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Epidemiology of Critical Illness in Pregnancy

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Introduction

The successful epidemiologic evaluation of any disease or condition has several prerequisites. Two of the most important prerequisites are that the condition should be accurately defined and that there should be measurable outcomes of interest. Another requirement is that there must be some systematic way of data collection or surveillance that will allow the measurement of the outcomes of interest and associated risk factors. The epidemiologic evaluation of critical illness associated with pregnancy has met with mixed success on all of these counts.

Historically, surveillance of pregnancy-related critical illness has focused on the well-defined outcome of maternal mortality in order to identify illnesses or conditions that might have led to maternal death. Identification of various conditions associated with maternal mortality initially came from observations by astute clinicians. One of the best examples is the link described by Semmelweis between handwashing habits and puerperal fever. In most industrial and many developing countries, there are now population-based surveillance mechanisms in place to track maternal mortality. These are often mandated by law. In fact, the World Health Organization uses maternal mortality as one of the measures of the health of a population [1].

Fortunately, in most industrialized nations, the maternal mortality rates have fallen to very low levels. Unfortunately, recent statistics for the United States suggest that overall maternal mortality has been increasing, but it remains unclear whether this is just due to improvements in surveillance [2]. Although maternal mortality is an important maternal health measure, tracking maternal deaths may not be the best way to assess pregnancy- related critical illnesses since the majority of such illnesses do not result in maternal death. As stated by Harmer [3], “death represents the tip of the morbidity iceberg, the size of which is unknown.” Unlike mortality, which is an unequivocal endpoint, critical illness in pregnancy as a morbidity outcome is difficult to define and, therefore, difficult to measure and study precisely.

There are many common conditions in pregnancy – such as hypertensive diseases, intrapartum and postpartum hemorrhage, venous thromboembolism, diabetes, thyroid disease, asthma, seizure disorders, and infection and sepsis – that occur frequently and require special medical care, but do not actually become critical illnesses. Most women with these complications have relatively uneventful pregnancies that result in good outcomes for both mother and infant, but each of these conditions can be associated with significant complications that have the potential for serious morbidity, disability, or death. The stage at which any condition becomes severe enough to be classified as a critical illness has not been clearly defined. However, it may be helpful to consider critical illness as impending, developing, or established significant organ dysfunction, which may lead to long-term morbidity or death. This allows some flexibility in the characterization of disease severity, since it recognizes conditions that can deteriorate rather quickly in pregnancy.

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Maternal mortality data collection is reasonably well established in many places, but specific structured surveillance systems that track severe complications of pregnancy (without maternal mortality) are rare. It has been suggested that most women suffering a critical illness in pregnancy are likely to spend some time in an intensive care unit (ICU) [3–5]. These cases have been described by some as "near-miss" mortality cases [6,7]. Therefore, examination of cases admitted to ICUs can provide insight into the nature of pregnancy-related critical illnesses and can complement maternal mortality surveillance. However, it should be noted that nearly two-thirds of maternal deaths might occur in women who never reach an ICU [5].

The remainder of this chapter reviews much of what is currently known about the epidemiology of critical illness in pregnancy. Some of the information is based on published studies; however, much of the data are derived from publicly available data that are collected as part of nationwide surveillance systems in the United States.

Pregnancy-related hospitalizations

Pregnancy complications contribute significantly to maternal, fetal, and infant morbidity, as well as mortality [8]. Many women with complicating conditions are hospitalized without being delivered. Although maternal complications of pregnancy are the fifth leading cause of infant mortality in the United States, little is known about the epidemiology of maternal complications associated with hospitalizations. Examination of complicating conditions associated with maternal hospitalizations can provide information on the types of conditions requiring hospitalized care. In the United States, between 1991 and 1992, it was estimated that 18.0% of pregnancies were associated with non-delivery-related hospitalization, with disproportionate rates between black (28.1%) and white (17.2%) women [9]. This 18.0% hospitalization rate comprised 12.3% for obstetric conditions (18.3% among black women and 11.9% among white women), 4.4% for pregnancy losses (8.1% among black women and 3.9% among white women), and 1.3% for nonobstetric (medical or surgical) conditions (1.5% among black women and 1.3% among white women). The likelihood of pregnancy-associated hospitalizations in the United States declined between 1986–1987 and 1991–1992 [9,10].

More recent data about pregnancy-related hospitalization diagnoses can be found in the aggregated National Hospital Discharge Summary (NHDS) data for 2005–2009. These data are assembled by the National Center for Health Statistics (NCHS) of the US Centers for Disease Control and Prevention. The NHDS data are a survey of medical records from short-stay, nonfederal hospitals in the United States, conducted annually since 1965 [11]. Briefly, for each hospital admission, the NHDS data include a primary and up to six secondary diagnoses, as well as up to four procedures performed for each hospitalization. These diagnoses and procedures are all coded based on the International Classification of Diseases (9th rev., clinical modification). We examined the rates (per 100 hospitalizations) of hospitalizations by indications (discharge diagnoses) during 2005–2009 in the United States, separately for delivery-related (n = 20,862,592) and non-delivery-related (n = 2,225,243) hospitalizations. We also examined the mean hospital length of stay (LOS; with a 95% confidence interval [CI]). Antepartum and postpartum hospitalizations were grouped as non-delivery-related hospitalizations.

During 2005–2009, nearly 8.8% of all hospitalizations were for hypertensive diseases associated with a delivery and 9.1% were for hypertensive diseases not delivered (Table 1.1). Mean hospital LOS, an indirect measure of acuity for some illnesses, was higher for delivery-related than for non-delivery-related hospitalizations for hypertensive diseases. Hemorrhage, as the underlying reason for hospitalization (as either a primary or secondary diagnosis), occurred with similar frequencies for delivery- and non-delivery-related hospitalizations. Non-delivery-related hospitalizations for genitourinary infections occurred over nine times more frequently (12.3%) than delivery-related ones (1.3%), although the average LOS was shorter for non-delivery-related hospitalizations.

Hospitalizations for preterm labor occurred over twice as frequently for non-delivery-related hospitalizations (18.0%) than for delivery-related hospitalizations (8.0%). This is expected since many preterm labor patients are successfully treated for arrest of labor and some of these hospitalizations are for "false labor." Liver disorders were uncommonly associated with hospitalization. However, the mean hospital LOS for liver disorders that occurred with non-delivery-related hospitalizations was 6.6 days, compared with a mean LOS of 3.7 days if the liver condition was delivery related. Coagulation-related defects required 4.6 days of hospitalization if not related to delivery compared with a mean LOS of 3.7 days if the condition was delivery related. Hospitalizations for embolism-related complications were infrequent, but generally required extended hospital stays during delivery-related hospitalizations.

The top 10 conditions associated with hospital admissions, separately for delivery- and non-delivery-related events, are presented in Figure 1.1. The chief cause for hospitalization (either delivery or non-delivery related) was preterm labor. The second most frequent condition was hypertensive disease (8.8% for delivery related and 9.1% for

Table 1.1 Rate (per 100 hospitalizations) of delivery- and non-delivery-related hospitalizations, and associated hospital length of stay by diagnosis: United States, 2005–2009.

	Delivery-related hospitalization (n = 20,862,592)		Non-delivery-related hospitalization (n = 2,225,243)	
Hospital admission diagnosis[a]	**Rate (%)**	**Mean LOS (95% CI)**	**Rate (%)**	**Mean LOS (95% CI)**
Hypertensive diseases				
Chronic hypertension	4.6	3.0 (3.0, 3.1)	4.6	2.6 (2.4, 2.9)
Preeclampsia/eclampsia	3.8	4.0 (3.8, 4.1)	3.9	3.0 (2.7, 3.4)
Superimposed preeclampsia	0.4	5.7 (5.0, 6.3)	0.7	3.9 (2.1, 5.8)
Hemorrhage-related				
Placental abruption	1.0	4.0 (3.5, 4.4)	0.7	4.3 (3.3, 5.3)
Placenta previa	0.6	4.5 (3.7, 5.3)	0.1	4.4 (2.9, 6.0)
Hemorrhage (undetermined etiology)	0.3	3.3 (2.9, 3.7)	1.4	2.0 (1.6, 2.4)
Vasa previa	<0.01	4.8 (2.6, 7.1)	–	–
Postpartum hemorrhage	2.5	2.8 (2.7, 3.0)	1.0	2.4 (1.9, 3.0)
Infection-related				
Viral infections (not malaria/rubella)	1.8	2.9 (2.7, 3.1)	1.5	4.2 (3.0, 5.4)
Genitourinary infections	1.3	3.8 (3.5, 4.1)	12.3	3.1 (2.7, 3.6)
Infection of the amniotic cavity	1.5	4.0 (3.7, 4.2)	0.5	4.1 (1.4, 6.9)
Anesthesia-related complications	<0.01	4.0 (3.0, 5.0)	–	–
Diabetes				
Preexisting diabetes	0.9	3.5 (3.3, 3.7)	3.2	3.6 (3.2, 4.0)
Gestational diabetes	5.0	3.0 (2.9, 3.1)	3.2	4.6 (3.5, 5.8)
Preterm labor	8.0	4.1 (3.9, 4.3)	18.0	3.3 (3.0, 3.7)
Maternal anemia	8.5	3.1 (3.0, 3.2)	6.8	3.6 (3.2, 4.0)
Drug dependency	<0.01	3.4 (2.9, 3.9)	0.8	4.9 (3.2, 6.7)
Renal disorders	0.2	3.2 (2.5, 4.0)	1.8	2.9 (2.2, 3.6)
Liver disorders	<0.01	3.7 (2.9, 4.6)	0.2	6.6 (2.8, 10.4)
Congenital cardiovascular disease	0.9	3.3 (3.1, 3.6)	1.6	3.7 (3.0, 4.5)
Thyroid disorders	0.4	2.5 (2.3, 2.7)	0.7	3.2 (2.1, 4.2)
Uterine tumors	0.9	3.4 (3.2, 3.7)	0.5	2.4 (1.8, 3.0)
Uterine rupture	0.1	3.6 (3.1, 4.1)	–	–
Postpartum coagulation defects	0.2	4.0 (3.1, 4.9)	<0.1	3.5 (2.6, 4.4)
Shock/hypotension	0.1	3.7 (2.8, 4.7)	0.3	4.6 (1.4, 7.9)
Acute renal failure	0.02	7.0 (3.0, 11.0)	0.02	3.4 (0.1, 6.7)
Embolism-related				
Amniotic fluid embolism	–		–	–
Blood clot embolism	0.01	6.0 (4.9, 7.2)	0.2	3.3 (2.3, 4.3)
Other pulmonary embolism	–	–	–	–

CI, Confidence interval; LOS; length of stay.

[a] The diagnoses associated with hospital admissions include both primary and secondary reasons for hospitalizations. Each admission may have had up to six associated diagnoses.

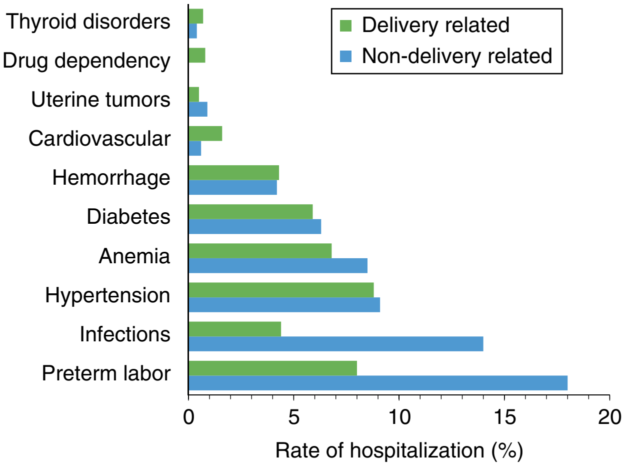

Figure 1.1 Ten leading causes of delivery- and non-delivery-related maternal hospitalizations in the United States, 2005–2009.

non-delivery related), followed by anemia (6.8% vs. 8.5%). Hospitalizations for infection-related conditions occurred over twice more frequently for non-delivery-related episodes (14.0%) than delivery episodes (4.4%). In contrast, the proportion hospitalized for hemorrhage was similar for deliveries (4.3%) and nondeliveries (4.2%). These data provide important insights into the most common complications and conditions associated with pregnancy hospitalization. The LOS data also give some indication of resource allocation needs. While this is important for understanding the epidemiology of illness in pregnancy, it does not allow a detailed examination of illness severity.

Maternal mortality

The national health promotion and disease prevention objectives of the Healthy People 2010 indicators specified a goal of no more than 3.3 maternal deaths per 100,000 live births in the United States [12]. The goal for maternal deaths among black women was set at no more than 5.0 per 100,000 live births. As of 2020, this objective remains elusive. The pregnancy-related maternal mortality ratio (PRMR) per 100,000 live births for the United States peaked at 17.8 in 2009 and 2011, with a modest decrease to 15.9 for 2012 [2], and with the ratio over threefold greater among black compared with white women [13]. Therefore, the Healthy People 2020 target of 11.4 maternal deaths per 100,000 live births also seems overly optimistic given the most recent trends. Several studies that have examined trends in maternal mortality statistics have concluded that a majority of pregnancy-related deaths (including those resulting from ectopic pregnancies, and some cases of infection and hemorrhage) are preventable [1,13–15].

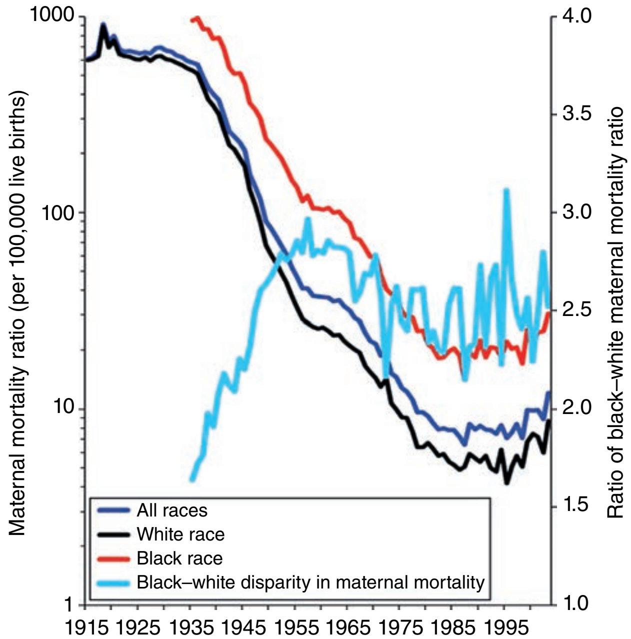

Figure 1.2 Trends in the maternal mortality ratio (number of maternal deaths per 100,000 live births) in the United States, 1915–2003, and the black–white disparity in the maternal mortality ratio. The term ratio is used instead of rate because the numerator includes some maternal deaths that were not related to live births and, thus, were not included in the denominator. *Source:* Figure reproduced from Ananth and D'Alton [2], with permission of the publisher.

However, maternal deaths due to other complications, such as pregnancy-induced hypertension, placenta previa, retained placenta, and thromboembolism, are considered by some as difficult to prevent [16,17]. Nevertheless, some mortality prevention should be possible, even in these situations.

The maternal mortality ratio (MMR) has undergone dramatic shifts over the past century (Figure 1.2). The MMR dropped precipitously from the turn of the 20th century from 600 per 100,000 live births in 1915 to approximately 40 per 100,000 live births in the mid-1960s to about 7 per 100,000 live births in the mid-1980s. Subsequently, the MMR increased between 1987 (7.2 per 100,000 live births) and 1990 (10.0 per 100,000 live births). During the period 1991–1997, the mortality ratio further increased to 11.5 per 100,000 live births. The mortality ratio continued to increase to 17.8 in 2009 and 2011, to more recent statistic of 23.8 per 100,000 live births in 2020. The reasons for the most recent increases are not clear, but they may be related to a combination of true increases and improved surveillance using better case-tracking methods. Of note, the high pregnancy mortality ratios in 2009 and 2011 may have been attributable, at least in part, to infection-related deaths during the influenza A H1N1 pandemic from 2009 to 2010 [13].

Table 1.2 Pregnancy-related maternal deaths (n = 3358) by underlying cause: United States, 2006–2010.

	All outcomes		Pregnancy outcome					
Cause of death	**%**	**PRMR[a]**	**Live birth**	**Stillbirth**	**Ectopic**	**Abortion[b]**	**Undelivered**	**Unknown**
Embolism	14.9	2.4	16.4	10.8	0	12.2	16.1	10.9
Cardiovascular conditions	14.6	2.3	14.4	11.4	0	7.8	20.2	12.7
Infection	13.6	2.2	12.5	22.2	1.0	46.7	12.1	13.8
Noncardiovascular conditions	12.8	2.0	10.4	18.4	0	5.6	22.4	10.9.
Cardiomyopathy	11.8	1.9	14.6	1.3	0	0	5.0	20.6
Hemorrhage	11.4	1.8	8.8	17.7	97.1	17.8	4.5	9.4
Hypertension	9.4	1.5	11.3	12.0	0	0	6.3	8.5
Cerebrovascular accidents	6.2	1.0	6.1	1.9	0	0	8.0	8.5
Anesthesia	0.7	0.1	0.7	0	1.0	7.8	0	0.3
Unknown	4.7	0.8	4.8	4.4	1.0	2.2	5.4	4.4
Total		16.0						

PRMR, Pregnancy-related mortality ratio.
[a] PRMR (condition-specific) per 100,000 live births for 20,959,533 live births from 2006 to 2010.
[b] Includes both spontaneous and induced abortions.
Source: Adapted from Creanga *et al*. [13].

Several maternal risk factors have been examined in relation to maternal deaths. Women aged 35–39 years carry a 2.6-fold (95% CI, 2.2, 3.1) increased risk of maternal death, and those over 40 years are at a 5.9-fold (95% CI, 4.6, 7.7) increased risk. Black maternal race confers a relative risk of 3.7 (95% CI, 3.3, 4.1) for maternal death compared with white women. Similarly, women without any prenatal care during pregnancy have an almost two-fold increased risk of death relative to those who received prenatal care [18]. Although these risks have been recognized for over 25 years, there has been little progress in reducing these risks.

The chief cause for a pregnancy-related maternal death depends on whether the pregnancy results in a live birth, stillbirth, ectopic pregnancy, abortion, or molar gestation (Table 1.2). For the period 2006–2010, embolism was the most common cause of overall pregnancy-related mortality (14.9%), leading to an overall PRMR for embolism of 2.4 per 100,000 live births. This is a significant change from the 1987–1990 data, when the most common cause (28.8%) of pregnancy-related mortality was the family of hypertensive diseases (PRMR 2.6). For the 2006–2010 period, the next most common etiologies were cardiovascular diseases (PRMR 2.3) and infection-related deaths (PRMR 2.2). Among ectopic pregnancies, the chief cause of death was hemorrhage (97.1%). Infections were the leading cause of stillbirth-related (22.2%) and abortion-related (46.7%) maternal deaths [13].

Understanding the epidemiology of pregnancy-related deaths is essential to targeting specific interventions. Improved population-based surveillance through targeted reviews of all pregnancy-related deaths, as well as additional research to understand the causes of maternal deaths by indication, will help in achieving the Healthy People 2020 targets for reduction in maternal mortality.

Perinatal mortality

Perinatal mortality, defined by the World Health Organization as fetal deaths plus deaths of live-born infants within the first 28 days, is an important indicator of population health. Examination of the maternal conditions related to perinatal mortality can provide further information on the association and impact of these conditions on pregnancy outcomes. Table 1.3 shows the results of our examination of perinatal mortality rates among singleton and multiple births (twins, triplets, and quadruplets) by gestational age and high-risk conditions. The study population comprises all births in the United States that occurred in 1995–1998. Data were derived from the national linked birth/infant death files, assembled by the NCHS of the Centers for Disease Control and Prevention [19]. Gestational age was predominantly based on the date of the last menstrual period [20], and it was grouped as 20–27, 28–32, 33–36, and >37 weeks. Perinatal

Table 1.3 Perinatal mortality rates among singleton and multiple gestations by gestational age and high-risk conditions: United States, 1995–1998.

	20–27 weeks		28–32 weeks		33–36 weeks		≥37 weeks	
High-risk conditions	PMR	Relative risk[a] (95% CI)	PMR	Relative risk[a] (95% CI)	PMR	Relative risk[a] (95% CI)	PMR	Relative risk[a] (95% CI)
Singletons								
Number of births	n = 103,755		n = 352,291		n = 1,072,784		n = 13,440,671	
Hypertension[b]	200.4	0.6 (0.5, 0.7)	53.1	0.6 (0.5, 0.6)	13.5	0.6 (0.5, 0.7)	3.6	1.3 (0.5, 0.7)
Hemorrhage[c]	308.9	1.1 (1.0, 1.2)	73.1	1.4 (1.3, 1.5)	19.9	1.6 (1.5, 1.7)	3.6	1.6 (1.5, 1.7)
Diabetes	287.0	1.0 (0.9, 1.1)	60.8	1.2 (1.1, 1.3)	19.5	1.8 (1.7, 1.9)	5.0	2.3 (2.1, 2.4)
SGA	467.4	2.3 (2.1, 2.5)	196.3	6.2 (6.0, 6.4)	56.3	7.8 (7.5, 8.1)	9.1	5.5 (5.4, 5.7)
No complications[d]	297.6	1.0 (Referent)	38.8	1.0 (Referent)	7.0	1.0 (Referent)	1.5	1.0 (Referent)
Multiples								
Number of births	n = 23,055		n = 76,329		n = 147,627		n = 187,109	
Hypertension[b]	183.5	0.7 (0.6, 0.8)	21.4	0.5 (0.4, 0.6)	5.3	0.6 (0.5, 0.7)	4.9	0.8 (0.6, 1.1)
Hemorrhage[c]	251.6	1.0 (0.9, 1.1)	36.6	1.1 (1.0, 1.3)	9.6	1.2 (1.0, 1.4)	6.7	1.3 (1.1, 1.5)
Diabetes	214.9	0.8 (0.7, 1.1)	28.7	0.9 (0.7, 1.2)	9.7	1.3 (1.0, 1.7)	5.9	1.2 (0.9, 1.7)
SGA	394.5	2.0 (1.6, 2.4)	133.4	6.8 (6.3, 7.4)	36.8	7.5 (6.6, 8.4)	24.9	8.6 (7.6, 9.7)
No complications[d]	251.1	1.0 (Referent)	23.4	1.0 (Referent)	5.2	1.0 (Referent)	2.8	1.0 (Referent)

CI, Confidence interval; PMR, perinatal mortality rate per 1000 births; SGA, small-for-gestational-age births.
[a] Relative risk for each high-risk condition was adjusted for all other high-risk conditions shown in the table.
[b] Hypertension includes chronic hypertension, pregnancy-induced hypertension, and eclampsia.
[c] Hemorrhage includes placental abruption, placenta previa, and uterine bleeding of undermined etiology.
[d] No complications include those who did not have any complications listed in the table.

mortality rates were assessed for hypertension (chronic hypertension, pregnancy-induced hypertension, and eclampsia), hemorrhage (placental abruption, placenta previa, and uterine bleeding of undetermined etiology), diabetes (preexisting and gestational diabetes), and small-for-gestational-age (SGA) births (defined as birth weight below the 10th centile for gestational age). We derived norms for the 10th centile birth weight for singleton and multiple births from the corresponding singleton and multiple births that occurred in 1995–1998 in the United States. Finally, relative risks (with 95% CIs) for perinatal death by each high-risk condition were derived from multivariable logistic regression models after adjusting for all other high-risk conditions.

Perinatal mortality rates progressively decline, among both singleton and multiple births, for each high-risk condition with increasing gestational age (Table 1.3). Among singleton and multiple gestations, with the exception of SGA births, mortality rates were generally higher for each high-risk condition, relative to the no complications group. Infants delivered small for their gestational age carried the highest risk of dying during the perinatal period compared with those born to mothers without complications. Among singleton births, the relative risks for perinatal death for SGA infants were 2.3, 6.2, 7.8, and 5.5 for those delivered at 20–27 weeks, 28–32 weeks, 33–36 weeks, and term, respectively. Among multiple births, these relative risks were similar at 2.0, 6.8, 7.5, and 8.6, respectively, for each of the four gestational age categories.

Pregnancy-related ICU admissions

Evaluation of obstetric admissions to ICUs may be one of the better ways to approach surveillance of critical illnesses in pregnancy. Unfortunately, there are no publicly available population-based databases for obstetric admissions to an ICU that provide sufficiently detailed information to allow in-depth study of these conditions. Therefore, it is reasonable to examine descriptive case series for information on these conditions. We reviewed 76 studies published between 1990 and 2021 involving approximately 15,233,420 deliveries and found an overall obstetric-related admission rate to an ICU of 1.40% (range, 0.07–3.97%) (Table 1.4). We excluded studies that reported ICU admissions during the recent severe acute respiratory syndrome coronavirus 2 (COVID-19) pandemic due to the disproportionate impact of the virus on maternal critical illness.

Table 1.4 Obstetric admission rates to an ICU and corresponding maternal mortality rates from 76 studies from 1990 to 2021.

Reference	Years	Location	Total deliveries	Maternal ICU admissions	Maternal deaths per ICU admissions	Fetal/neonatal deaths per ICU admission
Mabie and Sibai (1990) [24]	1986–1989	USA	22,651	200 (0.88%)	7 (3.5%)	–
Kilpatrick and Matthay (1992) [25]	1985–1990	USA	8000[a]	32 (0.4%)	4 (12.0%)	6 (18.8%)
Collop and Sahn (1993) [26]	1988–1991	USA	–	20 (–)	4 (20.0%)	7 (35.0%)
El-Solh and Grant (1996) [27]	1989–1995	USA	–	96 (–)	10/93 (10.8%)	10 (10.4%)
Monoco *et al.* (1993) [28]	1983–1990	USA	15,323	38 (0.25%)	7 (18.4%)	4 (10.5%)
Panchal *et al.* (2000) [23]	1984–1997	USA	822,591	1023 (0.12%)	34 (3.3%)	–
Afessa *et al.* (2001) [29]	1991–1998	USA	–	78 (–)	2 (2.7%)	13 (16.7%)
Gilbert *et al.* (2000) [30]	1991–1998	USA	49,349	233 (0.47%)	8 (3.4%)	–
Hogg *et al.* (2000) [31]	1989–1997	USA	30,405	172 (0.57%)	23 (13.4%)	2 (1.2%)
Munnur *et al.* (2005) [32]	1992–2001	USA	58,000	174 (0.3%)	4 (2.3%)	23 (13.2%)
Muench *et al.* (2008) [33]	24 months	USA	2565	34 (1.33%)	–	–
Maan *et al.* (2009) [34]	1997–2005	USA	1,004,116	15,447 (1.54%)	–	–
Small *et al.* (2012) [35]	2005–2011	USA	19,575	94 (0.48%)	5 (5.3%)	–
Orsini *et al.* (2012) [36]	2009–2012	USA	4715	19 (0.40%)	–	–
Wanderer *et al.* (2013) [37]	1999–2008	USA	698,379	2927 (0.42%)	53 (1.8%)	–
Thakur *et al.* (2016) [38]	2006–2010	USA	27,295	69 (0.25%)	3 (4.3%)	–
Oud *et al.* (2017) [21]	2001–2010	USA	4,060,659	158,410 (3.90%)	414 (0.3%)	3009 (1.9%)
Mahutte *et al.* (1999) [4]	1991–1997	Canada	44,340	131 (0.30%)	3 (2.3%)	–
Lapinsky *et al.* (1997) [39]	1997	Canada	25,000[a]	65 (0.26%)	0	7 (10.8%)
Baskett and Sternadel (1998) [6]	1980–1993	Canada	76,119	55 (0.07%)	2 (3.6%)	–
Rios *et al.* (2012) [40]	2008–2010	Argentina	30,053	242 (0.81%)	5 (2.1%)	23 (9.5%)
Vasquez *et al.* (2007) [41]	1998–2005	Argentina	23,044	161 (0.70%)	11 (6.8%)	18 (11.2%)
Bandeira *et al.* (2014) [42]	2007–2009	Brazil	–	299 (-)	14 (4.7%)	–
Paternina-Caicedo *et al.* (2015) [43]	2006–2011	Columbia	50,897	724 (1.42%)	31 (4.3%)	–
Hazelgrove *et al.* (2001) [5]	1994–1996	England	122,850	210 (0.17%)	7 (3.3%)	40/200 (20.0%)
DeMello and Restall (1990) [44]	1985–1989	England	9425	13 (0.14%)	0	–
Selo-Ojeme *et al.* (2005) [45]	1993–2003	England	31,097	22 (0.11%)	1 (4.5%)	1 (4.5%)
Ryan *et al.* (2000) [46]	1996–1998	Ireland	26,164	17 (0.07%)	0	–
Bouvier-Colle *et al.* (1996) [47]	1991	France	140,000[a]	435 (0.31%)	22 (5.1%)	58 (13.3%)
Koeberle *et al.* (2000) [48]	1986–1996	France	27,059[a]	46 (0.17%)	2 (4.3%)	–
Lelong *et al.* (2013) [49]	1997–2006	France	–	96 (–)	2 (2.1%)	20 (20.8%)
Chantry *et al.* (2015) [50]	2006–2009	France	3,262,526	11,824 (0.36%)	154 (1.3 %)	–
Barry *et al.* (2019) [22]	2010–2014	France	4,030,409	16,011 (3.97%)	208 (1.3%)	–

(*Continued*)

Table 1.4 (Continued)

Reference	Years	Location	Total deliveries	Maternal ICU admissions	Maternal deaths per ICU admissions	Fetal/neonatal deaths per ICU admission
Farr *et al.* (2017) [51]	1996–2003, 2011–2014	Austria	37,236	238 (0.64%)	12 (5.0%)	–
De Greve *et al.* (2016) [52]	2012	Belgium	–	190 (-)	-	–
Loverro *et al.* (2001) [53]	1987–1998	Italy	23,694	41 (0.17%)	2 (4.9%)	5 (12.2%)
Keizer *et al.* (2006) [54]	1990–2001	Netherlands	18,581	142 (0.76%)	7 (4.9%)	35 (24.6%)
Zwart *et al.* (2010) [55]	2004–2006	Netherlands	371,021	847 (0.23%)	29 (3.4%)	–
Heinonen *et al.* (2002) [56]	1993–2000	Finland	23,404	22 (0.14%)	1 (4.5%)	–
Seppänen *et al.* (2016) [57]	2007–2011	Finland	–	291 (-)	1 (0.3%)	–
Krawczyk *et al.* (2021) [58]	2007–2014	Poland	21,180[a]	266 (1.3%)	4 (1.5%)	–
Demirkiran *et al.* (2003) [59]	1995–2000	Turkey	14,045[a]	125 (0.89%)	13 (9.6%)	–
Yuvaci *et al.* (2018) [60]	2014–2015	Turkey	16,728	68 (0.41%)	2 (2.9%)	–
Munnur *et al.* (2005) [32]	1992–2001	India	157,694	754 (0.48%)	189 (25%)	368 (48.81%)
Gupta *et al.* (2011) [61]	2009–2010	India	16,756	24 (0.14%)	10 (41.7%)	–
Ramachandra *et al.* (2013) [62]	2005–2011	India	16,804	65 (0.39%)	22 (33.8%)	–
Chawla *et al.* (2013) [63]	2007–2010	India	6592	35 (0.53%)	10 (28.6%)	–
Ashraf *et al.* (2014) [64]	2012–2013	India	14,474	55 (0.38%)	7 (12.7%)	–
Gombar *et al.* (2014) [65]	2007–2012	India	21,943	144 (0.66%)	42 (29.2%)	32 (22.2%)
Jain *et al.* (2016) [66]	2010–2011	India	15,775	90 (0.57%)	30 (33.3%)	–
Murki *et al.* (2016) [67]	–	India	1127	19 (1.69%)	–	–
Rathod *et al.* (2016) [68]	2010–2013	India	61,615	765 (1.24%)	119 (15.6%)	–
Bibi *et al.* (2008) [69]	2006	Pakistan	2224	30 (1.35%)	10 (33.3%)	13 (43.3%)
Thakur *et al.* (2015) [70]	2012	Nepal	–	192 (–)	24 (12.5%)	–
Shrestha *et al.* (2018) [71]	2012–2017	Nepal	9524	80 (0.84%)	4 (5.0%)	–
Okafor and Aniebue (2004) [72]	1997–2002	Nigeria	6544	18 (0.28%)	6 (33%)	–
Adeniran *et al.* (2015) [73]	2010–2013	Nigeria	–	90 (%)	41 (45.6%)	–
Platteau *et al.* (1997) [74]	1992	South Africa	–	80 (-)	17 (21.3%)	39 (48.6%)
Cohen *et al.* (2000) [75]	1994–1998	Israel	19,474	46 (0.24%)	1 (2.3%)	10 (21.7%)
Lewinsohn *et al.* (1994) [76]	8 years	Israel	–	58 (-)	4 (6.9%)	–
Lataifeh *et al.* (2010) [77]	2002–2008	Jordan	11,665	43 (0.37%)	3 (7.0%)	8 (18.6%)
Richa *et al.* (2008) [78]	1998–2005	Lebanon	–	15 (-)	5 (33.3%)	–
Al-Suleiman *et al.* (2006) [79]	1992–2004	Saudi Arabia	29,432	64 (0.22%)	6 (9.4%)	8/55 (14.5%)
Aldawood *et al.* (2011) [80]	1999–2009	Saudi Arabia	–	75 (0.15%)	6 (8.0%)	–
Mirghani *et al.* (2004) [81]	1997–2002	UAE	23,383	60 (0.26%)	2 (3.3%)	–

2

Organizing an Obstetrical Critical Care Unit: Care without Walls

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Background

The prevailing model for the intensive care unit (ICU) is a physical location within the hospital where care is provided on a minute-to-minute basis for a critically ill patient. ICU care is associated with invasive methods for monitoring vital status (e.g., central venous catheters, peripheral arterial catheters, and pulmonary artery catheters) as well as invasive means of providing organ support (e.g., mechanical ventilation, vasopressors and inotropes, continuous renal replacement therapy, and circulatory assist devices). The goal of monitoring and supporting failing organ systems requires intensive oversight to ensure that opportunities to intervene are not missed. Therefore, another feature of the ICU is the staffing by nurses and physicians to ensure a patient-to-provider ratio that meets these needs.

Historically, Florence Nightingale is credited with the strategic organization of a critical care unit when she was serving as a nurse supervisor to other nursing attendants during the Crimean War. Sick and injured soldiers were located near operating suites, where nurse attendants were more readily available to provide immediate patient care. This unit-based system of care, along with improved sanitation and handwashing, is believed to be among the best practices that reduced the death rate of soldiers during the war [1]. However, unit-based care for patients with similar diagnoses or medical needs was not commonplace until the polio epidemic in the 1950s. Hospitals became overwhelmed with patients requiring respiratory support, but did not have enough respirators (iron lungs) in order to support these patients. New innovations, including positive pressure ventilation with tracheostomy and manual bag ventilation, were utilized to meet this growing need. During this time, patients received intensive care in dedicated hospital wards with skilled medical providers and nurses assigned to attend to their needs, thus triggering the beginning of the intensive care specialty [1,2].

The first National Institutes of Health Consensus Conference on critical care was convened in 1983 to establish guidelines and protocols for the care, design, and staffing of these units [3]. According to the American Hospital Association's Fast Facts on US Hospitals 2022 Edition, more than 5100 hospitals are registered in the United States. Of a total 789,354 hospital beds in community hospitals, there were 112,359 intensive care beds, including Medical-Surgical, Cardiac, Neonatal, Pediatric, Burn, and other miscellaneous units [4]. Between 2000 and 2010, critical care costs increased to $108 billion annually, accounting for 13% of hospital costs and 4% of the US national health expenditures. Nonetheless, there is some evidence that timely and appropriate intensive care is ultimately cost saving [5].

Due to the evolution of technology used to provide support and the growing appreciating for the complexity of caring for critically ill patients, the critical care team has expanded to involve multiple disciplines and levels of organizational management. The critical care team includes respiratory therapists, pharmacists, nutrition and diet specialists, physical therapists, perfusionists, social workers, and more. Traditionally conceptualized as either "closed" or "open" units with respect to whether intensivists alone or any specialist could write orders and make decisions in the ICU, contemporary practice emphasizes

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collaborative patient rounds that include input from all members of a patient's care team (e.g., primary nurse, intensivist, cardiologist, social worker, and pharmacist). Collaboration with other subspecialties is increasingly sought, and this is particularly important in case of critically ill obstetric patients. Obstetricians and maternal-fetal medicine (MFM) specialists should ensure that they are included in multispecialty collaborative rounds in the ICU, and intensivists should seek out input from obstetric specialists. Pregnancy alters maternal physiology with respect to many organ systems, including hematologic, cardiopulmonary, renal, endocrinologic, and gastrointestinal. In turn, maternal health status directly impacts fetal well-being. Addressing the intensive care needs of these high-risk patients requires specific expertise on behalf of not only the intensivist, obstetrical provider, and medicine subspecialists, but also the nursing and ancillary staff through a multidisciplinary team approach.

During the COVID-19 pandemic, the traditional ICU model was dramatically modified to meet the intensive care needs of the community, highlighting the importance of a multidisciplinary approach. As the need for ICU capacity rapidly expanded, nonintensivist physicians were trained on the basics of critical care and deployed through a hybrid staffing model to meet patient care needs [6,7]. Despite these extenuating circumstances, the pandemic staffing model introduced new opportunities for multidisciplinary collaboration and care that continue to inform our current ICU practice and models.

Critical care for obstetric patients

Intensivist-led, interdisciplinary care has been shown to reduce ICU mortality and improve ICU outcomes with shorter lengths of stay [8]. MFM specialists are often involved in managing the care of the critically ill obstetrical patient who presents to a tertiary or quaternary care medical center. However, many acutely ill pregnant patients will present to facilities without MFM presence. Furthermore, the static model for adult critical care may not be feasible or sustainable within our rapidly changing healthcare landscape. In a growing population of older patients with medical comorbidities, multidisciplinary teams are overworked in settings with high patient-to-staff ratios, resulting in high levels of burnout and attrition [9,10]. In responding to the COVID-19 pandemic, hospitals were forced to reconsider the traditional spaces allocated for critical care, expanding staffing, ancillary services, and equipment to other hospital units. Newer organizational models have emerged in order to address this need and provide a more innovative approach to care. These options include a tiered approach, in which an intensivist serves as a director to a number of ICU teams; regionalization of care in which patients are transferred to higher levels of care at specific hospitals; telemedicine services with critical care consultation; and consideration of a critical care unit without walls, where subspecialty teams are available on specific wards where patients warrant a higher level of care.

Obstetrical ICU (OB ICU) admissions in both developed and underdeveloped countries account for approximately 0.4–16% of total ICU admissions [11–17]. This broad range likely reflects variations in local practice patterns, criteria for ICU admission, and availability of critical care services. Not all hospital settings where obstetric patients receive care will have the availability of either critical care services or specialists in MFM.

The landmark publication "Toward Improving the Outcome of Pregnancy Recommendations for the Regional Development of Maternal and Perinatal Health Services" (TIOP I), released by a committee on perinatal health consisting of the March of Dimes, American Congress of Obstetricians and Gynecologists, American Academy of Family Physicians, American Academy of Pediatrics, and American Medical Association, defined levels of specialty care within perinatal medicine in the United States. Its framework categorized neonatal care based on local resources and hospital capabilities, allowing for collaborative efforts of hospital systems to provide "risk"-appropriate care at different levels, ensuring that patients receive care at institutions with the appropriate capabilities or be transferred to such a facility [18,19]. The tertiary care facility, in addition to providing direct patient care, additionally provides training and educational opportunities to the Level I and II care centers. Expansion and differentiation of these levels within a model of subspecialty care now includes a Level IV designation for women whose newborns are expected to have complex medical and surgical needs [20].

An analogous maternal medical risk-based system does not exist. The American College of Obstetrics and Gynecology and Society for Maternal Fetal Medicine consensus on levels of maternal care was initially a call to action for maternal regionalization of care. In this model, the hospital with the highest level of care acts as the central hub for maternal care, providing the maximum level of resources and personnel to high-risk obstetric patients. The relationship between these institutions is enhanced by continued educational opportunities for obstetric care providers, ongoing training with evidence-based practices, and continuity of care through telemedicine and electronic medical records. Although proposals for how to operationalize these levels of maternal care have evolved, paramount to the organizational structure are the policies and guidelines of evidence-based care that algorithmically support best practices in obstetrics [21,22]. In summary, obstetric critical care continues to evolve along with models of critical care for the nonpregnant patient population.

Unit design: ICU without walls

ICU designs that are in current use in the United States generally follow two basic models of organization: open and closed ICUs, as well as hybrid models [23]. In an open ICU model, the patient's attending physician may admit the patient to the unit without prior approval or with only minimal screening, as long as they have appropriate privileges to treat. This is generally considered a lower-intensity unit. In this setting, the admission and discharge criteria tend to be less strict. Intensivists are, therefore, not necessarily the primary provider, but are available as consultants, while the attending physician of record makes the management and treatment plans. This model allows the maintenance of the physician–patient relationship through continuity of care. Unfortunately, most open ICU attending physicians (also called *attendings of record*) are not hospital-based physicians and have other patient care duties. At times, this may lead to ineffective communication with hospital-based staff regarding treatment plans due to inconsistent physician availability. Furthermore, this can impact the patient's quality of care, length of stay, and resource utilization with an increase in overall cost. This model may be more cost-effective in small hospitals with a shortage of trained in-house intensivists [24–26].

A more structured, intensivist-managed (high-intensity), closed-unit model provides certain advantages over an open ICU model. Approximately one-quarter of ICUs in the United States are closed units [27]. Lower morbidity and mortality, as well as decreased ICU and hospital length of stay, have been demonstrated with closed ICU models [28–32]. In this model, a board-certified intensive care specialist directs the care of the critically ill patient with adherence to well-defined admission and discharge criteria. Intensivists undergo specialized training to treat critically ill patients by completing a fellowship in critical care medicine after finishing a residency in internal medicine, pulmonary medicine, anesthesia, or surgery. This physician typically has no other competing clinical duties and is dedicated to the care of these patients. The inclusion of physician assistants, nurse practitioners, and trainees in the care team allows for continued provision of intensive care without necessitating 24 hour in unit coverage by a physician. This provides for better utilization of healthcare resources, improved patient outcomes, decreased length of stay, and reduction in healthcare expenditures. The Leapfrog Group, founded in 2000 by large employers and purchasers of healthcare to evaluate hospitals for their quality of care and patient outcomes, endorses a closed model of ICU care with recommendations for best practices in ICU staffing [33]. A closed ICU model may be more feasible in large teaching hospitals due to the availability of effector providers and trainees in-house. Potential disadvantages to this model are loss of the physician–patient relationship with the primary provider, leading to potential gaps in knowledge regarding the patient's medical history that may impact patient care [34].

Most ICUs are organized as a hybrid model with a focus on centralized decision-making and management. In this model, the intensivist provides direct patient care in collaboration with the attending of record, who is also allowed to write orders. While the attending of record is not a part of the ICU team, they are able to remain actively involved in their patient's care. Collaboration of the intensivist with the attending of record maximizes the level of care delivered while maintaining continuity of care for the patient [34]. Timely communication, structured reporting, and timely evaluation and documentation of care are important tenets for success in this dynamic environment.

Application of the traditional ICU models for an obstetrical critical care unit is most beneficial through a hybrid model. The obstetrical specialist plays a key role in the management of the critically ill parturient within a multidisciplinary care team. In designing an OB ICU, there are several important considerations, including location of the unit within the hospital, available equipment and ancillary staff for a separate unit, and a large enough population of critically ill pregnant patients to make an OB ICU practical and fiscally tenable. For many hospital settings, a separate OB ICU is not possible due to physical constraints or lack of available resources. Therefore, innovative approaches must be considered.

In critical care, the concept of an ICU without walls has been around for several years with intensivists calling attention to the fact that the knowledge and tools of critical care can, and perhaps should, transcend the bricks and mortar of the conventional unit. Many have emphasized the challenge of patients who become unstable or critically ill outside the walls of the ICU and have advocated for more agile teams and technology to deliver optimal care [35]. The role of emergency response teams in timely resuscitation, for example, is an important consideration. As with obstetric early warning systems, some of the proposed models have focused on early warning signs to alert a resuscitation team to evaluate a patient. There has been research in this area that indicates that ICU admissions are reduced and patient outcomes are improved when critical care specialists were involved with patient care outside of the ICU. Similarly, obstetricians have advocated for a virtual OB ICU model, emphasizing that the volume of dedicated OB ICUs will always be expected to be low, and the expense of staffing and equipment possibly too high to justify.

As with the ICU without walls, the virtual OB ICU emphasizes the expertise of a dedicated group of providers who attend to a patient wherever specialized care is deemed most appropriate. In this model, the ICU is organized not necessarily by location, but by the components of the multidisciplinary team in order to meet the specific needs of the patient. This team is organized by the MFM specialist and the medical subspecialists involved in comanagement of the patient's illness. A "virtual" obstetrical critical care unit, or ICU without walls, optimizes care by providing a team of specialists who treat the patient where the patient is located, utilizing mobile monitoring capabilities and obstetrical staff to meet intensive care needs. Ideally, this can be accomplished on the Labor and Delivery unit with obstetrical operating suites available for emergencies. Proximity to the obstetrical operating suite with the availability of obstetric anesthesiology specialists allows for immediate intervention for maternal or fetal indications. However, monitoring capabilities such as mobile telemetry, dialysis machines, electronic fetal monitoring, and hemodynamic and ventilator support can be mobilized in the event that there is no bed availability in the unit.

Patient population

The health of our obstetric population reflects that of our nation as a whole, which is changing rapidly secondary to increased rates of obesity, hypertension, diabetes, and cardiac disease. These and other medical comorbidities are becoming increasingly prevalent in our obstetrical population and are compounded by advancing maternal age [36,37]. Previously rare obstetric and maternal conditions necessitating intensive care are now becoming more prevalent, due to the novel generation of women with repaired congenital heart disease who have now reached the age of childbearing, as well as the increased incidence of placenta accrete spectrum disorders following higher-order cesarean deliveries [38].

The incidence of OB ICU admission for all obstetrical patients is approximately 0.1–1% [13–16]. The two predominant causes of maternal ICU admission are hypertensive disorders of pregnancy (preeclampsia and eclampsia) and obstetric hemorrhage [39]. Other common causes of obstetric intensive care admissions include respiratory failure, cardiac disease, maternal sepsis, and hemodynamic instability warranting a higher level of care [14–15,40–43]. Approximately 12–45% of ICU admissions occur during the antepartum period, 50% occur intrapartum or within the first 24 hours postpartum, and 10–15% occur in the later postpartum period. The majority of ICU admissions occur in the early postpartum period. Antepartum patients are more likely to present for ICU admission due to nonobstetric reasons such as respiratory failure and distress, while postpartum ICU admissions have a higher association with obstetric and delivery complications requiring invasive hemodynamic monitoring for hemodynamic instability [44,45].

It is important to recognize that both a pregnant person with deteriorating health status secondary to comorbid medical conditions and a healthy pregnant person who is unstable from an obstetrical complication can equally benefit from intensive care. Furthermore, a variety of comorbid conditions and obstetrical complications may require intensive care management around the time of delivery (Table 2.1). Fortunately, intensive care management of obstetrical patients with critical care needs, undoubtedly bolstered by the generally favorable health status of this patient population, yields lower mortality rates and improved outcomes compared to nonpregnant cohorts admitted to medical/surgical ICUs [15,46].

Members of the team

Critical care management of the obstetric patient requires a multidisciplinary team with insight into the physiologic changes that occur in pregnancy and the impact on fetal well-being. Members of this highly trained team may include obstetricians, MFM specialists, obstetric intensivists (obstetricians board certified in critical care), medical subspecialists, intensivists, obstetric anesthesiologists, neonatologists, allied health professionals (effector providers), nurses, respiratory therapists, perfusionists, clinical pharmacists, case managers, social workers, and other ancillary healthcare team members. Patient-centered care incorporates all members of the team with the common goal of providing quality, evidence-based care in an efficient, system-driven model.

Physician staffing

MFM specialists are often the obstetrical providers with the highest level of training to provide obstetrical critical care. However, critical care training may be pursued after a residency in obstetrics and gynecology, either with or without subspecialty training in MFM. It is essential that a physician familiar with the physiologic changes in pregnancy be involved in the care of a critically ill pregnant patient.