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Trauma in Pregnancy

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Abstract: In the United States, trauma is the leading nonobstetric cause of maternal death. The principal causes of trauma in pregnancy include motor vehicle accidents, falls, assaults, homicides, domestic violence, and penetrating wounds. The managing team evaluating and coordinating the care of the pregnant trauma patient should be multidisciplinary so that it is able to understand the physiologic changes in pregnancy. Blunt trauma to the abdomen increases the risk of placental abruption. Evaluation of the pregnant trauma patient requires a primary and secondary survey with emphasis on airway, breathing, circulation, and disability. The use of imaging studies, invasive hemodynamics, critical care medications, and surgery, if necessary, should be individualized and guided by a coordinating team effort to improve maternal and fetal conditions. A clear understanding of gestational age and fetal viability should be documented in the record.
Key words: trauma, critical care, maternal death, pregnancy

Introduction

BACKGROUND

When trauma patients are transported to an emergency department, its personnel must be prepared to handle the physiologic complexity of their injuries. This is particularly important in the case of the gravid trauma patient. The care of the pregnant trauma patients requires a multidisciplinary approach typically involving Maternal-Fetal Medicine and/or Obstetrics, Anesthesiology, Surgery, Emergency and Intensivist caregivers. Trauma is now the leading nonobstetric cause of maternal death during pregnancy.[1–6] It is estimated that in the United States from 5% to 8% of women experience trauma during pregnancy.[1–3,7] There are numerous difficult management decisions that are compounded by the fact that one must simultaneously consider the effect of the trauma on 2 patients. Aside from maternal injuries, clinicians must keep in mind the potential for miscarriage, preterm labor, preterm premature rupture of membranes, abruption, and fetal demise, which can occur in major and minor trauma. The likelihood of adverse fetal outcomes is often unpredictable and sometimes counter-intuitive when the degree of trauma is considered. Physiologic adaptations also occur in the mother as a response to the demands of pregnancy that may alter her clinical presentation as compared with nonpregnant patients. A better understanding of these adaptations to pregnancy improves our

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ability to anticipate the effects of pregnancy on the underlying pathologic conditions for the best chance at meaningful recovery from trauma for both the mother and fetus. This study will review the most common types of trauma seen in pregnancy and also the epidemiology, risk factors, pathophysiology, and key management considerations for the care of these patients.

RISK FACTORS

In the review of the literature, several major risk factors for maternal trauma are apparent. These include young age (<25 y), African-American or Hispanic race, use of illicit drugs or alcohol, domestic violence, noncompliance with proper seatbelt use, and low socioeconomic status.[1,2,8–11] The impact of mind altering substances is significant. Ikossi et al[1] presented data from the American College of Surgeons National Trauma Data Bank, which revealed that 19.6% and 12.9% of pregnancy-related traumas were associated with the use of illicit drugs or alcohol, respectively. One institutional study showed intoxicants use in up to 45% of the pregnant population involved in motor vehicle accidents (MVAs).[10] Intoxication, as anticipated, also contributes to a significantly lower use of restraints while driving when compared with sober patients (22% vs. 46%, respectively).[10] Education about the use of drugs and alcohol during pregnancy along with the help of social services programs to support these women in high-risk areas may impact the degree to which mind altering substances play a role in trauma-related injury. Proper seatbelt use is also a major area where injuries can be attenuated by education and compliance. The National Highway Traffic Safety Administration recommends that the seatbelt is placed across the lower dome of the abdomen and the shoulder strap along the side of the uterus between the breast and midclavical.[5] It is estimated that approximately half of all fetal losses associated with improper seatbelt use could be prevented.[12] Depending on the region of the country, anywhere between 34% and 64% of pregnant patients involved in MVAs are reported to be unrestrained.[1,2,12,13] According to the most recent Centers for Disease Control and Prevention Report, only 30% of drivers use seatbelts.[8] Although seatbelt use by women in pregnancy is higher than in the general population, compliance and education about the proper use of seatbelt are still suboptimal. Reasons for noncompliance with seatbelt use include maternal concern for applying harmful pressure to the uterus and fetus, discomfort, and forgetfulness.[1] On the basis of injury, the identified risks for fetal loss or adverse outcomes include a high Injury or Abbreviated Severity Score, severe maternal cranial, abdominal, thoracic, or lower extremity injuries, Glasgow Coma Scale <8, high base deficit, and uterine contractions.[1,2]

TYPICAL MECHANISMS OF TRAUMA-RELATED MATERNAL INJURY

Blunt trauma is the overwhelming mechanism of maternal injury (Fig. 1). By far, most commonly MVAs comprise the majority of blunt injuries (55% to 70%), followed by assaults (11% to 21%) and falls (9% to 22%).[1–3] Other less common causes of maternal trauma include burns and penetrating injuries. Depending on the region of the country, the rate of these injuries may be higher. For example, a review of maternal deaths in New York from 1987 to 1991 showed a shockingly high rate of homicides as a cause of maternal death from trauma. Out of 115 maternal deaths from injury, 63% ($n = 72$) of them were from homicide.[14] Race also plays a role in the rate of intentional injuries. Intentional injuries include suicides, homicides, and assaults. In the case of domestic violence, homicide is the most common intentional cause of traumatic maternal death. Domestic violence is reported in 7% to 23% of trauma cases, and

this is likely an underestimate of the true incidence because of underreporting. One should suspect domestic violence if a patient has multiple injuries in various stages of healing, minimizes her injuries, has inconsistent explanations of her injuries, or delays in seeking medical attention for injuries sustained.[3] A survey of the National Trauma Data Bank revealed that African-American gravidas are significantly more likely to be victims of intentional injury as compared with Whites (19.5% vs. 8.7%).[1] This trend is also significantly higher in African-Americans than in other minority groups for unclear reasons. Physical and sexual abuse happens in approximately 17% to 32% of pregnancies.[2] Sixty percent of these cases are associated with multiple earlier events and the abuser is typically known to the patient. Of note, it is not unusual for a first offense or escalation of physical or sexual abuse to happen during pregnancy or early in the postpartum period.[2]

DELIVERY RATES AND MODES

During hospitalization for trauma, 5% to 24% of patients are reported to be delivered.[1,7,11,15] The number of women requiring delivery varies greatly based on the gestational age at admission, maternal stability, and year of presentation. Patients underwent higher rates of delivery in older studies. Most studies addressing fetal outcomes in maternal trauma do not specify mode of delivery. In a few studies that do include mode of delivery, 71% to 75% of patients who present with trauma were delivered through cesarean section, and a majority of all deliveries were done within 24 hours of injury.[1,15] This makes sense because evidence of uteroplacental insufficiency from trauma typically arises within 24 hours of the injury if continuous fetal monitoring is employed. The trend in delivery rates and modes correlate with the severity of injury. Patients with more severe injuries are more likely to be delivered if viable and >28 weeks.[15] This does not mean that cesarean delivery is a mandate for pregnant trauma patients. Oftentimes, logistics play a role in a center's ability to induce a patient who is ventilated, for example. Other contributing factors include the likelihood of successful induction of labor in a woman who is remote from term, and in the face of declining maternal status or fetal status, is remote from delivery, cesarean section

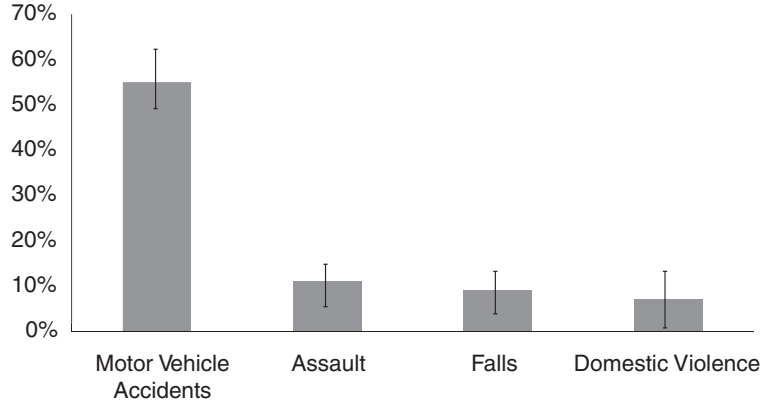

FIGURE 1. Most common causes of maternal injury. It is well established that the majority of all maternal injuries in trauma are known to be caused by motor vehicle accidents. The range of reported incidence in the literature is represented by the brackets.

is a way to expedite the delivery process. Practitioners should keep in mind the limited value of performing a cesarean section on a borderline stable patient, especially, if the fetus is stable. The quick hemodynamic changes that occur with cesarean delivery could also worsen the maternal status. Once the mother is stabilized, the fetus is expected to gradually recover, and it can take up to 30 minutes before the fetal heart tracing shows full fetal recovery. It is recommended that the mother should be made stable before fetal delivery is addressed. One exception to this is recommended in the case of a malignant maternal arrhythmia [ie, ventricular tachycardia or pulseless electrical activity (PEA) arrest] or cardiac arrest when a perimortem cesarean is performed to salvage the fetus.

Emergency evacuation of the uterus through cesarean delivery can be done within 1 minute from skin to the baby in skilled operators. A midline vertical incision is preferred as this minimizes bleeding and maximizes abdominopelvic exposure. A supraumbilical or periumbilical incision may be used in morbidly obese patients. The type of abdominal incision decided should take into account the full clinical scenario and ease of delivery. A classical uterine incision is performed on premature, low birth weight, transverse back-down, or variable presentation fetuses. If necessary to perform in a pregnant trauma patient greater than 25 weeks, there is a possibility of approximately 45% fetal and approximately 72% maternal survival, respectively.[2]

The standard practice for the timing of a perimortem cesarean delivery is to initiate it within 4 minutes of a malignant arrhythmia or maternal arrest. Outcomes are optimal in neonates delivered within 5 minutes of maternal cardiac arrest.[16] Even if resuscitative efforts have extended beyond 5 minutes, it is still reasonable to consider delivery, as neonatal survival beyond this time frame is reported.[5] The longer the time interval between maternal cardiac arrest and fetal delivery, the higher is the likelihood of neonatal neurologic sequelae. Uterine evacuation may improve the cardiopulmonary resuscitation (CPR) efforts by minimizing the risk of supine hypotension and allowing for increased venous return with increased uterine tone. Caveats to note are avoiding cesarean delivery in the unstable mother, if the indication is ''impending'' cardiac arrest; if the CPR is successful, delivery may be deferred.[2,3,16] In patients, who are unresponsive to CPR, thoracotomy with direct cardiac massage and concurrent cesarean delivery has been performed.[3]

Maternal-Fetal Outcomes: Population-based Studies

Several population-based studies have been undertaken to evaluate maternal-fetal outcomes in trauma admissions. Looking at these may provide information on regional differences and potentially target patient education programs to modify the incidence of traumatic events during pregnancy.

El Kady et al[7] published a retrospective cohort study reviewing all maternal trauma admissions in California hospitals from 1991 to 1999. ICD-9 codes were used to classify injuries and outcomes. Losses less than 20 weeks were not identified. Injuries were considered ''nonsevere,'' if the ISS was less than 9. The goal of this study was to determine occurrence rates, outcomes, risk factors, and timing of delivery. Comparisons were made between the women who required delivery during the trauma admission and those who were undelivered relative to uninjured pregnant women in the state. The traumas included falls, MVAs, and assaults in order of most to least common mechanism. Most patients were White, and those delivered during the trauma admission had increased preterm delivery rates. It was found that during an admission for

trauma that requires fetal delivery there was an odds ratio (OR) of 9 for risk of abruption. The baseline risk for maternal death in that state was 0.01% in uninjured mothers and a significant difference of 0.86% in injured gravidas delivered during the index admission. For the fetus, ORs were 2, 4.6, and 3 for risks of preterm delivery, intrauterine fetal death, and neonatal demise, respectively. Internal injuries after intracranial injuries resulted in the highest risks for maternal death. Fetal injuries were highest in internal maternal trauma after open injuries. Fetal death was more commonly associated with maternal vascular injury. The largest contributor to fetal and neonatal deaths was gestational age less than 28 weeks. The authors of this study determined that the occurrence rate for hospitalization for trauma during pregnancy is 0.52 of 1000 deliveries and 24% will deliver during the initial trauma admission. Injury severity score was not predictive of outcomes. In summary, both maternal and fetal deaths were found to be highest with internal injuries to the thorax, abdomen, and pelvis.

Schiff et al[15] reviewed all trauma admissions to Washington State in a retrospective cohort study between 1989 and 1997. Cases were queried by ICD-9 codes, and only the patients who were delivered during the index admission for trauma were included. Patients with an ISS >9 were considered to be severely injured. The goal of this review was to determine outcomes in severely injured pregnant patients compared with those with minor injuries. This study is unique in that an analysis of the term patients revealed nonseverely injured women (compared with uninjured) had increased risks of abruption [relative risk (RR) 4.2] infant hypoxia (RR 4.6) and fetal death (RR 13.6). Severely injured mothers had increased risks of abruption (RR 15.8), cesarean delivery (RR 4.3), and nonreassuring fetal heart tracings (RR 3.9). This is one of the few studies to specifically address outcomes in term pregnancies. Later, in 2005, the same group evaluated statewide pregnancy outcomes, specifically in patients admitted after a MVA. A majority of these patients were discharged undelivered (82.9%) whereas the remainder delivered during their index hospitalization.[11] Of note, they also found that ISS did not correlate with adverse pregnancy outcomes. They concluded that women hospitalized after a MVA are at an increased risk for adverse pregnancy outcomes (preterm labor, abruption, meconium at delivery, and neonatal respiratory distress) regardless of the presence or absence of identifiable physical injuries.[11]

Weiss et al[17] reviewed fetal death certificates between the years 1995 and 1997 from 16 states that represent 55% of the total United States population. Out of the 240 injury-related fetal deaths, 27 mothers (11%) had associated demise. The authors describe an injury-related rate of 3.7 fetal deaths/100,000 live births. The highest rate of 9.3 fetal deaths/100,000 live births was noted in 15 to 19-year-old gravid patients.

Dannenberg et al[14] reviewed medical examiner records from 1987 to 1991 in New York. The majority of the patients had nonviable pregnancies, and 10 were within 6 months postpartum. Out of 115 patients included, 20 were in viable pregnancies. A closer look at the types of injuries sustained that led to maternal deaths revealed a shockingly high rate of homicide ($n = 72$, 63% of the patients included) of which 51% were from gunshot wounds, 17% stabbing, 14% strangulation, 7% burns, 7% blunt force, and 1% unspecified. After homicide, the remaining injury mechanisms included suicide (13%), MVAs (12%), and drug overdose (7%). This is the first study to really outline homicide as a leading cause of intentional injury-related deaths in an urban population. Other investigators have noted the striking finding of high rates of interpersonal violence during

pregnancy (reports indicate a range of 3% to 32%).[9] One author noted a 31.5% incidence of intentional injury out of the 203 pregnant trauma patients in Mississippi related to domestic violence.[9] Underreporting of physical abuse is an unfortunate reality and could result in fatal outcomes. One cannot emphasize enough the importance of screening vulnerable populations such as pregnant women for abuse and offer supportive services.

Maternal Physiology

Earlier chapters have discussed the changes in maternal physiology seen in pregnancy. The intensivist should be aware of physiologic and pathologic changes in pregnancy that may affect the way physical findings and laboratory results are interpreted. It is important to be aware of the way the physiologic changes of pregnancy can mimic pathologic conditions in nonpregnant patients in the context of their trauma evaluation. To the contrary, there are maternal adaptations in pregnancy that may allow for clinical compensation and illusion of greater stability relative to the degree of insult as in the case with hemorrhagic shock. (Figs. 2 and 3).

INVASIVE HEMODYNAMIC MONITORING

Although falling out of favor in the general critical care population for various reasons, there may be some justifiable use for the thermodilution pulmonary artery catheter (PAC) in pregnancy. The most common indications for PAC use in the obstetric population are preeclampsia with refractory oliguria or pulmonary edema (probably most widely accepted use), known severe mitral or aortic stenosis, NYHA class III-IV heart disease in labor, intrapartum or intraoperative cardiac failure, shock, and adult respiratory distress syndrome. There have been a few studies since the early 1990s showing good correlation between Doppler echocardiogram and PAC values. There are newer noninvasive arterial pressure waveform-based systems that are becoming attractive in obstetric patients and have been validated against thermodilution PAC measurements (within an acceptable 30% precision deviation). Systems such as the LiDCOplus, PiCCOplus, and Vigileo

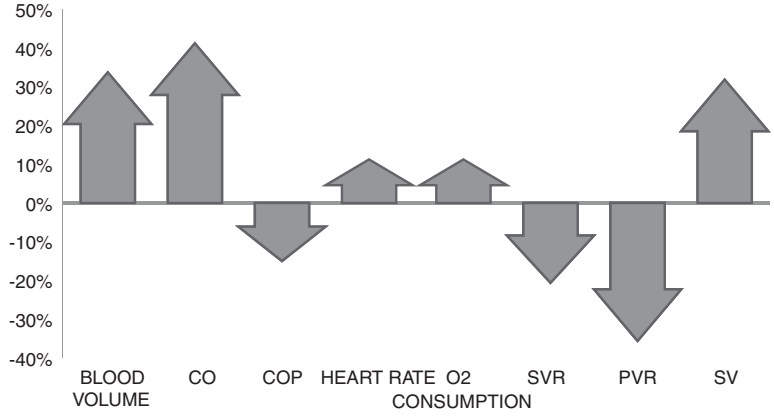

FIGURE 2. Hemodynamic alterations of pregnancy. CO indicates cardiac output; COP, colloid oncotic pressure; PVR, pulmonary vascular resistance; SV, stroke volume; SVR, stroke volume resistance.

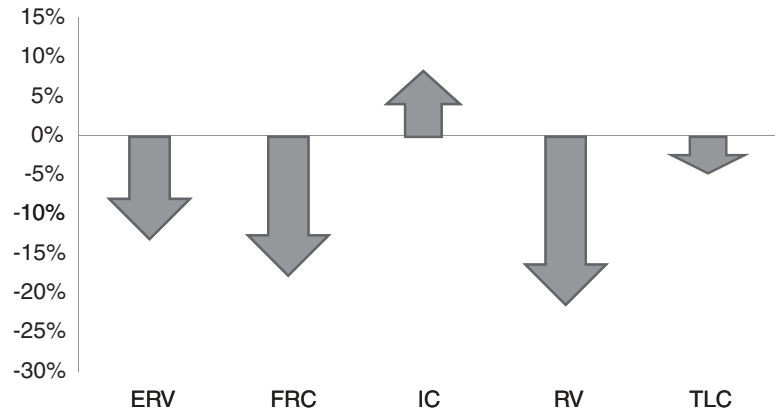

FIGURE 3. Pulmonary alterations of pregnancy. ERV indicates expiratory reserve volume; FRC, functional residual capacity; IC, inspiratory capacity; RV, reserve volume; TLC, total lung capacity.

monitor are quite promising in this regard and further study and acceptance of their use in pregnancy is on the horizon.[18]

Every monitoring method has its limitations: thermodilution PAC measurements can be affected by the temperature of resuscitation fluid and blood; transthoracic Doppler echocardiography may be of significantly limited value in obese patients or those with a pneumomediastinum, and continuous noninvasive arterial pressure waveform-based monitoring in pregnancy has not been well studied in large populations of spontaneously breathing obstetric patients.[18] That being said, the involvement of subspecialists well versed in maternal physiology, such as maternal-fetal medicine specialists and obstetric anesthesiologists with the trauma and critical care teams, is crucial in helping to guide the volume management of critically ill obstetric trauma patients.

CARDIOVASCULAR-MEDIATING DRUGS COMMONLY USED IN TRAUMA

Ephedrine and phenylephrine are considered the preferred options, as the uteroplacental vasculature is least affected by these in comparision with other pressors. Certainly, in the setting of an unstable patient regardless of gravidy, but particularly in those without a viable pregnancy, first-line pressors, such as norepinephrine and epinephrine are ideal. Volume status should be optimized when pressor use is under consideration. Maternal and fetal effects of drugs used in Advanced Cardiac Life Support protocols are presented in online-only Table (Supplemental Digital Content 1, http://links.lww.com/GRF/A5).[19–22]

MECHANICAL VENTILATION IN THE PREGNANT PATIENT

The need for mechanical ventilation support in pregnancy is rare. There are few studies that specifically address the most appropriate ventilation strategy in the gravid population. Most studies use volume control settings and, in particular, assist control modes with tidal volumes set at 8 to 10 mL/kg ideal body weight. In cases of pregnant women with ARDS and acute lung injury there is no literature on the best way to manage these patients. Pregnant women were excluded from the sentinel study that showed a survival benefit to the "lung protective" strategy of

low tidal volumes and higher positive end expiratory pressures in ARDS. Hypercapnea is the trade off one accepts when aiming for low tidal volumes for lung protection. There is no literature on the PCO_2 level acceptable in pregnancy to prevent fetal acidosis, and permissive hypercapnea is not generally recommended. In addition, there is no literature on the earliest gestational age that low tidal volume ventilation would be safe for the fetus. Of course, care needs to be individualized to accommodate the ventilatory support needs of the patient. There are some experts who would promote airway pressure release ventilation for support in the spontaneously breathing pregnant patient with ARDS or ALI because of the inherent decreased FRC and potential for lower sedative use overall with this mode. Unfortunately, there are no studies to date directly addressing advanced ventilation modes specifically in pregnancy. Patients with the need for ventilation support have higher rates of preterm delivery. Data on whether or not delivery actually improves the respiratory status of the patient beyond a lower FIO2 requirement are limited.

UTILITY OF KLEIHAUER-BETKE TESTING IN TRAUMA

Feto-maternal hemorrhage occurs in 10% to 30% of pregnant trauma patients.[5] The Rh-negative patients should receive Rh-D immunoglobulin (Rh-D Ig), if fetal cells are identified and some authors recommend Rh-D Ig be given to all Rh-negative mothers with trauma. The appropriate Rh-D Ig dose depends on the quantity of exposure. As little as 0.07 mL of fetal blood could result in maternal sensitization. Three hundred micrograms of Rh-D Ig cover 15-cc fetal cells (30-cc whole fetal blood). It should be given within 72 hours to prevent future Rh alloimmunization of the newborn. There is evidence to support administering Rh-D immunoglobulin even after the "3-day" window as that time frame is based on a study protocol used in male prisoners. The formation of antibodies far exceeds this time frame, which makes it reasonable to dose Rh-D immunoglobulin beyond 3 days if necessary.

The use of the Kleihauer-Betke (KB) test has been questioned outside of trauma, and some researchers suggest that it may not be as helpful in guiding management as thought earlier. However, an interesting retrospective study out of the University of Maryland investigated the usefulness of this test specifically in trauma patients and looked at the predictability of this test for preterm labor. Logistic regression analysis revealed a positive KB (regardless of maternal Rh status) was the single predictive risk factor for preterm labor (likelihood ratio 20.8). This relationship was more pronounced with larger volume of fetomaternal hemorrhage. KB testing was found to have 100% sensitivity and 96% specificity for uterine contractions. The positive predictive value for preterm labor was 54%, and the negative predictive value was 92.6%. As a result of their findings, the investigators changed their practice at this large trauma center and suggest that a negative KB can be interpreted as reassuring and patients are unlikely to need more than 2 hours of monitoring after trauma.[23] A prospective study of this same institution is underway and may provide more answers on the use of the KB test in maternal trauma patients. It is also suggested that in trauma patients, initial positive tests, regardless of maternal Rh status, should be repeated in 24 to 48 hours to determine the chronicity of fetomaternal hemorrhage and guide observation. Certainly, some institutions do not have quick availability of KB testing and this strategy would be of limited value if the delays in laboratory results are anticipated.

IMAGING IN PREGNANCY

The International Commission on Radiological Protection, National Council on Radiation Protection and Measurements

and the American College of Radiology and the American College of Obstetricians and Gynecologists agree that in the diagnostic evaluation of a pregnant trauma patient, the safest and most appropriate study that would yield the best result and chance at accurate diagnosis must be used. Benefit of timely and accurate diagnosis outweighs the typically low radiation risks to the fetus in the setting of trauma. It has been shown that an estimated 3% of trauma patients who undergo diagnostic imaging are pregnant and 0.3% may have unidentified pregnancies at the time of exposure.[24] Details of the diagnostic imaging in pregnancy overall are covered in a separate chapter.

DIAGNOSTIC IMAGING WITH NONIONIZING RADIATION

Ultrasound

Sonography has been well established as a safe imaging technique in pregnancy without adverse effects on the fetus. It is particularly useful when evaluating pelvic and intrauterine structures. It has poor sensitivity for accurately diagnosing abruption and 50% to 80% of cases can be missed.[25] The indications and use of ultrasound in the evaluation of trauma patients are expanding. Focused Abdominal Sonography for Trauma is a quick and useful diagnostic tool in the emergency room and has largely replaced diagnostic peritoneal lavage when evaluating a patient for suspected hemoperitoneum.[26] In more recent times, the technique has been expanded and validated for the evaluation of pericardial fluid and pneumothorax.[6] The diagnostic yield of this study becomes increasingly limited by gestational age, body mass index, ability to evaluate visceral injuries, and operator experience. According to Richards et al,[26] all gestational ages included, ultrasound has been shown to be 61% sensitive, 94% specific, with a positive predictive value of 45%, negative predictive value of 97%, and 92% accurate in the diagnosis of intra-abdominal injury. Evaluations in the first trimester are associated with the highest sensitivity (90%) but with the lowest specificity (89%) compared with other trimesters (Fig. 4).[26] Advantages of ultrasound evaluation in pregnant trauma patients include ability for bedside evaluation, avoidance of ionizing radiation exposure, and provision of diagnostic information in patients too unstable for transport to the computed tomography (CT) scanner.

Magnetic Resonance Imaging

Instead of ionizing radiation, powerful magnets are used to alter the energy state of hydrogen protons with magnetic resonance imaging (MRI).[27] It is one of the most useful tools in the evaluation of traumatic brain and spinal cord injuries, including ligamentous trauma. However, in the emergency setting, MRI is not recommended in the immediate evaluation because of lengthy examination time.[25]

Radiography

Imaging with plain films exposes the mother and fetus to very little radiation. Typically, the dose of radiation absorbed is usually in the range of 0.02 to 0.07 mrad and can be administered at any gestational age without fear of harm to the fetus.[25,27] Multiple planar images can be accomplished safely in pregnancy. Although the latter is true, one should be mindful of avoiding unnecessary imaging, and, instead, uterine shielding should be used. An unshielded fetus will receive approximately 30% of maternal absorbed dose.[5]

Angiography

Radiation exposure with fluoroscopy is dependent on the duration of the examination, number of blood vessels evaluated, and the depth of the patient's tissues.[25] It is not recommended to cause an embolization to the gravid uterus. However, embolization is a useful minimally invasive tool to control hemorrhage from other pelvic vessels not involved in

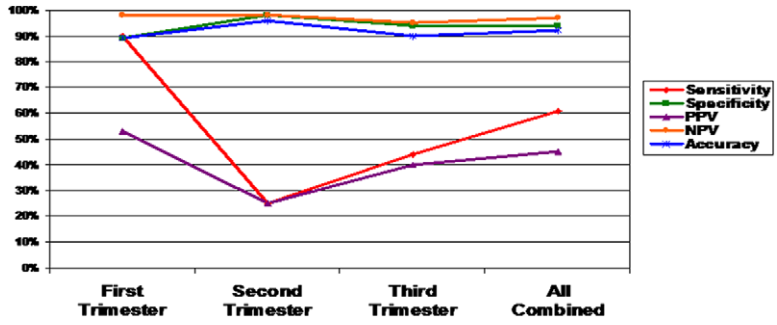

FIGURE 4. Focused Abdominal Sonography for Trauma (FAST) performance based on trimester. The graph illustrates the high specificity, negative predictive value and accuracy of FAST across each trimester. Sensitivity and positive predictive value are significantly reduced after the first trimester.

the circulation to the uterus, particularly in the case of pelvic fractures. The typical exposure from fluoroscopy ranges 20 to 100 mGy/min (2 to 10 rad/min).[25] This intervention should be used with caution, but not avoided in pregnant trauma patients where indicated. Appropriating the patient or the health proxy counseling should include risks specific to the procedure for any patient adding for the gravid trauma patient that despite attention to the use of radiation reduction techniques, shielding, and limiting the time of the procedure where possible, the amount of radiation exposure can vary considerably but the benefit of it as a possibly life-saving intervention justifies its use in certain clinical scenarios, particularly in those with pelvic fractures.

CT

Computerized axial tomography scans are the quickest and most sensitive, non-invasive imaging study used to evaluate stable trauma patients.[25] It is more widely available than MRI. Although generally considered safe, in 2008, the Food and Drug Administration cautioned radiologist to use the minimal amount of radiation as there have been reports of CT "sensitizing" of pacers, and ICDs causing temporary misfiring of these devices. Other devices that could malfunction according to the Food and Drug Administration are insulin and other medication infusion pumps, cochlear and retinal implants, and neurostimulators. Certainly, in an emergency, such as trauma, the benefit of this imaging modality outweighs the potential temporary dysfunction of the said devices, if present. Absorbed doses of ionizing radiation differ among various body regions. Scanning the abdomen and pelvis exposes the conceptus to larger radiation doses than the head or chest. Low-exposure techniques can significantly attenuate the amount of radiation exposure to the fetus.

Nuclear Medicine

There are almost no indications for tagged isotope studies in pregnant trauma patients with the exception of cerebral flow studies in the confirmatory evaluations of brain death. Technetium is one of the most commonly used isotope, and typical fetal exposures do not exceed 0.5 rad.[27] Pulmonary injuries or emboli are generally discovered during CT scanning, and the role for ventilation perfusion scanning in trauma is generally obsolete.

Fetal Monitoring

Early recognition of fetal distress may improve outcomes, and monitoring should begin once maternal stability is established. If fetal heart tones are present, efforts should be made to expeditiously estimate fetal gestational age either quickly by fundal height or rapid limited ultrasound of the femur length (most reliable in the third trimester) versus biparietal measurements midtrimester. Pregnancies beyond 24 weeks are considered viable and external fetal monitoring should be used if the mother is considered stable enough for surgical intervention in case a nonreassuring fetal pattern is discovered and the intervention is considered necessary for the reasonable fetal salvage. The neonatal intensive care staff should be notified early of any potential preterm delivery and counseling with the patient or family on neonatal outcomes at that gestational age and goals of care (including potential for comfort measures) should be conducted. The duration of fetal monitoring has been under debate in the past. Antenatal fetal testing, nonstress test, or biophysical profile cannot be used to predict sudden adverse events, such as abruptions. A nonreassuring fetal tracing may not be apparent until approximately 30% of the placenta is affected and fetal demise may occur in abruptions of half or more of the placental surface area. Continuous fetal monitoring is the only way to identify fetal distress from an acute event if one is lucky enough to catch the event as it is occurring.[28] The minimum amount of time one should be monitored is somewhat controversial. Most authorities would agree with a system that uses 4 to 6 hours of initial continuous monitoring as approximately 80% of abruptions will happen in that time. The remaining approximately 20% of abruptions, if contractions persist typically, occur within 24 hours of the traumatic event. The utility of continuous fetal monitoring beyond 24 hours is limited.[25]

Curet et al[28] reviewed 271 blunt maternal trauma admissions at a level I trauma center in New Mexico to identify predictors of fetal death and provide guidance for monitoring practices. A majority of injuries were MVAs (78.5%) in third trimester (53.5%) patients. There were 16 fetal deaths (5.9%) and 6 maternal deaths (2.2%). Logistic regression analysis showed that MVAs, ejections, maternal death, maternal tachycardia, ISS > 9, abruption, fetal bradycardia or tachycardia, and absent fetal heart tones were all predictive of fetal death. The univariate model showed the lack of restraint, Glascow coma scale less than 10, and need for general anesthesia predictive of fetal demise. Risks that were predictive of contractions, preterm labor, or vaginal bleeding were gestational age greater than 35 weeks (OR 3.7), pedestrian collision (OR 1.6), and assault (OR 1.2). They suggested that women without the above-mentioned risk factors for fetal death be monitored for 6 hours after blunt trauma for "fetal clearance," and anyone contracting regularly (regardless of perceived intensity) on tocomanometry beyond that time should have prolonged (24 h) monitoring.

Blunt Trauma

The types of injuries sustained in blunt traumas are typically related to the most common mechanism of injury, that is, MVAs. MVAs are also the most common cause of injury-related hospitalizations in pregnant patients.[11] Fetal outcomes have been shown to be most strongly correlated to crash severity.[12] Prolonged extrication time is known to be a risk factor for poor outcomes overall in MVA victims. Surprisingly, no investigator has established a relationship with direction of the impact or maternal positioning in the vehicle with fetal outcomes, although small sample sizes could be limiting the potential to find a correlation.[12] Injuries sustained often involve head trauma, intraabdominal bleeding, visceral rupture, and pelvic fractures.[11]

There is a higher incidence of hepatic, splenic, and uterine injuries in MVAs.[3] Gastrointestinal injuries are less common, as the gravid uterus tends to be protective.[3] The uterus is protected in the bony pelvis during the first trimester. Fetal loss from blunt trauma this early tends to be related to uterine hypoperfusion, secondary to maternal hypotension. Direct fetal injury occurs less than 1% of the time, and uterine rupture at any gestation is rare (0.6%) in blunt trauma.[2,5] The presence of meconium or vernix in the urine suggests vesicouterine rupture and needs an urgent laparotomy. The bladder migrates cephalad with the growing uterus making it prone to injury.[5] Hematuria should not be underestimated as a potential sign of genitourinary injury.

As the bony pelvis becomes more lax in pregnancy, it is not surprising that pelvic fractures are one of the more common injuries sustained by pregnant women with blunt trauma. Pelvic fractures and abruption are the most common causes of fetal loss in MVAs.[2,12] A single institution study showed pelvic injury and loss of consciousness to be independent predictors of poor fetal outcome in MVA victims.[13] If the fetal head is engaged in the pelvis, skull fractures and penetrating brain injury can occur.[5] Significant retroperitoneal hemorrhage from the pelvic venous plexus can occur, causing maternal hypotension and potentially fetal compromise. This risk is higher if both the anterior and posterior portions of the pelvis are affected. Aside from vascular injuries, pelvic fractures can also result in bowel, bladder, and urethral damage.[5] Pelvic fractures are not an absolute contraindication to vaginal delivery but lithotomy and McRobert positioning must be taken into consideration with advisement from the orthopedic service. In the setting of a pelvic fracture that has been stabilized, it is reasonable to avoid the potential for any further pelvic damage from positioning during parturition.

ABRUPTION

After approximately 20 weeks, uteroplacental shearing forces are responsible for abruptions. As the pregnancy progresses, the uterine musculature becomes more elastic whereas the placenta is fixed. An acceleration-deceleration injury, such as a motor vehicle collision or fall, may create shear forces that can cause placental detachment. This can occur in up to 40% to 50% of cases with severe trauma, and the overall incidence varies between 6% and 66% among all comers.[2,25] Common maternal complaints include abdominal pain, contraction severity out of proportion to cervical dilation, vaginal bleeding, and back pain. A physical examination may reveal a tender and rigid uterus or tetanic contractions, fetal bradycardia, or prolonged deceleration associated with uterine tachysystole or a nonreassuring fetal tracing pattern with repetitive late decelerations. The intrauterine cavity can accommodate one's entire blood volume. Bleeding can be occult and can result in coagulopathy and hemodynamic instability. Blood can also provoke tetanic contractions. Tissue thromboplastin release from an abruption leads to plasminogen activator-mediated fibrinolysis, resulting in or exacerbating disseminated intravascular coagulation.[5] Fetal mortality can approach 75%. Fifty percent placental surface area loss is associated with fetal demise.[25]

Penetrating Trauma

At 20 weeks the uterine fundus is at the level of the umbilicus. The bowel gets displaced by the gravid uterus and it takes on a protective role for maternal bowel injury. If the uterus is penetrated, massive hemorrhage can occur from uterine injury as the vessels become incredibly engorged and the volume of blood shunted to the uterus increases throughout pregnancy. Fetal injury occurs in roughly 70% gunshot wounds to the abdomen. With intrauterine

firearms injuries, approximately 40% to 70% of fetuses and 5% to 10% mothers die.[2,3,5] Part of the reason for the disparity between maternal and fetal demise with firearms injuries to the uterus is that the myometrium, amniotic fluid, and fetus are efficient at dispersing the kinetic energy of projectiles. As such, bullets tend to get lodged in the uterus or fetus, sparing other maternal viscera. The result of the enlarging and protective gravid uterus is an overall lower maternal mortality from penetrating injuries in pregnant patients as compared with nonpregnant patients.[3] Immediate exploratory laparotomy is recommended in high-speed projectile injuries. It may be deferred in a hemodynamically stable patient with a low-velocity injury below the uterine fundus. If the injury is above the fundus, visceral involvement is more likely and exploratory laparotomy is recommended.[3,5] Impaled objects should not be removed until the patient is on the operating table as they help tamponade lacerated vessels in the interim.[5] Antibiotics for gram positive organisms and clostridia should be given as early as possible.[5] Anaerobic and gram negative coverage should be added if bowel involvement is suspected.

Having an exploratory laparotomy is not an indication for immediate cesarean delivery if the fetus is stable, especially, in the extremely preterm. The fetus should be monitored periodically in the operating room with sterile sonography. Some may consider this as an additional vital sign. In the setting of early maternal decompensation, the fetus may show transient bradycardia. The uterus should be handled with care and excessive traction avoided as this can decrease uteroplacental perfusion through the uterine arteries. The decision to deliver should be made for obstetric reasons or if significant irreparable uterine damage compromises maternal life. Often in multiple trauma, an initial "damage control" laparotomy is conducted to control hemorrhage and the abdomen is left open (with visceral protection from desiccation) with plans to return at a later time for more definitive management, when the metabolic and volume status of the patient is improved.[6] The abdomen is often left open because typically large volumes of fluid and blood products are used in the resuscitation of unstable victims of penetrating abdominal trauma that would predispose them to the development of abdominal compartment syndrome.[6]

General Trauma Management

Management of the pregnant trauma patient should be commensurate with the Advanced Trauma Life Support management guidelines for general trauma victims. The evaluation is the same with the addition of obstetric considerations as maternal stability is achieved. During the primary survey, cardiopulmonary resuscitative efforts are initiated and organized with airway protection as priority. It involves a systematic ABCDs approach to the trauma victim, immediately addressing any compromise in "airway, breathing, circulation, and disability." The secondary survey allows for more in-depth physical assessment of injuries, laboratory tests, diagnostic imaging, and therapeutic procedures (Fig. 5). The need for surgical intervention and "damage control" of hemorrhage and injuries may be immediately apparent and the operative or interventional radiologic suites are often alerted in anticipation of the patient's arrival to the trauma bay.[6] Finally, depending on the severity of injuries sustained, the trauma victim may need long-term care in the trauma, surgical or neurologic intensive care unit.

Primary Survey

AIRWAY

The management of the airway has been discussed extensively in the anesthesia

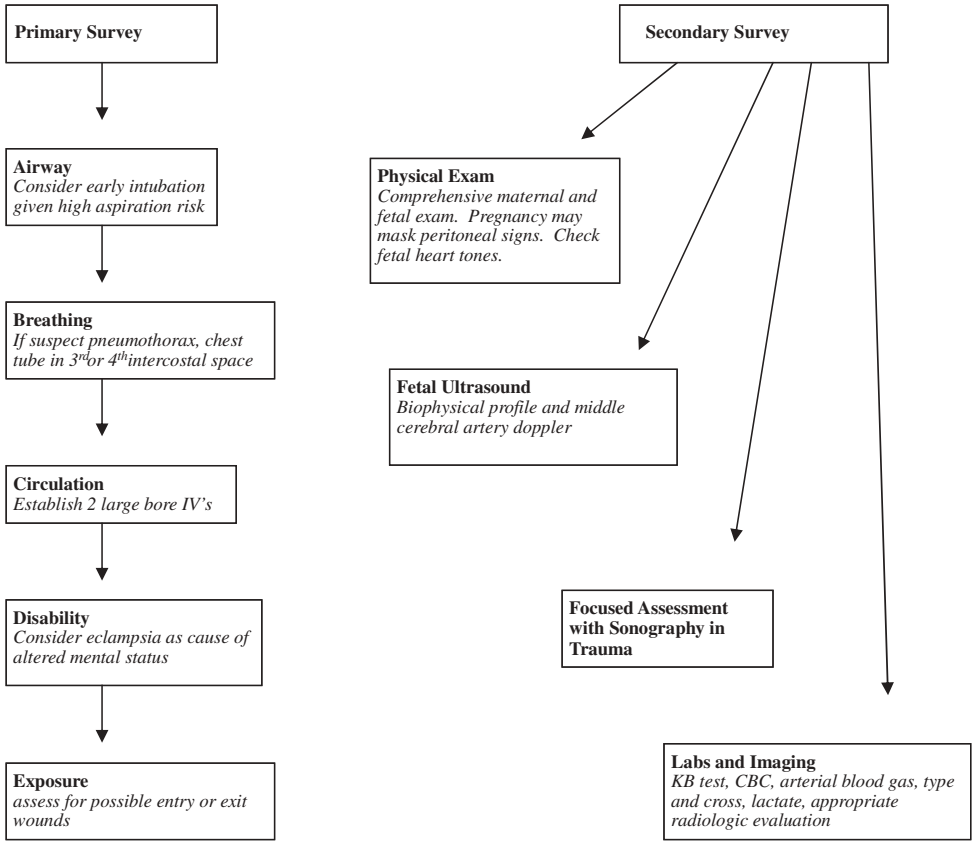

FIGURE 5. General management considerations in the pregnant trauma patient.

chapter. Initial airway assessment involves concurrent cervical spine stabilization. A low threshold for early intubation is generally recommended for pregnant trauma patients at high risk for airway compromise.[5] Owing to the potential for airway edema in a pregnant patient, it is recommended to use an endotracheal tube with an internal diameter that is 0.5 to 1 mm smaller than what would be used in her nonpregnant counterpart.[16] Rapid sequence induction is considered favorable for intubation of trauma patients, but caution is advised in those with traumatic brain injury (TBI) and risk for increased intracranial pressure.[6] Continuous cricoid pressure during bag mask ventilation in the unconscious pregnant patient is recommended to decrease the risk of emesis and subsequent aspiration.[16]

BREATHING

Breathing can be assessed by observing chest wall motion. Deformities consistent with flail chest will be obvious on inspection. Rib fractures are the most common serious thoracic injury and are related to the development of a pneumothorax and pulmonary contusions[6] (Table 1). Breath sounds in the apices and lateral lung segments should be auscultated.[6] Absent or bronchial breath sounds suggest pathology such as pneomothorax or hemothorax on that side and may be apparent on chest x-ray. Ipsilateral chest tube insertion is indicated for bronchial injuries,

TABLE 1. Causes of Respiratory Failure in Trauma

Facial trauma with airway loss
Laryngeal injury
Tracheal injury
Bronchial injury
Pneumothorax
Hemothorax
Narcosis
Traumatic brain injury
High cervical spine injury

pneumothorax, chylothorax, and hemothorax. Tension pneumothroax should be suspected in the patient with decreased breath sounds, hyperresonance to percussion, hypotension, and/or circulatory collapse.[6] Impressive mediastinal shifts may occur. Emergent decompression with a 16-gauge needle catheter is indicated; it is placed above the rib in the second intercostal space, midclavicular line followed by chest tube insertion of a 36-French or larger tube. Thoracotomy is typically required if >1200 mL of blood is rapidly lost from the thorax and is most often due to an injured intercostal artery.[6]

CIRCULATION

Shock is a state of inadequate oxygen delivery for maintenance of normal cellular and tissue function. One should assume the trauma patient who presents in shock is hemorrhaging. A few distinct areas of the body are large enough to accommodate enough blood for shock to develop, namely, the abdomen, retroperitoneum, thorax, thighs, and uterus. Direct pressure on extremities can help control peripheral bleeding. Long bone fractures can be reduced and splinted to help control blood loss. Internal bleeding is controlled surgically and/or with angiographic embolization that may expose the unborn child to large radiation doses if the examination is time consuming. Volume resuscitation and control of the bleeding source is paramount to the meaningful survival. Hypovolemic shock in the trauma patient is most common. Hypovolemia will manifest as thready pulses, tachycardia, flattened neck veins, pallor, and prolonged capillary refill. If a radial pulse is palpable, the systolic blood pressure is approximately 80 mm Hg. The absence of carotid and peripheral pulses indicates PEA and ACLS protocols should be initiated. If there is a need to defribillate the patient, standard ACLS voltage should be used. There is no evidence that the fetus is harmed by the current from defibrillation.[16] External fetal monitors should be removed before delivering shocks.[16] Chest compressions should be carried out with the understanding that the maternal heart is displaced upward in the chest by the gravid uterus at advanced gestations, and this should guide hand placement.[16] Protocols for defibrillation and doses of medications are not changed in pregnancy. The CPR should not be interrupted for the sake of giving medications because they get circulated with compressions.[22]Giving medications in pregnancy through lower extremity lines should be avoided because they may not adequately reach the maternal heart because of compression by the gravid uterus.[20] Palpable femoral pulses have not been shown to be reliable indicators of blood flow during CPR because retrograde flow in the femoral vein could mimic femoral artery pulsations.[21] The presence of a carotid pulse during CPR is also not an indicator of adequate cerebral or coronary blood flow.[21] An end-tidal CO_2 monitor can be used as an indicator of adequate CPR efforts and return of spontaneous circulation.[21]

Obstructive shock is caused by impediments to venous return to the heart and occurs in tension pneumothorax, cardiac tamponade, and air embolism. Obstructive shock may be exacerbated by positive pressure ventilation because of decreased venous return with increased intrathoracic pressure.[6] In the case of tamponade, PEA will ensue with increased pericardial

pressure and surgical decompression with pericardiocentesis, subxiphoid window (time consuming), or thoracotomy is indicated depending on the clinical picture and resources. Pericardial fluid, hypokinetic and underfilled chambers can be quickly seen with bedside extended Focused Abdominal Sonography for Trauma. Patients with suspected air embolism from large venous lacerations should be placed in the left lateral decubitus position as an attempt to keep the air bubbles in the right atrium. Unfortunately, air embolism is rapidly fatal and the patient often dies in the field. Distributive shock can be seen in patients with sepsis from bowel injury and feculent contamination, anaphylactic reactions, amniotic fluid embolism, and cervical or high thoracic spine trauma. Carcinogenic shock is a result of pump failure and may be seen in trauma in association with myocardial contusion, coronary artery, and valve injuries.[6] Amniotic fluid embolism should be considered in the differential for circulatory collapse and is treated with supportive measures. One should consider cardiopulmonary bypass, if the patient is suspected to have an amniotic fluid embolism and in extremis.[16]

Short, large-bore (16 to 18 gauge) peripheral intravenous catheters should be placed as soon as possible as a way to rapidly infuse fluids and blood products. If intravenous access cannot be obtained for fluid infusion, intraosseous access is a viable alternative. Central venous access should be obtained for pressors and ionotropic agents. Arterial lines should be placed for continuous blood pressure monitoring and serial blood gas and lactate analysis to help guide resuscitative end-points. In addition, noninvasive arterial pressure waveform monitors can track cardiac output and response to ongoing volume resuscitation in the intensive care units.

There is an ongoing controversy about the best resuscitative fluids to use in trauma. Crystalloid fluids are still the recommended standard. There is some evidence for the use of hypertonic saline, colloid and hemoglobin-based oxygen carriers, none of which are presently considered standard therapy.[6] The general rule of thumb is to replace fluids in a 3:1 ratio with blood loss starting with a 1 to 2 L bolus.[5] Volume status should ideally be optimized before resorting to pressor use (Table 1). There are limitations to every intervention. Patients, infused with large volumes of normal saline over a short period of time, may develop a hyperchloremic metabolic acidosis. Lactated Ringers infusions have been shown to be proinflammatory and may contribute to the multiorgan failure and ARDS seen in trauma victims. Dilution coagulopathy with hypothermia can occur in the setting of massive crystalloid resuscitation, and the emergency providers must keep in mind about the warm fluids and blood administered. Certainly, in the setting of hemorrhage, a 1:1 red blood cells to plasma ratio has been beneficial in the military trauma setting and now many obstetric and trauma centers have adopted this approach to blood product resuscitation. One last-ditch effort to control bleeding is the administration of recombinant factor VIIa. This medication is ineffective if fibrinogen levels are low; and most evidence on its use in pregnancy are from case reports and anecdotes. The clinician ordering rFVIIa should also be aware of the potential for extensive clotting and cerebrovascular accidents.

It has been shown that even in patients in whom volume resuscitation has resulted in normalization of blood pressure and urine output, there may still be evidence of tissue hypoperfusion with ongoing elevated lactic acid and base deficits.[6] Some experts suggest one of the end points of resuscitation to be normalization of serum lactate (< 1.5 mEq/L) and base deficit of not more than -2 mmol/L.[29]

DISABILITY

A rapid neurologic evaluation helps determine the degree of compromise in a trauma victim. Polytrauma in the setting of TBI presents one of the more challenging clinical scenarios as controversy over appropriate ventilation, blood pressure maintenance and fluid resuscitation type exists. There are no reliable data to suggest that the volume of fluids and blood products used exacerbate TBI.[6] Hypertonic saline may be the fluid of choice in TBI as it is not associated with an osmotic dieresis (as in the case with mannitol) and a risk of hypovolemia.[6] The cerebral perfusion pressure is recommended to be maintained above 60 mm Hg.[29] Hypotension (systolic blood pressure < 90 mm Hg), hypoxia, and hypercarbia must be avoided in patients diagnosed with TBI.[6,29] In addition, elevations in intracerabral pressure > 20 mm Hg should prompt intervention to lower the pressure.[29] Maneuvers such as maintenance of head elevation to 30 degrees, adequate sedation, avoidance of hyperthermia, and ventriculostomy placement have been used to decrease intracerebral pressures.[29] Burst suppression barbiturate therapy is a last-ditch effort in decreasing the cerebral metabolic demands in an attempt to lower the intracerebral pressure. This strategy may make the diagnosis of brain death difficult and prolong the process as the half-life of pentobarbital is long (15 to 50 h) and may affect brainstem reflex activity. Note that hyperventilation causes cerebral vasoconstriction, as it has been associated with worsened neurologic outcomes and is, therefore, no longer practiced.[29] In the general population, cervical spine injuries may be present in 4% to 20% of seriously traumatized patients.[6] It is important to obtain head imaging studies as early as possible in the multiple trauma patient, as the findings could seriously alter the management.[29] Serial head CT evaluations may be needed in the general population, it may be warranted in the stable pregnant patient with TBI as part of her intensive care strategy to follow pathology with an MRI instead of the serial CT scans to minimize cumulative ionizing radiation to the fetus.

General Management Considerations in Relation to the Obstetric Patient

Pregnant trauma patients should be treated the way their nonpregnant counterparts treated by a multidisciplinary team. The "ABCDs" of a trauma evaluation must be conducted in pregnant patients, however, additional workup for evidence of fetomaternal hemorrhage, preterm labor, abruption, and ruptured membranes must be included. Vaginal, cervical, and rectal examinations should be included in the secondary survey. A speculum examination can be conducted to visualize the cervix and vaginal mucosa for lacerations, contusions, or hematomas and to look for evidence of amniorrhexis, source of bleeding, or fetal parts/cord. Before conducting a digital examiantion on a vaginally bleeding patient, one should rapidly exclude placenta previa with a bedside ultrasound as a cause for the bleeding. Hemorrhage can be iatrogenically provoked during a digital examination on a patient with previa. Maternal stabilization and left lateral decubitus positioning is priority. Maternal oxygen supplementation is paramount. Fetal monitoring should be conducted in viable gestations.

Premature labor can affect up to 25% of trauma cases beyond 22 weeks.[2] Perinatal mortality depends largely on gestational age, birth weight, and use of antenatal steroids in the viable fetus. A fetus beyond 28 weeks has a better chance of survival than the younger gestations. In the setting of a relatively stable mother and nonreassuring fetal heart tracing in a viable fetus (especially if > 28 wk), cesarean delivery should be considered. If there is a concealed abruption, a woman may seem

stable but may have significant coagulopathy that could put her at risk for massive hemorrhage, hysterectomy, or mortality if not corrected, ideally preoperatively. The operating room, fluids, and blood products should be warmed because coagulopathy cannot be adequately corrected if the patient is hypothermia.

Necessary radiologic studies should not be avoided because of pregnancy. Certainly, the least invasive studies (while minimizing radiation exposure) for the highest diagnostic yield are required to used. The use of the abdominal portion of military antishock trousers is contraindicated, because inflation in pregnant patients can reduce uterine perfusion and venous return, but the legs can be inflated.[2,3] The tetanus vaccine is safe to give in pregnancy. Deep vein thrombosis prophylaxis should be used in the intensive care unit for pregnant trauma patients, particularly those with multiple orthopedic injuries.

Summary

Once a woman is admitted for trauma, she is at a higher risk for preterm delivery, placental insufficiency, and low birth weight for the remainder of the pregnancy. If discharged undelivered, close outpatient monitoring is warranted with serial growth examinations (typically monthly) and weekly or biweekly antenatal testing depending on the gestational age. Biweekly testing is favored beyond 36 weeks.

Providers of obstetric services should be mindful to educate patients on appropriate seatbelt use in pregnancy. Interpersonal violence and substance-abuse screening is paramount. Support, counseling, and rehabilitation services should be provided to any patient in need. These interventions may not eradicate maternal trauma completely, but the effort may significantly attenuate the risk to the patient and her child.

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