A Call to Action: The Need for Enhanced Maternal Hemodynamic Monitoring in Cesarean Birth

Maternal M&M is Unacceptably High[1]

Maternal Mortality May Be Preventable[2]

BP Arm Cuff Inadequacies[3,4]

Value of Continuous Noninvasive BP Monitoring[5,6]

Individualized, Predictive Hemodynamic Monitoring Can Improve Outcomes[7,8]

Maternal morbidity and mortality is a serious global health concern

Despite progress in recent years, global maternal morbidity and mortality rates remain unacceptably high.[1] In the US, maternal mortality rates have doubled over the past 2-3 decades.[9] Globally, hemorrhage and hypertensive disorders are leading causes of maternal death.[1] Cardiovascular conditions are another important cause, contributing to 25-33% of pregnancy-related deaths in the US.[2,10]

Severe maternal morbidity (SMM), defined as unexpected outcomes of labor and delivery that can result in significant short- or long-term health consequences, has been steadily increasing. SMM has increased by 45% in the US over the last decade with conditions such as renal failure, pulmonary embolism, acute respiratory distress syndrome, shock, blood transfusion, and ventilation all on the rise.[9,11] Consequences are extensive and include long-term health effects for the mother, as those who experience SMM are at increased risk of hypertension, kidney failure, and heart failure after pregnancy.[11] Additionally, traumatic childbirth experiences, including emergency cesarean birth or maternal complications such as pre-eclampsia, have been associated with increased risk of postpartum psychiatric disorders.[12] Longer hospital stays and increased costs for those with SMM add additional burden to health systems, as SMM is associated with an 111-175% increase in total mean health care costs.[13,14]

Who is most at risk?

The pregnant population is increasingly presenting older and with more comorbidities than ever before. Rising maternal age, obesity, diabetes, and hypertensive disorders all increase risk of SMM and mortality.[2] Those with multiple chronic conditions face a 276% higher risk of SMM and mortality than those with none.[2] Hypertensive disorders, particularly pre-eclampsia, pose significant risks during pregnancy and can affect both maternal and neonatal health.[15] Vigilant blood pressure management in patients with hypertensive disorders and pre-eclampsia is critical to reduce severe maternal complications including stroke, heart failure, and kidney injury.[15,16]

Cesarean birth is one of the most common surgical procedures in the world, and rates continue to increase. By 2030, global projections estimate that cesarean births will account for roughly 1 in 3 births.[17] While it can be an important life-saving intervention, cesarean birth is still major abdominal-pelvic surgery associated with increased maternal morbidity and mortality compared to vaginal birth.[2] Cesarean birth increases risk of postpartum hemorrhage (PPH), infection, thromboembolism, ICU admission, and death.[2,18] It also increases risk of future placenta previa and placenta accreta, conditions which also heighten hemorrhage risk.[2]

A preventable harm

Despite high morbidity and mortality, most pregnancy-related deaths are preventable.[2] Maternal mortality review committees found that more than 60% of pregnancy-related deaths were preventable, with contributing factors being lack of knowledge of early warning signs, misdiagnosis or ineffective treatment, and lack of coordination between providers.[2] Delayed provider response or management has also been identified as contributing to maternal cardiovascular death.[19] Implementation of standardized practices that improve both the quality of care and patient safety will improve maternal outcomes.[2]

Maternal and fetal hemodynamics

A variety of physiologic changes occur during pregnancy to support the developing fetus, which have important hemodynamic implications for the mother.[6] Significant hemodynamic shifts are expected during active labor, delivery, and postpartum (Figure 1).[6, 20] While women with healthy cardiac function normally tolerate these changes well, those with diminished cardiac function may not.[6,10]

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Monitoring to detect rapid cardiovascular changes, especially in high-risk patients, is important.[6]

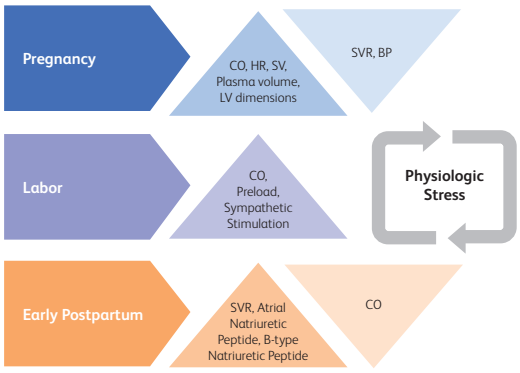

Figure 1. Changes in Maternal Cardiovascular Physiology[20]

Blood flow to the uterus, placenta, and fetus depends on maternal blood flow and is not autoregulated, meaning that shifts in maternal blood flow may impact fetal perfusion.[5,21] While clinical management typically focuses on maintaining maternal blood pressure, adequate maternal blood pressure alone does not necessarily equal adequate fetal perfusion.[5] Rather, placental blood flow is dependent on both maternal blood pressure and cardiac output (CO) and its distribution.[22] A more complete view of hemodynamics might be warranted to gain a better understanding of the underlying causes of instability.

Hemodynamic instability & intraoperative hypotension during cesarean birth is prevalent

Hemodynamic instability, primarily hypotension, is common due to significant physiological shifts that occur during pregnancy and cesarean birth such as rapid blood pressure swings and substantial shifts in intravascular volume.[5,6] Pharmacologic agents also play an important role. For instance, spinal anesthesia is commonly used as the preferred anesthetic technique for cesarean birth, which has vasodilatory effects that frequently result in maternal hypotension.[4] Maternal hypotension after spinal anesthesia has been reported to occur in 30-80% of cases.[23] It has even been reported in up to 70-80% of those receiving pharmacological prophylaxis.[24] Spinal anesthesia can also be associated with a reduction in maternal CO even when blood pressure is normal.[22]

Untreated maternal hypotension can pose detrimental effects for both mom and baby.[24] Due to the profound and rapid drop in maternal blood pressure, patients who experience hypotension also commonly experience severe nausea and vomiting.[5] This can contribute to poor patient experience, decreased satisfaction, and delayed mother-baby bonding after cesarean birth.[25] The importance of mother-baby bonding during delivery and hospitalization is strongly supported by medical literature. Specifically, early skin-to-skin contact is key to promote both maternal and infant outcomes.[26] Intraoperative maternal nausea and vomiting can cause patient distress and interfere with the surgical procedure.[27] In more severe cases of postoperative maternal nausea and vomiting, pulmonary aspiration, bleeding, suture dehiscence, and incisional hernias can occur.[25] Establishing breast feeding can also be difficult or delayed for those experiencing severe obstetric complications.[28]

Additional negative consequences associated with maternal hypotension include fetal hypoxia due to impaired placental perfusion, fetal bradycardia or prolonged heart rate decelerations, and fetal acidosis.[24,29,30] Fetal acidosis has been associated with lower Apgar scores at birth.[31] Additionally, both fetal acidosis and maternal hypotension are independently associated with poor developmental and neurologic outcomes.[32] While both severity and duration of maternal hypotension have been associated with adverse effects, hypotension duration may be more concerning for fetal outcomes.[5,29] As such, maternal hypotension during delivery should ideally be prevented or managed early.[33]

Delayed recognition - Can we close the gap?

Across different surgical populations, delayed recognition and management of abnormal blood pressure (hyper- or hypotension) during the perioperative period is associated with worse patient outcomes.[34] Maternal mortality review committees have determined that delays in recognition, treatment, and escalation of care contribute to maternal death.[35] Recognizing early warning signs – especially abnormal vital signs – is the first step to detecting deterioration and initiating treatment, making timely monitoring and escalation important for preventing harm. Systems that can help identify and escalate the right patients could improve outcomes.[36] Clinical deterioration is physiologically detectable with the right monitoring, which may enable appropriate action or escalation.

The clinical and economic burden of PPH

PPH is of particular concern as it is the leading cause of maternal death within the first 24 hours of birth.[37] As PPH can lead to shock, multi-organ dysfunction, and death in as little as 2 to 6 hours after birth, rapid recognition and response is vital.[38] This is especially true as 54-93% of maternal deaths from PPH may be preventable.[37] However, recognition of PPH is difficult as it can occur in the absence of any identifiable risk factors.[39] Diagnosis of PPH can also be challenging as it commonly relies on visual estimations of blood loss, which can be inaccurate.[38] An American College of Obstetricians and Gynecologists Committee Opinion determined that inaccurate estimation of blood loss is a leading cause of delayed response to hemorrhage.[37] Additionally, delayed surgical intervention has been associated with increased complications including hysterectomy and disseminated intravascular coagulation.[40] Furthermore, PPH is associated with substantial economic

burden. Total hospital costs increase for those who receive treatment for abnormal bleeding after cesarean birth, ranging from $12,279 to $16,288 per case.[41] Earlier intervention may help improve outcomes and reduce overall healthcare resource use, warranting more advanced monitoring for at-risk patients.

Recommendations and best practices for maternal hemodynamic monitoring

During cesarean birth, the American Society of Anesthesiology (ASA) recommends frequent maternal blood pressure monitoring from spinal anesthesia administration until birth, ideally every 1-2 minutes. This is more frequent than the minimum ASA standard of every 5 minutes.[42] Consensus recommendations from the Society for Obstetric Anesthesia and Perinatology for managing hemodynamics during cesarean birth recommend preventing maternal hypotension to maintain fetal perfusion and prevent nausea and vomiting.[21] Recommended strategies to treat hypotension include prophylactic intravenous vasopressor administration or co-loading with intravenous fluids during administration of spinal anesthesia.[5,21,42] Additionally, administration of fluids, vasopressors, and inotropes should be individualized for women with cardiac disease.[5,42]

Is the current standard of monitoring adequate?

The current standard for blood pressure monitoring in pregnant patients is the traditional arm cuff, also referred to as the oscillometric or upper arm cuff. However, the traditional arm cuff may not be suitable for all patients as it has notable limitations:

1) **Delays:** Because it measures blood pressure intermittently, the arm cuff can miss critical physiological changes, thus delaying recognition and treatment of hypotension.[3]
2) **Inaccuracy:** Evidence demonstrates that traditional arm cuffs are not as accurate as radial arterial lines.[43-46] A retrospective study of over 27,000 patients found that almost half of intraoperative blood pressure measurements from the traditional arm cuff were inaccurate when compared to intra-arterial blood pressure.[45] Here, the traditional arm cuff overestimated blood pressure in lower ranges and underestimated blood pressure in higher ranges.[45] Accurate blood pressure measurement is important for pregnant patients with spinal anesthesia-induced hypotension or pre-eclampsia.[46,47]
3) **Patient habitus:** Traditional arm cuffs are less reliable when sized inappropriately.[48] For instance, arm shape can contribute to inaccurate readings in obese patients.[49]
4) **Situational barriers:** Patient shivering, a common side effect of spinal anesthesia, can disrupt automated oscillometric measurements with the traditional arm cuff.[50]

Moving from reactive to proactive care with continuous noninvasive blood pressure monitoring

Continuous blood pressure monitoring has the potential to detect rapid changes in blood pressure, which may allow clinicians to quickly recognize and respond to hypotension.[5] Blood pressure is the most utilized indicator of hemodynamic instability in the perioperative period, and hypotension is often a late indicator of underlying pathology.[51] Continuous monitoring of blood pressure may detect hypotension, and thus hemodynamic instability, earlier than traditional monitoring.[51] This is important as a faster, more proactive response to hypotension by maintaining maternal blood pressure closer to baseline has been shown to improve maternal and neonatal outcomes compared to waiting until blood pressure falls below a certain threshold.[52]

BD's continuous, noninvasive finger cuff technology*† provides beat-to-beat blood pressure measurements with accuracy comparable to a radial arterial line.[53,54] BD's Finger Cuffs*† have demonstrated accuracy and precision for blood pressure measurement during cesarean birth with strong trending performance.[4,55,56] Within a 35-patient prospective comparison study, BD's noninvasive Finger Cuffs*† have also shown comparable accuracy to a radial arterial line for blood pressure measurements in obese surgical patients, which is notable given the limitations of the traditional arm cuff in this population.[57]

Improved outcomes and patient experience with continuous BP monitoring in cesarean birth

A randomized controlled trial including 40 patients undergoing cesarean birth found that use of a BD Finger Cuff*† reduced hypotension compared to those monitored intermittently with a traditional arm cuff.[4] Specifically, 0% of patients who were monitored continuously experienced hypotension during the surgical period between induction of spinal anesthesia and birth versus 45% in those monitored intermittently.[4] This is particularly important given the increased risk of hypotension after spinal anesthesia. Those monitored continuously also experienced less nausea and vomiting during surgery compared to those monitored intermittently, likely due to reduced maternal hypotension.[4] Ultimately, continuous monitoring with BD's Finger Cuff*† can help clinicians maintain hemodynamic stability and facilitate safe anesthetic management during cesarean birth.[4]

A separate retrospective study applied continuous noninvasive blood pressure monitoring with BD's Finger Cuff*† to 31 patients undergoing cesarean birth and surveyed both patients and medical professionals[56]. Survey results showed that both medical professionals and patients preferred continuous noninvasive blood pressure monitoring with BD's Finger Cuff*† over the traditional arm cuff.[56] Patients felt that BD's Finger Cuff*† was more comfortable, while medical professionals felt it was superior in detecting early warnings for hypotensive episodes.[56] Continuous blood pressure monitoring with BD's Finger Cuff*† has been shown to enable clinicians to more rapidly detect changes in blood pressure compared

to the traditional arm cuff.[3] This is an important advantage when delayed recognition and care escalation remain leading contributors to maternal morbidity and mortality.[35]

A comprehensive review of the advantages of continuous blood pressure monitoring over traditional intermittent arm cuff measurements can be found here.

Individualized care in high-risk patients reduces complications

While continuous noninvasive blood pressure monitoring helps proactively manage hypotension, more advanced monitoring may be helpful to provide a more comprehensive hemodynamic assessment for patients at higher risk of complications.[6] When managing high-risk patients, access to parameters that reflect preload, contractility, and afterload to support individualized, risk-based monitoring can improve detection of deterioration, guide timely intervention, and enhance maternal and fetal outcomes.[6,23]

In addition to continuous blood pressure measurements, the noninvasive Acumen IQ™ Finger Cuff*† delivers advanced hemodynamic insights, including CO, stroke volume (SV), and systemic vascular resistance (SVR), enabling clinicians to proactively identify and treat the underlying mechanisms of hemodynamic instability. As BD's Finger Cuff*† technology has evolved over time, some clinical studies may reference different versions of the finger cuff offering advanced parameters, which include Acumen IQ Finger Cuff*† and ClearSight Finger Cuff.*†

Evidence supports that individualized, goal-directed hemodynamic management – including optimized fluid and vasopressor therapy – can improve maternal outcomes.[7] For example, a retrospective study examined 40 patients with major placenta previa who were managed with BD's noninvasive ClearSight™ Finger Cuff*† to apply goal-directed therapy during cesarean birth.[7] These patients had less maternal hypotension, lower maternal lactate levels indicating improved perfusion, and fewer postoperative complications compared to those receiving standard hemodynamic monitoring.[7] Additionally, a prospective study of 21 patients with placenta previa or accreta undergoing cesarean birth concluded that continuous monitoring with ClearSight™ Finger Cuff*† was useful in this high-risk patient population for identifying acute fluctuations in hemodynamics caused by anesthesia, hemorrhage, or surgical stimulation.[55]

With its proactive, predictive capability, the Acumen IQ™ Cuff*† can enhance clinical decision-making, optimize therapeutic management, and facilitate earlier intervention.[8,58] When used with a compatible monitor, Acumen IQ™ Cuff*† unlocks Acumen Hypotension Prediction Index™ (HPI™) Software*, which can predict hypotension up to 15 minutes in advance. In animal studies (non-pregnant), Acumen HPI™ Software* detected early hemodynamic instability during hemorrhage (as little as 5% blood loss) associated with reduced gastrointestinal microcirculation before clinically relevant changes were seen in other hemodynamic parameters.[59,60] In humans (non-pregnant), a retrospective study of 1,683 cardiac and noncardiac surgery patients found that Acumen HPI™ Software* predicted hemodynamic instability defined as clinically significant changes in mean arterial pressure (MAP), stroke volume variation, cardiac index, or SVR.[61] Results showed that over 94% of Acumen HPI™ Software* alerts were followed by some form of hemodynamic instability regardless of whether MAP decreased in the subsequent 15 minutes.[61] Acumen HPI™ Software* provides comprehensive insights into preload, afterload, and contractility, enabling clinicians to drill down to the potential root cause of hemodynamic instability and provide appropriate treatment.

Evidence suggests that Acumen HPI™ Software* enabled by Acumen IQ™ Cuff*† can predict maternal hypotension and reduce adverse maternal effects of hypotension.[8,58] For instance, a retrospective analysis of 50 patients undergoing cesarean birth under spinal anesthesia concluded that Acumen HPI™ Software* provided real-time and accurate prediction of impending hypotension in this patient population.[58] Furthermore, a randomized controlled trial of 171 patients undergoing cesarean birth under spinal anesthesia found that Acumen HPI™ Software*-guided management significantly reduced maternal hypotension compared to intermittent blood pressure monitoring with the traditional arm cuff.[8] While continuous noninvasive blood pressure monitoring also reduced hypotension compared to the traditional arm cuff, those who received Acumen HPI™ Software*-guided management had the lowest incidence of hypotension.[8]

Conclusion

Risk factors for pregnancy-related complications continue to rise, contributing to persistently high maternal morbidity and mortality. Maternal hypotension is common and can have serious consequences. Traditional approaches to maternal blood pressure management are insufficient, often leading to delayed recognition and intervention.

BD's noninvasive continuous finger cuff technology*† delivers accuracy comparable to radial arterial monitoring and enables clinicians to shift from reactive to proactive care. By providing continuous insight, it supports early detection of hypotension and timely intervention.[4,58,62]

Higher-risk patients, particularly those with multiple comorbidities or elevated risk for PPH, may benefit from advanced hemodynamic monitoring tailored to individual physiological needs. Access to Acumen IQ™ Cuff*† provides continuous data on preload, afterload, and contractility, supporting earlier recognition of instability, earlier intervention based on the root cause, and more informed decision-making.[58]

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* HemoSphere™ and HemoSphere Alta™ Advanced Monitoring Platforms, when used with a compatible finger cuff, are indicated for use in critical care environments in a hospital setting in the OR, ICU and ER. Acumen HPI™ Software is unlocked by Acumen IQ™ Finger Cuff and is indicated for use in adult surgical and nonsurgical patients. Acumen IQ™ Finger Cuff is indicated for patients over 18 years of age. For more device information and for indications and intended use, including information on the target patient population specific to these devices, consult the device's instructions for use. **Caution:** The effectiveness of the finger cuff has not been established in pre-eclamptic patients.

† Please note that BD's Finger Cuff technology has evolved over time. All iterations are based on volume-clamp technology, though technical details may vary. Clinical performance studies may reference different versions, which include ClearSight™ Cuff, Acumen IQ™ Cuff, and Acumen IQ™ Plus Cuff. All BD Finger Cuffs, when used with a compatible monitor, provide continuous noninvasive BP. VitaWave™ Cuff provides only continuous noninvasive BP. ClearSight™ Cuff, Acumen IQ™ Cuff, and Acumen IQ™ Plus Cuff offer additional access to advanced parameters (CO, SV, SVR). Acumen IQ™ Cuff and Acumen IQ™ Plus Cuff unlock Acumen HPI™ Software.

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