Aortocaval Compression Syndrome: Time to Revisit Certain Dogmas

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More than 70 years ago, the phenomenon of "postural shock" in the supine position was described in healthy women in late pregnancy. Since then, avoidance of the supine position has become a key component of clinical practice. Indeed, performing pelvic tilt in mothers at term to avoid aortocaval compression is a universally adopted measure, particularly during cesarean delivery. The studies on which this practice is based are largely nonrandomized, utilized a mix of anesthetic techniques, and were conducted decades ago in the setting of avoidance of vasopressors. Recent evidence is beginning to refine our understanding of the physiologic consequences of aortocaval compression in the context of contemporary clinical practice. For example, magnetic resonance imaging of women at term in the supine and tilted positions has challenged the dogma that 15° of left tilt is sufficient to relieve inferior vena cava compression. A clinical investigation of healthy term women undergoing elective cesarean delivery with spinal anesthesia found no difference in neonatal acid-base status between women randomized to be either tilted to the left by 15° or to be in the supine position, if maternal systolic blood pressure is maintained at baseline with a crystalloid coload and prophylactic phenylephrine infusion. This review presents a fresh look at the decades of evidence surrounding this topic and proposes a reevaluation and appraisal of current guidelines regarding entrenched practices. (Anesth Analg 2017;125:1975–85)

Avoidance of the supine position in late pregnancy, to prevent aortocaval compression (ACC) by the gravid uterus, is a fundamental principle in the management of pregnant women, particularly during labor or at cesarean delivery. The negative consequences of ACC were first brought to light over 70 years ago, and much of clinical practice today is based on studies that are now decades old. Most of the clinical studies on which current obstetric anesthesia practice is based were not designed according to current modern standards, failed to account for confounding variables, failed to support maternal blood pressure (BP), and failed to limit the risk of a type 1 error in the context of multiple comparisons.[1–3] New evidence is challenging some previous assumptions about the phenomenon, and the accepted dogma related to ACC syndrome needs to be addressed.

In this review, we examined the body of literature that has accumulated since the 1920s on the effect of the gravid uterus on maternal hemodynamic physiology, encompassing the earliest evidence of obstruction of the inferior vena cava (IVC) based on dye injection studies, to the more recent use of magnetic resonance imaging (MRI). The direct and indirect evidence for compression of the aorta is addressed, as well as the potential for detrimental effects on uteroplacental perfusion. The evidence for the practice of left uterine displacement during cesarean delivery is challenged, and we propose a critical reappraisal of common beliefs.

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HISTORICAL PERSPECTIVES: FROM POSTURAL SHOCK TO "THE SUPINE HYPOTENSIVE SYNDROME"

The earliest report of the phenomenon of maternal postural shock, published in 1942, is attributed to the German obstetrician, Hansen,[4] who incorrectly speculated that the etiology of maternal postural shock was mechanical pressure on the heart by the gravid uterus. In 1951, McRoberts[5] reported on 6 cases of circulatory collapse in the supine position in mid-to-late pregnant women, which could be relieved by transfer to the lateral position or by delivering the fetus. Based on his knowledge of an earlier report describing elevated venous pressure in the lower extremities near-term, he correctly theorized that abdominal venous obstruction by the gravid uterus must cause "a rise in venous pressure caudally and a fall in the pressure in the right auricle."[6]

The term supine hypotensive syndrome was coined by Howard et al[7] in 1953, during observations that 18 (11.2%) of 160 women at term made to lie supine for several minutes experienced either a drop in systolic blood pressure (SBP) of >30 mm Hg or developed an SBP of <80 mm Hg. Several similar reports were published between 1950 and 1960.[8–12] In the first large report on a group of 500 women evaluated during antenatal visits in the last month of pregnancy, Holmes[12] described that 8.2% of women experienced a greater than 30% decrease in SBP when placed supine and 3.6% experienced a decrease by as much as 40% or more, although there was no mention of how symptomatic women were. Supine hypotension tended to become less severe as the patient approached full term, which was thought to be explained by descent of the fetal head into the pelvis.[12]

Significant exacerbation of postural hemodynamic changes with spinal anesthesia was recognized as early as 1950, and several authors separately noted improvement with assuming the lateral position, by performing manual displacement of the uterus or in response to delivery.[8,13–16]

EVIDENCE FOR COMPRESSION OF THE IVC

The gravid uterus begins to compress the IVC in the supine position beginning at approximately the 20th week of pregnancy, with obstruction becoming virtually complete at term.[17,18] The first evidence of IVC obstruction was demonstrated by Runge[6] in 1924. Higher venous pressure in the legs than arms was recorded before delivery, which was followed by a fall in leg venous pressure postpartum.

In 1963, Scott and Kerr[19] validated the premise that IVC compression by the gravid uterus occurs in the supine position and reported near-complete IVC occlusion using direct catheter transducer measurements of IVC pressure in women undergoing cesarean delivery. In almost every case, before delivery, elevated pressure was measured along the length of the vessel (18–24 mm Hg) and only normalized (4–8 mm Hg) above the level of the diaphragm.

In 1964, the same group reported on their evaluation using dye injection via bilateral femoral vein catheterization in supine women at term.[18] Complete obstruction to the passage of contrast medium while supine was demonstrated in 10 of 12 cases, with return of venous flow visualized via collateral channels—the ascending lumbar veins and paravertebral venous plexuses to the azygos veins. In a subset of women rotated to the lateral position, more normal passage of dye upward in the IVC was noted, although some compression was still present.

Recent MRI of term pregnant women substantiates near-complete IVC compression by the gravid uterus at term in the supine position.[20] With 15° of maternal left tilt compared with the supine position, even though a minimal volume increase was noted in half of the subjects, there was no significant increase in IVC volume (Figure 1). With 30° of left tilt, however, IVC volume increased in all subjects, with significant variability in the extent of volume increase.

From a clinical standpoint, despite MRI findings of near-complete IVC occlusion, it is remarkable that over 90% of women at term seem to be asymptomatic and hemodynamically stable in the supine position, which attests to the robustness of maternal intrinsic compensatory mechanisms.[12] Compensation requires peripheral venoconstriction, which promotes venous return via collateral channels, which are believed to develop over the course of pregnancy. This mechanism is blunted after administration of anesthesia, especially following the sympathectomy induced by neuraxial blockade, when women at term are at risk of severe hypotension if unmanaged with vasopressors and fluids.

Maternal Cardiac Arrest

In certain clinical scenarios, left uterine displacement is a crucial life-saving maneuver. During maternal cardiac arrest, relief of IVC obstruction is imperative to facilitate venous return and improve cardiac output. Both the Society for Obstetric Anesthesia and Perinatology (SOAP) consensus statement published in 2014[21] and the American Heart Association (AHA) scientific statement published in 2015[22] recommend manual uterine displacement during cardiac arrest in pregnancy if the uterus is palpable or visible at or above the umbilicus, instead of the 30° left tilt position. Indeed, the tilt position may interfere with the adequacy of chest compressions, and as MRI demonstrates, even 30° of tilt may not completely relieve venous obstruction.[20] The level of evidence for the manual displacement technique is however extremely limited[23]; hence, the proposed recommendation was Class I; Level of Evidence C.[22]

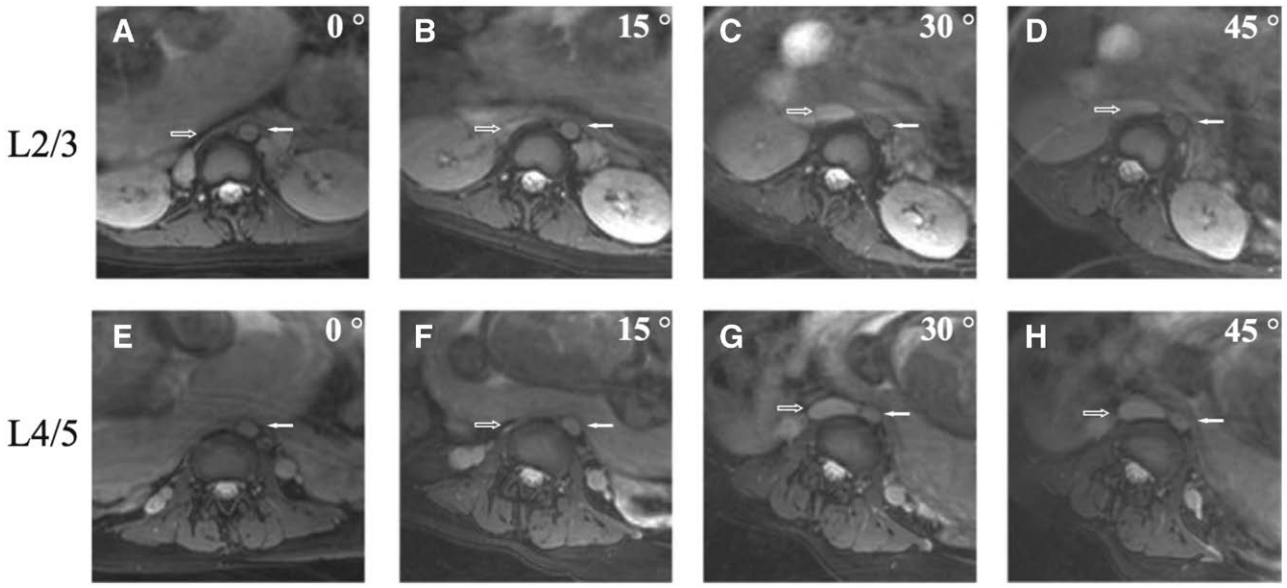

Figure 1. Magnetic resonance images of a 42-year-old pregnant woman (the fetus was in the right occiput position) in either the supine position (A and E) or at 15° (B and F), 30° (C and G), or 45° (D and H) left tilt positions at the L2-3 disk level (A–D) and the L4-5 disk level (E–H). Aortic size (solid arrow) did not change significantly in any position. The inferior vena cava (IVC; outlined arrow) was almost completely compressed, and the shape appeared band-like in the supine position. In the 15° left tilt position, the fetus was moved slightly to the left, slightly reducing IVC compression. IVC compression was significantly reduced in the 30° left tilt position. The IVC was not identifiable in the supine position. In the 30° and 45° left tilt positions, IVC compression was significantly reduced. The abdominal aorta did not divide to the common iliac artery at this level. The aorta was slightly deformed in the 15°, 30°, and 45° left tilt positions. In these axial images, anterior is at the top of the figure, and anatomic right is to the left in the figure. Used with permission from Higuchi et al.[20]

EVIDENCE FOR COMPRESSION OF THE AORTA

The most serious concern related to aortic compression in the supine position is impeded uteroplacental circulation, since the uterine arteries arise distal to the level of compression. Decreased BP or blood flow in the lower extremity relative to the upper extremity in the supine position at late term has widely been interpreted to indicate aortic compression by the gravid uterus. A plethora of modalities have been used to detect such changes (summarized in Table 1).[24–31]

There is limited direct evidence that under normal circumstances significant compression of the thick-walled, high pressure aorta occurs. Coutts et al[35] in 1935 demonstrated filling defects in the common iliac arteries in aortograms performed in women ≥32 weeks' gestation, under spinal anesthesia, presumably in the supine position, as maternal position was not described. The details of the spinal anesthetic, maternal hemodynamics, use of vasopressors, and maternal position were also not reported.

The notion that in the supine position at term, compression of the abdominal aorta by the gravid uterus is commonplace, derives from landmark experiments in 1968 by Bieniarz et al.[24,32] With abdominopelvic arteriography in the supine position in 70 pregnant women ≥27 weeks' gestation (an unspecified proportion of whom were in labor), displacement of the aorta by the gravid uterus was identified in most cases, typically toward the left and dorsally, with narrowing at the L3-5 vertebral levels.[32] Decreased dye opacification in the distal part of aorta and common iliac artery crossing the vertebral column were observed, which was most marked at L4-5 (the level of the lumbar lordosis) when the uterus was relaxed (Figure 2). Among the subset of parturients, significantly increased aortic obstruction and complete iliac occlusion were observed during uterine contractions.

In a second study that same year, Bieniarz et al[24] compared transduced femoral artery BP measurements concomitantly with external sphygmomanometric measurement of the brachial artery in the supine position. During periods of severe maternal hypotension, there were much larger decreases in femoral BP relative to the brachial BP, which provides indirect evidence of aortic compression during severe hypotension. In cases where the BP subsequently improved, the disparity between femoral and brachial BP decreased.

Investigators in the 1970s continued to focus on the impact of maternal supine position on lower extremity BP relative to upper extremity BP, as evidence of aortic compression by the gravid uterus.[27,28,34] Episodes of lower extremity hypotension were reported to occur more frequently (25%–60%) than upper extremity hypotension (18%), and during severe hypotension, lower extremity SBP tended to be even lower, relative to upper extremity SBP.[27,28,34] Marx et al[28] detected femoral hypotension as early as 19 weeks' gestation, with the peak occurrence at 28 to 32 weeks. Brachial hypotension was only detected after week 28. Factors associated with more severe decreases in lower extremity BP were lack of fetal head engagement and uterine contractions.

Table 1. Studies Comparing Upper Versus Lower Extremity Blood Pressure or Flow in the Supine Position During Late Pregnancy

Author, Year	Technique	Measurement Locations and Parameter	Positions Studied
Bieniarz et al,[32] 1968	External sphygmomanometry—brachial intra-arterial pulse contour—femoral	Brachial BP, femoral BP	Supine
Goodlin,[25] 1971	Photoelectric plethysmographic probes—hallux, finger, vaginal apex	Finger, hallux, vaginal apex—pulsations	Supine
Goodlin,[26] 1971	Photoelectric plethysmographic probes—hallux	Hallux—pulsations	Supine, lateral, or semilateral
Eckstein and Marx,[27] 1974	Riva-Rocci method—arm, leg	Brachial BP, femoral BP	Supine, left lateral, right hip wedge, LUD with Colon-Morales or Kennedy displacer
Drummond et al,[33] 1974	Strain gauge method	Right calf and forearm	Supine, left lateral
Abitbol,[34] 1977	Brachial ultrasonic instrument combined with a cuff transducer—femoral and/or popliteal	Arm BP—not specified femoral and/or popliteal BP	Supine, lateral (side not specified)
Marx et al,[28] 1980	Riva-Rocci method—right arm, right leg	Brachial BP, femoral BP	Supine, left lateral, "roll over test"
Janbu,[29] 1989	Pulsed Doppler ultrasound—foot, wrist	Dorsalis pedis—blood velocity Radial artery—blood velocity	Supine, lateral (side not specified)
Kinsella et al,[31] 1990	Finapres digital arterial pressure—finger, hallux photoelectric plethysmograph—toe	Right hallux, toe—pulse pressure right middle finger—digital arterial pressure	Resting position (not specified), left pelvic tilt, right pelvic tilt
Kinsella et al,[30] 1990	Perivein strain gauge plethysmography—right leg	Right leg—blood flow	Supine, left lateral, left or right pelvic tilt
	Continuous-wave Doppler ultrasound	Left ankle—mean arterial pressure	
	Accutorr 2 device—left ankle	Brachial, femoral, uterine umbilical artery—arterial flow velocity waveforms	

Abbreviations: BP, blood pressure; LUD, left uterine displacement.

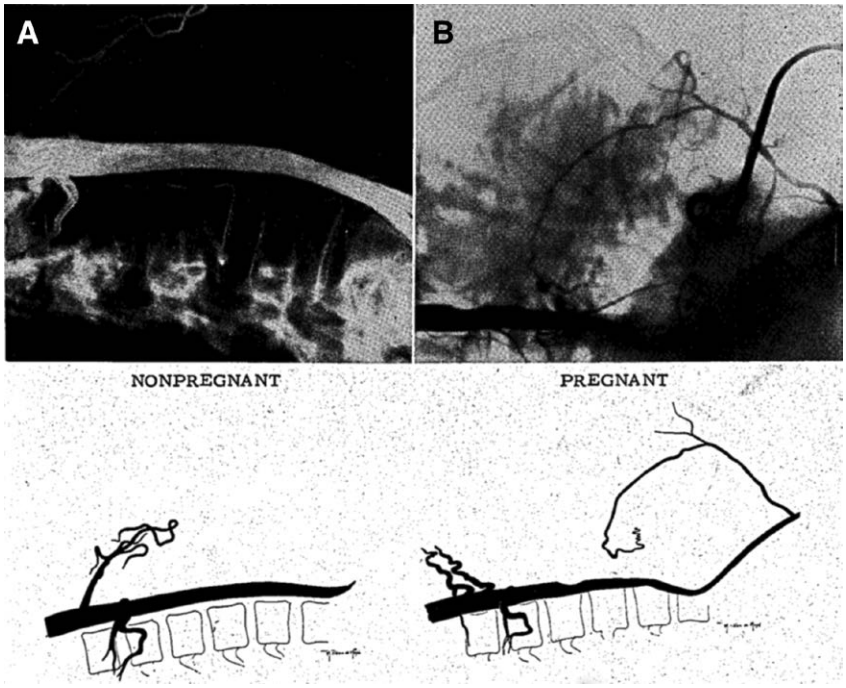

Figure 2. A, Lateral angiogram of a nonpregnant woman in the supine position, showing a clear gap between the vertebral column and an aorta with uniform width, indicating no compression. Drawing of the same below. B, Lateral angiogram during late pregnancy, showing the aorta being displaced dorsally, encroaching on the spine, and narrowed at the level of the lumbar lordosis. Drawing of the same below. Used with permission from Bieniarz et al.[32]

By the 1980s and 1990s, the research focus shifted to studies of lower extremity blood flow relative to upper extremity blood flow, with variable findings.[29–31,33] Janbu[29] recorded wide fluctuations in Doppler ultrasound lower extremity blood velocity among parturients without epidural analgesia (n = 11), which was believed to be secondary to increased sympathetic outflow due to pain, since increased velocities were also recorded in the radial artery. Among patients receiving labor epidural analgesia (n = 16), blood flow in the lower extremities was unchanged in both supine and lateral positions, which raised the question of whether sympathetic blockade from neuraxial anesthesia helps preserve both lower extremity blood flow and uteroplacental perfusion, provided maternal BP is supported.

Kinsella et al[31] used the Finapres digital arterial pressure instrument with probes placed simultaneously on a toe and finger, in 32 women at term, of whom 29 were in labor, to detect reversible decreases in toe pulse pressure and plethysmographic pulse amplitude. Measurements were performed with the women tilted using a Crawford wedge in 15° left tilt (n = 32), in 15° right tilt (n = 21), and in the supine position (n = 4). Episodes of decreased toe pulse pressure, which were believed to represent aortic compression, occurred in 12 of 32 women in left tilt, 5 of 21 in right tilt, and 2 of 4 while supine. The investigators attempted to relieve the apparent aortic compression by incrementally increasing the degree of pelvic tilt until the pulse pressure returned to baseline. Episodes of decreased toe pulse pressure were observed at degrees of tilt even as high as 34°. Despite the presumed aortic compression in some women, no fetal heart rate (FHR) abnormalities were observed, which was attributed to collateral placental supply from the ovarian arteries.[36,37]

Kinsella et al[30] also evaluated leg blood flow during change of position from left lateral to supine using strain gauge plethysmography in women in late gestation. In the supine position, a 45% reduction in leg blood flow was noted despite no change in leg BP, which was attributed to IVC rather than aortic compression. No positional changes in arterial resistance using Doppler assessment were found in the femoral, brachial, uterine, or umbilical arteries, suggesting no compensatory vasoconstriction. The authors concluded that leg BP and Doppler ultrasound measurements of uterine artery resistance may not be adequate measures of the positional effects on uteroplacental perfusion.

As early as 1977, evidence began to emerge that during normotension the aorta appears more likely to be displaced than compressed in the supine position. Abitbol[34] described the aorta as "slippery," when external manual compression with weights was attempted in 44 postpartum patients. For the same weight, the pulse pressure drop (palpated in the popliteal artery) was barely noticeable in cases of hypertension, average in normotension, and severe in hypotension. For example, with a 4-kg weight, the pulse pressure drop was nil with a BP of 148/94 mm Hg, 70% with a BP of 110/73 mm Hg, and 100% with a BP of 92/47 mm Hg.

Recent MRI studies were unable to demonstrate compression of the aorta by the gravid uterus in the supine position in healthy pregnant women without anesthesia.[20,38] In 2015, Higuchi et al[20] easily identified the aorta in all subjects (n = 10, gestational age 37–39 weeks, BMI ≤ 30 kg/m^2) on MRI and found no significant difference in volume between the supine position and any left lateral tilt position (15°, 30°, and 45°). The bilateral common iliac arteries distal to the bifurcation could not be evaluated because of MRI low resolution, which raises the possibility of more distal obstruction. In 2016, Saravanakumar et al[38] reported MRI findings of 6 obese term women undergoing MRI in various positions; aortic compression was said to be "only just noticeable in the supine position"; however, poor resolution of images precludes firm conclusions.

Taken together, MRI findings do not suggest significant aortic compression, by the gravid uterus, although the distal aorta is usually poorly visualized.[20,38] No study has evaluated aortic compression in the presence of hypotension or while under neuraxial anesthesia. Furthermore, neither the impact of fetal head engagement nor that of uterine contractions on the degree of aorta/iliac artery impingement by the gravid uterus has been robustly described using contemporary imaging techniques. Both lack of fetal head engagement[12,27,34,39] and uterine contractions[29,31,34] have been implicated as factors exacerbating the severity of ACC. Overall, the degree and significance of aortic compression by the gravid uterus during neuraxial anesthesia, in the setting of hypotension, and during uterine contractions, remains debatable.

THE EFFECT OF ACC ON UTEROPLACENTAL PERFUSION

Despite various evaluations over decades, it remains unclear whether reported decreases in blood flow and BP in the lower extremities directly correlate with diminished uteroplacental perfusion pressure/flow.[24,28,29,31] The impact that ACC may have on uteroplacental perfusion is not fully understood, and a variety of techniques have been used to evaluate the impact of ACC on umbilical and placental blood flow in late pregnancy.

Preferential perfusion of the placenta was revealed by Bieniarz et al[40] in 1969 with serial abdominopelvic angiography in 70 supine nonlaboring "late pregnant women." Venous drainage was observed via ovarian plexuses (essentially bypassing the IVC). The 2 mechanisms, preferential perfusion and ovarian venous drainage, were suggested to be protective with respect to preserving uteroplacental perfusion and may partially compensate for any negative effects of ACC.

Radionuclide studies suggest that there is a decrease in intervillous flow associated with the maternal supine position in late pregnancy. Suonio et al[41] in 1976 compared uteroplacental blood flow in 15° left lateral tilt with the supine position using the ^{99m}Tc accumulation method, in 10 women with gestational age between 33 and 42 weeks. Placental blood flow was determined after 20 minutes in each position. Although the 17% decrease in blood flow reported was not statistically significant, the study appears to have been underpowered to detect a difference. Using Xe washout in 1980, among 22 nonlaboring women with gestational age between 36 and 40 weeks, Kauppila et al[42] did find 19% lower intervillous blood flow in the supine position (113 ± 48 mL/min/dL) than the left-tilted 45° position (141 ± 48 mL/min/dL; $P < .01$). The patients spent 15 minutes in each position. Myometrial blood flow was similar in both positions, suggesting that the autoregulation occurs only in the nonplacental component of uterine circulation of the gravid uterus. The greater degree of left lateral tilt (45°) used may have been more effective in reducing IVC compression and could be partially responsible for the significantly improved intervillous flow in the tilted position that was not observed at 15° of tilt in the study using the ^{99m}Tc accumulation method.

Mean umbilical blood flow velocity wave systolic peak to diastolic trough (S/D) ratios were reported by Marx et al[43] in 1986 to be significantly higher in the supine (2.52 ± 0.48) than in either right or left lateral positions (2.16 ± 0.41; $P < .001$) among 16 parturients, 12 of whom received epidural analgesia, indicating increased umbilical artery (UA) vascular resistance in the supine position, but the ratios were all within the range of normal. The recordings were made after spending 3 to 5 minutes in each position. There was no difference in umbilical flow velocity wave S/D ratios between left and right side positions in 2 subjects, ratios were lower on the left than right in 9 subjects, and in 5 subjects the ratios were lower on the right than left. Interestingly, when the effect of epidural analgesia alone was assessed (n = 16, including the 12 women for whom the effect of position was also assessed), the S/D ratios did not change after epidural blockade in 3 and were variably decreased in 13, which may indicate the beneficial effects of sympathetic blockade on UA vascular resistance.

In contrast, Witter and Besinger[44] in 1989 found no influence of the lateral decubitus and supine positions on uterine artery flow velocity waveforms using continuous wave Doppler techniques during nonstress testing in 10 nonlaboring women, suggesting no significant effect of maternal position on uterine artery hemodynamics; however, the small sample size may not have provided sufficient power to detect a difference. The time spent in each position was not reported. Of note, the nonstress tests in 2 of 10 patients became nonreactive in the supine position.

Pirhonen and Erkkola,[45] in 1990, recorded uterine artery S/D ratio in both the supine and the lateral position in 10 nonlaboring women with a known history of dizziness in the supine position. When moved from left lateral to the supine position, the observed decreases in mean arterial pressure (MAP) (mean 19%) were associated with an increase of 26% in uterine artery S/D ratio ($P = .002$). The authors noted that after being positioned supine, the MAP remained stable for 5.4 ± 1.3 minutes before beginning to decrease; decreases in MAP by >15 mm Hg then occurred within approximately 2 minutes after the initial decline. The increases in uterine artery S/D ratio occurred more slowly and recovered more quickly than the MAP. Two of 10 women developed transient FHR decelerations in the supine position simultaneous with an increase in UA S/D ratio. One was symptomatic with a clinically significant decrease in FHR from 130 to 80 beats/min for 2 minutes, whereas the other was asymptomatic with a decrease in FHR from 150 to 120 beats/min for 4 minutes, a change which was not clinically significant. The findings support avoidance of the supine position in women who have documented symptoms of supine hypotensive syndrome.

Fetal Compromise

The supine position, even in the absence of maternal anesthesia, hypotension, or symptoms, has been implicated in possible negative consequences for the fetus. A recent study involving third trimester women with uncomplicated singleton pregnancies (n = 29) demonstrated that maternal supine position was more frequently associated with fetal quiescence and reduced FHR variability compared with the left lateral position.[46] The findings suggest that the fetus may be responding with adaptive behaviors to reduce oxygen consumption. Additionally, maternal nonleft lateral sleep position,

particularly the supine sleep position, has been associated with late-pregnancy stillbirth in the compromised fetus.[47] Apart from ACC, one possible reason is decreased maternal Po_2 produced by the supine position, particularly among women with disordered breathing during sleep. The duration of exposure to the supine position may be an important factor in assessing the adverse effects of maternal position.

IVC obstruction by the gravid uterus has been implicated as a cause of placental abruption. Mengert et al[48] attributed the phenomenon to venous congestion, based on their observation of premature separation of the placenta during cesarean delivery in 2 women, subsequent to intentional digital compression of the IVC before delivery. Howard et al[7] had similarly observed the development of placental abruption in 1 of 5 late pregnant dogs during experimental ligation of the IVC; however, there is limited evidence to support IVC compression as a significant cause of placental abruption.

EFFECTS OF THE SUPINE POSITION ON MATERNAL CARDIAC OUTPUT

Decreased venous return secondary to IVC compression by the gravid uterus in the supine position is typically associated with a decrease in maternal cardiac output (CO), with or without a concomitant change in BP. Because CO has been shown to be significantly correlated with UA pulsatility index (difference between peak systolic and diastolic velocity divided by the mean velocity), yet no correlation has been found with BP or heart rate (HR)[49]; there is concern that unrecognized decreases in CO may have a detrimental impact on uteroplacental perfusion.

A range of modalities, both invasive[17,39,50,51] and noninvasive,[20,52–56] have been utilized to quantify the global hemodynamic effects of the supine position in late pregnancy; not surprisingly, earlier studies from the 1960s relied on more invasive dye-dilution techniques (summarized in Table 2). The typical changes associated with the supine position include decreased right atrial pressure, increased systemic vascular resistance (SVR), increased HR, and decreased CO (from 5% to 21%) compared with the lateral or semilateral position. SBP appears to be maintained by a concomitant increase in SVR.

There has been little uniformity among studies describing maternal CO changes with position during late pregnancy. Specifically, studies have varied with respect to the modality used, laterality of positioning, and the degree of tilt. Furthermore, many techniques utilized to measure CO have not been validated during pregnancy.

With bioimpedance cardiography, Bamber and Dresner[53] assigned patients (n = 33) who were at 38 to 40 weeks'

Table 2. Cardiac Output Studies in Late Pregnancy Comparing Supine Versus Tilted or Lateral Position

Author, Year	Technique	Positions Compared	Decrease in Cardiac Output (Supine Versus Lateral/Tilt)	Decrease in Stroke Volume (Supine Versus Lateral/Tilt)
Vorys et al,[50] 1961	Dye-dilution spectrophotometry	Supine versus left lateral	13.5%	n.r.
Lees et al,[39] 1967	Indocyanine dye-dilution	Supine versus right lateral (measured twice)	12% (4.9)[a]	9% (4.1)
			14% (2.6)[a]	12% (4.3)[a]
Ueland et al,[17] 1969	Indocyanine dye-dilution	Supine versus lateral (side not defined)	28.5%[a]	n.r.
Newman et al,[52] 1983	Transcutaneous aortovelography	Supine versus left lateral	0.18%	n.r.
		Supine versus 15°° left tilt	2.16%	
Clark et al,[51] 1991	Direct Fick technique	Supine versus left lateral	9%[a]	n.r.
Danilenko-Dixon et al,[56] 1996	Acetylene rebreathing	2 separate groups managed either in supine versus left lateral position	Baseline difference between groups	Baseline difference between groups
			21%	21%
Bamber and Dresner,[53] 2003	Bioimpedance cardiography	Supine versus right and left—12.5°, 5° tilt	18%	n.r.
			Left tilt 12.5°°	
Lee et al,[54] 2012	Suprasternal Doppler	Supine versus left 90°, 15°, 7.5° tilt	5%	5% (supine versus lateral)
			Left tilt ≥15°	
Rossi et al,[57] 2011	Cardiac magnetic resonance imaging	Supine versus left lateral	24%[a]	35%*
Nelson et al,[55] 2015	Cardiac magnetic resonance imaging	Supine versus left lateral (all groups)	16%	[a,b]
		Supine versus left lateral (normal weight)	[a,b]	18[a]
		Supine versus left lateral (obese patients)	n.s.[b]	
Higuchi et al,[20] 2015	Thoracic bioimpedance	Supine versus left 15°°, 30°°, 45°° tilt	<4%	n.r.
			n.s. at left tilt ≥15°°	

Values are mean and standard error of the mean when reported.
Abbreviations: n.r., not reported; n.s., difference not statistically significant.
[a]Statistically significant values.
[b]Magnitude of difference not reported.

gestational age to different degrees of right tilt, left tilt, and the supine position, in random order. Notably, they demonstrated no significant increase in CO from the supine position (mean 6.5 ±1.4 L/min; 95% confidence interval [CI], 5.9–6.9; n = 31) to left table tilt of 12.5° (mean 7.0 ± 1.6 L/min; 95% CI, 6.4–7.5; n = 33), although a more marked increase was noted in the full left lateral position (mean 7.7 ± 1.9 L/min; 95% CI, 7.0–8.5; n = 33). The volunteers spent 2 minutes in each position before taking measurements over a 3-minute period.

With suprasternal Doppler performed on women with mean gestational age 38.4 weeks (n = 157), Lee et al[54] compared 4 levels of left lateral tilt (0° [supine], 7.5°, 15°, and 90°). Maternal CO was on average 5% higher in positions ≥15° ($P = .001$) compared with the supine position. Measurements were made after a period of at least 5 minutes in each tilted position. Notably, 11 of 157 (7%) patients exhibited CO decreases >20% in 7.5° and 0° of tilt compared with the 15° left tilted position, which the authors felt represented severe ACC compression. It was suggested that CO measurements in the supine and 15° or full left lateral tilt positions might be used to identify patients with ACC. Lower SVR and pulse pressure were seen with greater degrees of tilt, probably indicating a decrease in sympathetic tone when CO is increased. Noninvasive sphygmomanometry was performed by placing a cuff on the left arm and left calf. Only one patient showed an arm SBP 25 mm Hg higher than the lower limb, which was believed to represent aortic compression.

Compared with baseline CO measured after 30 minutes in the left lateral recumbent position using the direct Fick technique (n = 10), Clark et al[51] reported that the standing position led to a much greater decrease in CO (18%; $P < .05$)

Table 3. Studies Evaluating the Effect of Tilted Versus Supine Maternal Position During Cesarean Delivery on Neonatal Outcome

Author, Year	Maternal Positions	Randomized (N)	Mode(s) of Anesthesia (n)	Vasopressor Use	Significant Findings, Mean (SD)
Ansari,[66] 1970	10° left tilt versus supine Tilted position avoided in cases of "fetal distress"	No (N = 65)	Spinal (n = 35) tilt, n = 13 supine, n = 22 General (n = 30) tilt, n = 6 supine, n = 24	Spinal group: ephedrine—31/35 phenylephrine—4/35 none for general group	Spinal group: mean UA Sao_2 (%): tilt = 25 ± 16.6 supine = 14 ± 10.1 $P < .05$ Mean UV Sao_2 (%) tilt = 64 ± 16.0 supine = 45 ± 18.2 $P < .005$
Crawford et al,[2] 1972	15° left or right tilt versus supine majority in tilt group tilted right	No (N = 150)	General (n = 150) tilt, n = 63 supine, n = 87	Not described	Mean UA pH: Tilt = 7.309 ± 0.039 Supine = 7.27 ± 0.091 $P < .001$ Mean UA Pco_2 (mm Hg) Tilt = 54.65 ± 7.23 Supine = 60.37 ± 12.24 $P < .001$
Clemetson et al,[1] 1973	10° left tilt + 10° leg elevation versus supine	No (N = 53)	Spinal (n = 20) tilt, n = 10 supine, n = 10 general (n = 33) tilt, n = 17 supine, n = 16	Ephedrine—7/20 spinal cases	Spinal group: UV Sao_2 (%) tilt = 65.2 ± 13.36 supine = 45.2 ± 10.88 $P < .002$
Downing et al,[3] 1974	10° left or right tilt versus supine majority in tilt group tilted right	Yes, process not described (N = 100)	General (n = 100) tilt, n = 50 supine, n = 50	Not described	UA pH[a] tilt = 7.260 (0.005) supine = 7.242 (0.006) $P < .05$ UA Sao_2 (%)[a] Tilt = 34.9 (2.2) Supine = 28.5 (2.2) $P < .05$ UA BD (mEq/L)[a] Tilt = 7.9 (0.4) Supine = 9.4 (0.5) $P < .05$ UV Po_2 (mm Hg)[a] tilt = 33.9 (1.0) Supine = 29.9 (1.0) $P < .01$ UV Sao_2 (%)[a] tilt = 71.7 (1.8) supine = 63.3 (2.0) $P < .005$
Lee et al,[58] 2017	15° left tilt versus supine	Yes (N = 100)	Spinal (n = 100) tilt, n = 50 supine, n = 50	Phenylephrine infusion titrated to maintain baseline maternal SBP	No significant differences between groups

Values presented are mean ± SD, except where indicated.
Abbreviations: BD, base deficit; SBP, systolic blood pressure; UA, umbilical artery; UV, umbilical vein.
[a]Values are mean (SE mean).

than the supine position (9%; $P < .05$). Measurements were made after spending 10 minutes in each position.

Cardiac magnetic resonance imaging (c-MRI) is considered to have greater accuracy and reproducibility than other noninvasive techniques. Using c-MRI, Rossi et al[57] reported a 24% ($P = .012$) increase in CO in the left lateral position compared with the supine position in 8 women at 32 weeks' gestation. In a second study using c-MRI, Nelson et al[55] reported a nonsignificant difference in CO in the left lateral position compared with the supine position in women at gestational age 32 to 36 weeks ($P = .067$); however, this may reflect an insufficient sample size (n = 23).

LEFT UTERINE DISPLACEMENT DURING CESAREAN DELIVERY

The dogma that left lateral tilt during cesarean delivery must be maintained until delivery, to prevent ACC and negative effects on uteroplacental perfusion, is based on a handful of studies from the 1970s (summarized in Table 3), stipulating that women tilted during cesarean delivery had superior neonatal outcomes compared with women kept in the supine position. The reports were published in the context of avoidance of vasopressors due to fears about uterine artery vasoconstriction. Most were not randomized trials, patients received varied anesthetic approaches, and many patients underwent surgery in the right tilted position because of surgeon preference. The relevance of these studies is questionable considering the dramatic departure from contemporary study design and clinical practice that now incorporates superior control of maternal hemodynamics, using more ideal vasopressor agents such as phenylephrine.[59]

A report in 1971 by Goodlin[25] brought attention to the link between ACC and neonatal depression during cesarean delivery, among a cohort of women receiving either general (n = 26) or neuraxial (spinal or epidural; n = 21) anesthesia in the supine position. The women were monitored using photoelectric plethysmographic probes placed in the vaginal apex, a hallux, and a finger. ACC was diagnosed in 7 of 47 women based on a decrease or disappearance of pulsations from the vagina or hallux probes in conjunction with upper extremity hypotension of SBP 80 to 100 mm Hg (n = 3) or SBP ≤80 mm Hg (n = 4). Newborn depression occurred in 5 of the 7 cases. The 1-minute Apgar was <4 in 3 cases, 4 to 7 in 2 cases, and ≥7 in 2 cases. Only 1 of the 7 women had received general anesthesia, pointing to the increased risk of severe hypotension associated with neuraxial blockade.

In 1972, Crawford et al[2] published the most influential study to date evaluating the effect of lateral tilt by means of a wedge versus the supine position on the incidence of "birth asphyxia" in term women undergoing cesarean delivery under general anesthesia. The report made no comment regarding vasopressor use, and intravenous fluids administered were either 5% dextrose water or 5% laevulose in water. Because of surgeon preference, most patients in the tilted group were actually tilted to the right side. The investigators reported that there was a statistically significant difference in mean UA pH of 7.309 ± 0.039 for the tilt group compared with 7.27 ± 0.091 for the nontilt group ($P < .001$); however, this difference is not clinically meaningful. No difference was found between groups with respect to UA base excess (UA-BE). Subsequently, the "Crawford wedge," designed for the purpose of instituting left uterine displacement, became highly popular, likely contributing to the disproportionate impact of the study's findings on clinical practice.

In 1974, Downing et al[3] randomly assigned women undergoing elective cesarean delivery with general anesthesia to be placed supine (n = 50) or in the right or left 10° tilted position (n = 50). The majority of women in the tilt group were tilted right because of surgeon preference. The authors reported significant findings were lower mean UA and umbilical vein (UV) Sao_2, UA pH, and UV Po_2 and higher UA base deficit ([9.4 (SEM 0.5] mEq/L in the supine group versus the tilted group 7.9 [SEM 0.4] mEq/L; $P < .05$). However, when accounting for multiple comparisons, the only difference between groups approaching statistical significance was the UV Sao_2.

It is well documented that 15° of tilt is almost never achieved in practice.[60,61] In 2003, Jones et al[60] observed that during elective cesarean delivery, nearly all of 16 different anesthetists positioned their patients in less than 15° left table tilt because they overestimated the angle of tilt. In 2016, Aust et al[61] similarly reported that 75 of 100 patients undergoing cesarean delivery with 21 anesthetists were tilted less than 15° despite previous implementation of a training program in left lateral positioning for cesarean delivery with neuraxial anesthesia. Furthermore, only 3% of obstetricians tolerated the 15° tilted position intraoperatively; the vast majority requested a reduction in the degree of tilt due to impaired surgical conditions.[61] In addition, 76% of patients expressed discomfort with being tilted, complaining of feelings of sliding or toppling.

Because of the challenges maintaining 15° of tilt continuously until delivery, anecdotally, a compromise practiced in many institutions is to utilize left uterine displacement or table tilt immediately following induction of anesthesia, throughout the period of Foley catheter insertion, abdominal preparation and draping, then flattening the surgical table at the time of incision. This compromise may temporarily support maternal hemodynamics and decrease vasopressor requirements until surgery begins.

A REAPPRAISAL OF THE LEFT UTERINE DISPLACEMENT DOGMA DURING CESAREAN DELIVERY

With anesthesiologists routinely misjudging the degree of tilt, a large proportion of women disliking the tilt position and feeling unsafe at 15° of tilt, and most obstetricians finding that this degree of tilt increases the technical difficulty of surgery, routine lateral tilt during cesarean delivery may not be necessary with current obstetric anesthesia practice. For all these reasons, we designed a randomized clinical trial to evaluate the effect (or lack of effect) of 15° left tilt position in healthy women (n = 100) undergoing an elective cesarean delivery with spinal anesthesia with current hemodynamic management that includes crystalloid coloading and a phenylephrine infusion.[58] The study was designed as a noninferiority trial, with a sample size of 50 per group, based on a tolerance limit of 1 mmol/L for our primary outcome, UA-BE, for a 2-tailed analysis with alpha 0.5 and 90% power. Of note, this question had not been reevaluated for elective cesarean delivery since the study published by Downing et al,[3] over 40 years ago.

Women receiving a standardized spinal anesthetic, with a phenylephrine infusion to maintain SBP at baseline values, were randomized to being either in the supine horizontal position (n = 50) or in 15° left tilt position (n = 50). Cardiac output measurement using the noninvasive hemodynamic monitoring system (NICOM; Cheetah Medical Inc, Vancouver, WA) was recorded at baseline in each position and every minute after administration of anesthesia. No differences were found with respect to UA-BE, other umbilical gas parameters, Apgar scores, or need for resuscitation. The UA-BE (mean ± SD) in the supine group was −0.5 ± 1.6 mmol/L vs −0.65 ± 1.5 mmol/L in the tilt group (P = .64). During the first 15 minutes, a trend toward significantly lower CO was noted in the supine group (P = .014). Phenylephrine requirements were higher in the supine group—at 15 minutes after intrathecal injection, the mean dose was 789 ± 321 μg in the supine group vs 611 ± 228 μg in the tilt group (P = .002), a difference which is probably not clinically consequential. Indeed, there were no differences in maternal or neonatal outcomes that could be attributed to this 20% to 30% increase in vasopressor dose, which was similar to the effective dose range for phenylephrine infusions previously reported by Ngan Kee et al,[62] and considered to be safe among healthy women with uncomplicated pregnancies that were positioned in left uterine displacement for cesarean delivery. One patient in the tilt group exhibited the signs and symptoms of supine hypotensive syndrome after 3 minutes in the supine position before administration of anesthesia.

A randomized trial in 1998 reported no apparent benefit to maternal left tilt during emergency cesarean delivery; however, the findings did not appear to be valid.[63] Subjects were parturients ≥36 weeks' gestation (n = 204) randomized to the supine or 20° left tilt position, receiving a nonstandardized either spinal or general anesthetic, the choice of which was selected at the discretion of the anesthesiologist. The 3 most common indications for delivery were "fetal distress," cephalopelvic disproportion, and failed induction of labor. Ephedrine was the vasopressor used in one patient. The authors reported that slightly lower UA pH and Pco_2 were found in the supine group compared with the lateral group, but the difference was not statistically significant. The base deficit was also lower in the supine group, which is an impossible combination physiologically. There was also a higher Po_2 in the supine group, which is an unlikely finding.

Additional well-conducted studies are warranted to corroborate our findings and to examine the value of positioning with left tilt women with comorbid conditions such as obesity or hypertension and with a compromised fetus; these women were not evaluated in our study. Future work should also focus on how to recognize women who would benefit from being tilted intraoperatively, since tailoring intraoperative management to women's specific susceptibility to hypotension will be most beneficial.

Indeed, Holmes[12] had already identified in 1960 that interindividual differences in the degree of supine hypotension may also be related to anatomical differences such as the distance between T12 and S1, the degree of lumbar lordosis, the size of the uterus, and uterine tone. To that effect, Kinsella and Norris[64] proposed in 1996 a preoperative "supine stress test" for women undergoing cesarean delivery with spinal anesthesia, defined by an increase in maternal HR >10/min or leg flexion movement after lying supine for 5 minutes. They found that a "positive test" was associated with a 4.1 times higher incidence of intraoperative severe systolic hypotension (BP < 70% baseline) than for those with a "negative test," with a sensitivity of 75% (97% CI, 48%–93%) and a specificity of 82% (95% CI, 48%–98%). Mean intraoperative ephedrine dose was twice as common in patients with a positive test (30.7 ± 14.5 mg vs 13.5 ± 9.9 mg; P = .0014). We believe that such preoperative screening will allow clinicians to identify the subset of women who may benefit from left uterine displacement.

CONCLUSIONS

Current evidence indicates that in the supine position at term, virtually complete IVC obstruction is present and begins to be significantly relieved only at 30° of tilt or higher. The aorta appears more likely to be displaced than obstructed in normotension. Left uterine displacement does not appear to be practical and may not be necessary during elective cesarean delivery in healthy women and fetuses, if maternal BP is maintained at baseline with vasopressors. However, in women at term, particularly during episodes of maternal hypotension or fetal compromise, there is benefit to placing the parturient in the lateral position to maximize cardiac output and uteroplacental perfusion, and lateral positioning is considered to be a therapeutic maneuver. During maternal cardiac arrest in late pregnancy, current guidelines recommend manually displacing the uterus and keeping the patient in the supine position to allow effective resuscitative efforts. Finally, a small proportion of women at term experience significant hemodynamic changes in the supine position and are more sensitive to postural changes; reliable methods for identifying this subset of women should be developed. ■

What We Thought We Knew

- 15° of maternal left lateral tilt is sufficient to relieve compression on the inferior vena cava by the gravid uterus.
- The aorta is typically compressed in the supine position during late pregnancy.
- 15° of maternal left lateral tilt must be routinely instituted during cesarean delivery.

What This Review Adds

- Inferior vena cava obstruction is only significantly relieved by ≥30° of left tilt.
- Magnetic resonance imaging reveals the aorta is not compressed in the supine position, although the distal aorta is not well visualized.
- Maternal tilt position during elective cesarean delivery of healthy women with uncomplicated pregnancies may not be necessary; maternal supine position is not detrimental to neonates if maternal blood pressure is supported with vasopressors and a fluid coload.
- The degree and significance of aortic compression by the gravid uterus during neuraxial anesthesia, in the setting of hypotension, and during uterine contractions, remains debatable.

DISCLOSURES

Name: Allison J. Lee, MD.
Contribution: This author helped conduct literature review and prepare the manuscript.
Name: Ruth Landau, MD.
Contribution: This author helped conduct literature review and prepare the manuscript.
This manuscript was handled by: Jill M. Mhyre, MD.

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