to-beat flow velocity across the aortic valve using continuous-wave Doppler ultrasound. With a validated internal algorithm, the aortic cross-sectional area is estimated based on patients' height, weight, and gender and haemodynamic parameters including CO and SV are calculated. All measurements were performed by a single experienced investigator (S.W.Y.L.).

Repeated haemodynamic measurements were made with patients positioned on the operating table with four levels of left lateral tilt sequentially applied: 0° (lying completely supine), 7.5°, 15°, and 90° (complete left lateral with the hips and knees slightly flexed). An engineering spirit level specially modified for this study was used to ensure accurate application of each level of tilt. A second modified engineering spirit level was placed across the anterior superior iliac spines to confirm that each patient was lying level on the operating table. Repeated haemodynamic measurements were made with patients positioned on the operating table in one of the four levels of left lateral tilt 0° (lying completely supine), 7.5°, 15°, and 90° (complete left lateral with the hips and knees slightly flexed) in a predetermined semi-random sequence. This sequence was structured to generate the same proportion of patients, positioned according to a random order at each tilted position. The sequence was stored in opaque envelopes which would be shuffled and drawn for each patient just before the commencement of the study. Patients were maintained in each tilted position for at least 5 min for the stabilization of haemodynamic parameters before formal haemodynamic measurements were made. The measurements, including brachial AP, lower limb AP, and HR, were automatically measured and data were recorded using a computer program designed by our department. CO, SV, and SVR calculated by the suprasternal Doppler apparatus were automatically recorded by the machine. At the end of the study, patients were transferred to the operating theatre for elective Caesarean section under standard anaesthetic management.

Statistical analysis

Based on a pilot study of 30 term parturients in whom the mean (SD) of CO was 5.5 (1.5) litre min^{-1} and of systolic AP was 110 (12) mm Hg, we estimated that a sample size of 141 patients would have >80% power to detect a 10% difference in CO output between groups with a type I error probability of 0.05. This sample size would also provide 95% power to detect a 10% change in AP with a type I error probability of 0.001. Statistical comparisons were performed using Student's *t*-test or one-way repeated-measures analysis of variance with *post hoc* pairwise comparisons using the Bonferroni test. Bivariate Pearson's correlation was performed to explore the association between AP and CO. Results are presented as mean and SD or median and range where appropriate. A value of $P<0.05$ was considered significant.

Data were summarized and analysed by a non-clinical investigator who was blinded to the sequence order of the tilt positions. For analysis in this study, we considered a ≥20% difference in CO or systolic AP after a change in the tilted position to be clinically significant and attributable to the consequence of IVC compression. Aortic compression was considered present if a difference of >20 mm Hg[11] was detected between the systolic AP measured in the upper and lower limbs.[12 13] Our contingency plan for patients who became dizzy or developed hypotension, defined as two consecutive measurements of systolic AP<90 mm Hg, was to position the patient in the full left lateral position and to restore the AP with i.v. bolus injections of phenylephrine 0.1 mg together with an i.v. bolus of 250 ml of Hartmann's solution.

Results

A total of 170 patients gave consent to participate in the study. Of these, data from 13 patients were excluded because of technical equipment malfunction or measurement artifacts. Two patients were withdrawn from the study after complaining of severe back discomfort from lying on the operating table, which was not associated with nausea, hypotension, or haemodynamic disturbances. The contingency plan was not implemented for any patient as there were no episodes of hypotension or fetal HR abnormalities. All patients were delivered by Caesarean section uneventfully. Data analysis was completed for 157 patients. Table 1 summarizes the patient characteristic data.

Analysis of the haemodynamic parameters with patients at different degrees of table tilts are summarized in Tables 2 and 3. Overall, CO was on average 5% higher when patients were positioned at 15° and 90° (full lateral) tilt compared with 0° (supine) and 7.5° tilt. There were no differences in the CO of patients in the 0° *vs* 7.5° and also 15° *vs* 90° tilted positions. These values are summarized in Table 2 and Figure 1.

We further explored the data by analysing the distribution of individual differences in CO for each degree of tilt (Table 4). A subgroup of patients ($n=11$) who had a $\geq$20% difference in CO between tilted positions were identified (Figs 2 and 3). In these patients, the mean CO was 24.4% (1.9 litre min^{-1}) higher in the 15° tilt compared with the 7.5° tilt position and was 24.5% (2.0 litre min^{-1}) higher in the 15° tilt compared with the 0° tilt position; we consider this to indicate the presence of severe ACC. For the remaining patients ($n=146$), the differences in CO between groups were substantially smaller in magnitude, which suggests the presence of only mild or absent ACC.

Systolic AP was similar between different tilt positions. However, diastolic and mean AP were lower in the 15° tilt compared with the 7.5° tilt position. When the tilt angle was at 15° or full lateral, a higher pulse pressure was observed as a result of a decrease in diastolic and mean AP accompanied by a higher CO. These changes in pulse pressure showed a weak but statistically significant correlation with the changes in CO ($r=0.154$, $P<0.0001$), although the magnitude of the mean difference (5 mm Hg) was small. The SVR was smaller with greater degrees of tilt, which may indicate a decrease in sympathetic tone, when the CO is increased.

Table 1 Patient characteristics. Values are mean (SD) or median (range)

	n=157
Age (yr)	32 (23–39)
Weight (kg)	69.6 (10.7)
Height (cm)	158.0 (6.0)
Body mass index (kg m^{-2})	27.8 (3.6)
Gestation (weeks)	38.4 (37.1–41.6)

In general, changes in AP measured in the lower limb mirrored those measured in the upper limb. In only one parturient, there was a large difference in systolic AP of >25 mm Hg between the upper and lower limbs in the supine position, suggesting the possible presence of aortic compression. Among all the tilt positions, the HR was highest in the supine position.

Discussion

In this study, we demonstrated that significant differences in CO and SVR occurred when non-labouring parturients were positioned at different angles of tilt on the operating table. We consider that these differences represent the effects of ACC that was not otherwise apparent from standard monitoring such as NIAP and HR. CO and pulse pressure were highest at 15° tilt or 90° full left lateral compared with other positions. However, there was no difference in CO or pulse pressure between the 0° and 7.5° tilt positions, implying that ACC was not relieved by 7.5° tilt. Despite the presence of ACC causing a decrease in CO and pulse pressure, all parturients remained asymptomatic and there were no associated changes in the systolic AP or HR.

Previously, Bamber and Dresner[5] measured CO changes secondary to ACC using transthoracic electrical bioimpedance and concluded that a table tilt of up to 12.5° was ineffective for avoiding ACC. In our study, we observed that CO was greater in patients tilted at $\geq$15° compared with those lying supine or tilted to 7.5°; we consider that this indicates increased venous return to the heart when ACC was avoided with the greater degrees of tilt. Moreover, there was no difference in CO between patients positioned at 15° tilt compared with patients in the full lateral position, which implies that positioning the operating table at 15° tilt was maximally effective for avoiding ACC.

We have taken a different approach to analysing the data in our study compared with other studies. In previous studies, changes in CO for all patients, which consisted of data from patients with mild and severe as well as patients with no ACC were considered together.[5 14] Thus, the CO changes in patients with severe ACC may have been diluted or masked by patients without ACC. In this study, as well as detecting the overall difference in CO of 5%, which we interpret as evidence for the presence of ACC, we analysed the distribution of the individual differences in CO of each patient in different tilted positions. Using this method for analysis, we were able to identify patients who had a large difference in CO of $\geq$20% between different angles of tilt which we believe indicates the presence of severe ACC.

Our finding suggests that the degree of ACC varies among individuals which probably reflect a dependence on multiple factors. Clinically, it may be useful to identify parturients who are prone to greater degrees of ACC as these patients might have more pronounced haemodynamic disturbances from sympathetic block during spinal anaesthesia. However, an unexpected finding in 11 patients was that despite a greater than 20% increase in CO in the lateral position

Table 2 CO and haemodynamic parameters for each lateral tilt. Values are mean (SD). *Post hoc* pairwise comparisons were performed for parameters with $P<0.05$. Values with *, †, ‡ or ¶ indicate those with significant differences (corrected $P<0.05$) detected between tilts

	0°	7.5°	15°	90°	*P*-value
Cardiac output (litre Min^{-1})	5.9 (1.3)*,‡	5.9 (1.3)†,¶	6.2 (1.3)*,†	6.3 (1.5)‡,¶	0.001
Stroke volume (ml)	74 (18)	74 (17)	76 (16)	78 (18)	0.055
Systemic vascular resistance (dyn s cm^{-5})	1006 (253)*	1024 (301)†	934 (198)*,†	979 (248)	0.003
Heart rate (beats min^{-1})	81 (13)	80 (13)	80 (13)	82 (13)	0.328

Table 3 AP measurements for each lateral tilt. Values are mean (SD). *Post hoc* pairwise comparisons were performed in parameters with $P<0.05$. Values with *, †, or ‡ indicate those with significant differences (corrected $P<0.05$) detected between tilts

	0°	7.5°	15°	90°	*P*-value
Systolic arterial pressure (mm Hg)					
Upper limb	107 (8)	107 (8)	106 (9)	108 (11)	0.074
Lower limb	138 (16)	138 (17)	139 (17)	140 (18)	0.450
Diastolic arterial pressure (mm Hg)					
Upper limb	58 (7)*	58 (8)†	54 (6)*,†	55 (7)	<0.0001
Lower limb	70 (8)*	69 (8)	68 (8)*,‡	71 (9)‡	0.012
Mean arterial pressure (mm Hg)					
Upper limb	78 (7)*	78 (7)†	75 (8)*,†	76 (11)	<0.0001
Lower limb	90 (10)*	90 (10)†	89 (9)*,†,‡	91 (10)‡	0.015
Pulse pressure (mm Hg)					
Upper limb	48 (8)*	49 (8)†	52 (8)*,†	51 (9)	<0.0001
Lower limb	68 (14)*	68 (15)†	70 (14)*,†	69 (15)	0.026

compared with the supine position (suggestive of severe IVC compression in the supine position), these patients could not be identified using a single measurement of their CO in the supine position, as CO was not significantly reduced compared with other patients. Patients with severe IVC compression could only be identified using serial CO measurements when their CO was found to be significantly higher when IVC compression was relieved at $\geq 15^{\circ}$ tilt.

Although patients with severe IVC compression were expected to have a reduced CO, it is likely that they were able to maintain a normal CO to meet the metabolic demands as a result of compensatory venoconstriction in the lower limbs. This compensatory mechanism increases venous pressure, which pushes blood at a greater rate through the collateral circulations such as the paraspinal veins and azygous veins to facilitate venous return to the heart. Therefore, even when IVC compression is present, CO is maintained at a level similar to patients without ACC. However, at $\geq 15^{\circ}$ tilt when IVC compression is relieved, this produces an enhanced return of blood to the heart resulting in an increase in CO. We also observed that in response to the increase in CO at $\geq 15^{\circ}$ tilt, the SVR decreases, keeping the AP relatively unchanged apart from a higher pulse pressure.

Further research would be of interest to confirm this. Furthermore, the differing degrees of IVC compression as suggested by our findings may partially explain the varying haemodynamic response to spinal anaesthesia and response

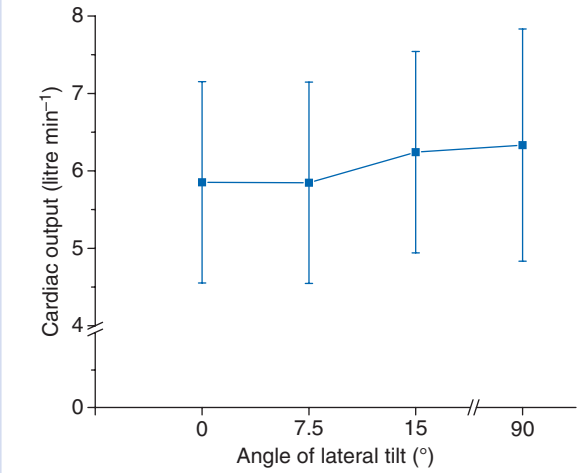

Fig 1 The mean CO changes ($n=157$) for the whole study group at different angles of lateral tilt [mean (SD)].

to treatment of hypotension that is observed both clinically and in research studies.

Our finding that AP measurement is insensitive for detecting ACC mirrors previously reported findings.[15–17] Notably, we did not detect any difference in systolic AP even when marked differences in CO were observed. We found small

Table 4 Changes in CO in the entire study group ($n=157$) and the subgroup with severe IVC compression ($n=11$). Values are mean CO change (% change) (% range of change)

Angles of lateral tilt compared	Δ cardiac output (litre min^{-1}), entire study group ($n=157$)	Δ cardiac output (litre min^{-1}), subgroup with <20% difference in cardiac output ($n=146$)	Δ cardiac output (litre min^{-1}), subgroup with ≥20% difference in cardiac output ($n=11$)
0° *vs* 7.5°	0 (0.1) (−13.7–13.9)	0 (0.1) (−13.7–13.9)	0 (−0.1) (−10.0–10.6)
0° *vs* 15°	0.3 (4.8) (−18.5–36.3)	0.2 (4.3) (−18.5–18.1)	2.0 (24.4) (14.3–36.3)
7.5° *vs* 15°	0.3 (4.8) (−14.0–35.2)	0.1 (3.9) (−14.0–18.3)	1.9 (24.5) (20.0–35.2)

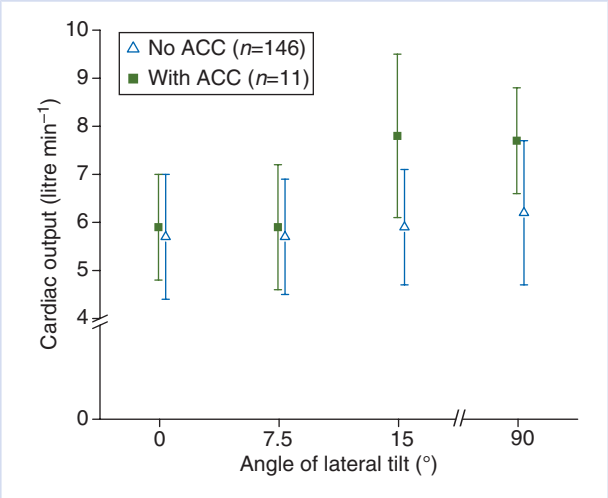

Fig 2 The mean CO changes in subgroup of patients without ($n=146$) and with ($n=11$) severe ACC (CO change of ≥20%) at different angles of lateral tilt [mean (SD)].

changes in pulse pressure that correlated with changes in CO which probably reflects changes in SV when IVC compression was relieved by tilting. However, the change in pulse pressure was small and measuring this change is probably impractical for use clinically to detect ACC.

Because of its simplicity, NIAP is commonly relied on in clinical practice for monitoring the cardiovascular system. However, the limitations of NIAP are shown by our demonstration of the absence of changes in AP measurements in the presence of ACC sufficient to cause changes in CO; this most likely reflects compensatory increases in SVR (Table 2). Previously, Ellington and colleagues[18] reported that only patients with symptomatic ACC who complained of dizziness when lying supine developed hypotension. No significant changes in AP were detected when asymptomatic patients were placed supine or in different tilted positions, even though ACC was probably present in some of these patients.

Imaging techniques have also been used to show the presence of ACC. Early studies utilized angiography[8 9] and IVC pressure measurements[3,19,20] to demonstrate occlusion of the aorta and IVC. With advances in imaging modalities, non-invasive techniques such as magnetic resonance imaging have been used to demonstrate complete IVC compression with engorgement of the epidural venous plexus in near-term parturients lying in the supine position.[21] However, these techniques are likely too impractical and costly for routine clinical screening.

Invasive measurement of CO in parturients using dye or thermal dilution methods have been described previously.[2 17 22] However, because of the risks of complications from these invasive methods, there has been much recent interest in non-invasive monitors of the circulation, such as transthoracic echocardiography,[23] suprasternal Doppler,[14 24–27] and transthoracic electrical bioimpedance.[28 29] In this study, we used the suprasternal Doppler technique which uses continuous-wave ultrasound to measure blood flow across the ascending aorta to estimate CO. Recent reports including our own laboratory animal study have validated the accuracy of its measurement of cardiac function,[30–32] and its ability to detect differences in CO in parturients at different positions for regional anaesthesia[14] and i.v. fluid preload.[26]

There was only one patient in whom we considered we could detect aortic compression, suggesting that this is rare in non-labouring term parturients. Similarly, Kinsella and colleagues[15] reported that aortic compression was not detected in 20 non-labouring parturients at term pregnancy. In contrast, they detected the presence of aortic compression with an incidence of 44% using similar methodology on 32 term labouring patients.[11]

In summary, CO was significantly higher when patients were positioned in the 15° and 90° compared with the 0° and 7.5° tilted positions, indicating that ACC is best relieved when the degree of tilt is ≥15°.

A subgroup of patients had a significant change of ≥20% in CO from serial measurements, suggesting that severe, concealed IVC compression occurs in a minority of patients at <15° tilt. It is important to point out that the CO measured in the supine position for this group of patients was within the normal range; however, when they were tilted, IVC compression is relieved resulting in an increase in venous return and hence CO. This finding suggests that simply measuring the CO in one position will not detect the presence of IVC compression. Instead, this can be achieved by detecting the changes in CO from serial measurements at two different tilt positions, one greater and the other less than 15°. This simple bedside method for detecting ACC allows the determination of an optimal table tilt for positioning term parturient during surgery.

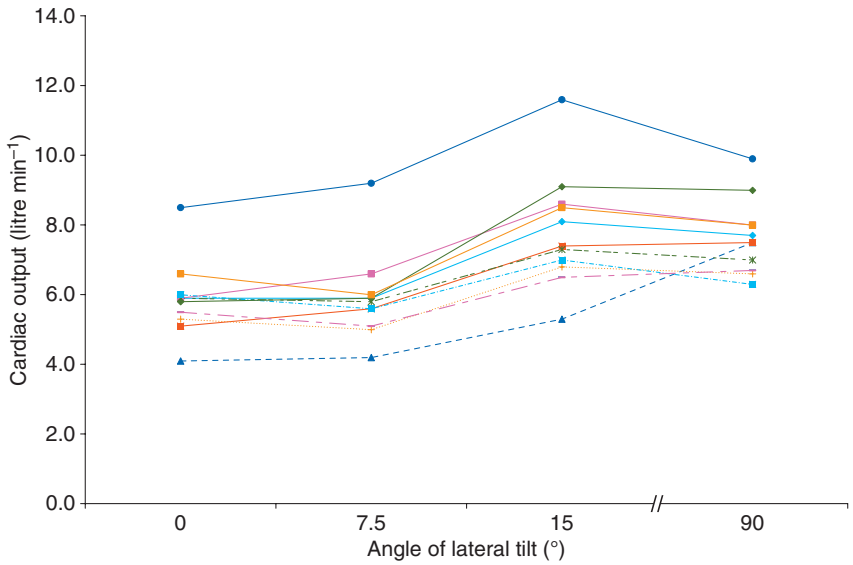

Fig 3 Individual CO changes in individual patients in the subgroup with ≥20% change at different angles of lateral tilt (n=11).

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Declaration of interest

None declared.

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