Published in final edited form as:

Am J Perinatol. 2016 May ; 33(6): 590–599. doi:10.1055/s-0035-1570380.

Association between Hospital Birth Volume and Maternal Morbidity among Low-Risk Pregnancies in Rural, Urban and Teaching Hospitals the United States

Katy B. KOZHIMANNIL, Ph.D., M.P.A.

Division of Health Policy and Management, University of Minnesota School of Public Health, Minneapolis, MN

Ms. Viengneesee THAO, M.S.

Division of Health Policy and Management, University of Minnesota School of Public Health, Minneapolis, MN

Ms. Peiyin HUNG, M.S.P.H.

Division of Health Policy and Management, University of Minnesota School of Public Health, Minneapolis, MN

Ms. Ellen TILDEN, C.N.M, M.S.

Department of Nurse-Midwifery, Oregon Health and Sciences University School of Nursing, Portland, OR

Aaron B. CAUGHEY, M.D., Ph.D

Department of Obstetrics and Gynecology, Oregon Health and Sciences University School of Medicine, Portland, OR

Jonathan M. SNOWDEN, Ph.D.

Department of Obstetrics and Gynecology, Oregon Health and Sciences University School of Medicine, Portland, OR

Abstract

Objectives—This study aims to examine the relationship between hospital birth volume and multiple maternal morbidities among low-risk pregnancies in rural hospitals, urban non-teaching hospitals, and urban teaching hospitals, using a representative sample of U.S. hospitals.

Study Design—Using the 2011 Nationwide Inpatient Sample from 607 hospitals, we identified 508,146 obstetric deliveries meeting low-risk criteria and compared outcomes across hospital volume categories. Outcomes include postpartum hemorrhage (PPH), chorioamnionitis, endometritis, blood transfusion, severe perineal laceration, and wound infection.

Results—Hospital birth volume was more consistently related to PPH than to other maternal outcomes. Lowest-volume rural (<200 births) and non-teaching (<650 births) hospitals had 80%

Corresponding author information: Katy B. Kozhimannil, Ph.D., M.P.A. Division of Health Policy and Management, University of Minnesota School of Public Health 420 Delaware St. SE, MMC 729, Minneapolis, MN 55455 Phone: 612-626-3812, Fax: 612-624-2196, kkbk@umn.edu.

The authors report no conflict of interest.

higher odds (adjusted odds ratio [AOR]=1.80; 95% CI=1.56–2.08) and 39% higher odds (AOR=1.39; 95% CI=1.26–1.53) of PPH, respectively, than those in corresponding high-volume hospitals. However, in urban teaching hospitals, delivering in a lower-volume hospital was associated with 14% lower odds of PPH (AOR=0.86; 95% CI=0.80–0.93). Deliveries in rural hospitals had 31% higher odds of PPH than urban teaching hospitals (AOR=1.31; 95% CI=1.13–1.53).

Conclusions—Low birth volume was a risk factor for PPH in both rural and urban non-teaching hospitals, but not in urban teaching hospitals, where higher volume was associated with greater odds of PPH.

INTRODUCTION

Approximately 4 million women give birth each year in the U.S.; it is the most frequent reason for hospitalization.¹ While most women enter pregnancy in good health, at least 50,000 experience potentially life-threatening maternal conditions or complications during childbirth each year.² Moreover, the rate of severe maternal morbidity has been increasing in the U.S.,^{2–4} as is maternal mortality, which doubled between 1990 and 2013.⁵

These trends raise concern for maternal health as perinatal morbidity may impact a woman's immediate (e.g. symptomatic anemia)⁶ and long-term physical (e.g. risks related to cesarean)⁷ health as well as her emotional well-being (e.g. postpartum depression)⁸ and her child's health (e.g. poor breastfeeding after cesarean).⁹ While morbidity risks are higher for complex pregnancies, the majority of adverse outcomes occur among low-risk pregnancies.¹⁰ Furthermore, recent work has demonstrated 5-fold variations between hospital-level rates of maternal complications of delivery.¹¹ Limited evidence demonstrates that hospital factors (e.g., teaching status, hospital geography) affect obstetric practice and outcomes.^{11–13} More research is needed on hospital-level correlates of maternal morbidity.

The relationship between higher hospital volume and improved clinical outcomes is well-documented in the general medical literature;^{14,15} however, evidence on whether higher hospital birth volume leads to improved maternal outcomes is limited. Most studies of perinatal outcomes have focused on very low birth weight infants, finding protective effects of both higher volume and level of care.^{16,17} Prior research on the volume-outcome relation in obstetrics^{18,19} did not use national data, which limits generalizability and hinders the practical application of study findings. Other national studies used physician volume, rather than hospital volume to predict adverse maternal outcomes²⁰ or focused on a subset of outcomes²¹ or on subgroups of patients.²² Aside from their limitations, previous studies have also offered conflicting conclusions about the association between hospital obstetric volume and maternal morbidity. Some have found that higher birth volume is not associated with better maternal outcomes.²³

To contribute evidence to the ongoing national dialogue aimed at reducing maternal obstetric complications^{24–26}, we examined the associations between hospital birth volume and a range of maternal outcomes among low-risk pregnancies, using a national sample of U.S. hospitals. Based on prior literature, we hypothesized that the relationship between hospital birth volume and maternal morbidity may differ across settings and outcomes, with higher

rates of adverse outcomes at the extremes of birth volume and in rural or non-teaching settings. In addition to rural-urban differences, we investigated the role of hospital teaching status, which may influence organizational culture, technology, clinical management skills, clinical techniques, utilization of current evidence for shaping clinical management, and personnel,²⁷ by looking separately at the relationships between volume and outcomes in rural hospitals, urban non-teaching hospitals, and urban teaching hospitals.

MATERIALS AND METHODS

Data and study population

We used data from the 2011 Nationwide Inpatient Sample (NIS), Healthcare Cost and Utilization Project (HCUP), Agency for Healthcare Research and Quality. The NIS is an all-payer inpatient claims database designed to approximate a 20% stratified sample of all U.S. community hospitals. It is one of the most comprehensive national information sources on hospital-based care in the U.S. and is routinely used in health services research, though it only contains administrative data. Detailed information on the NIS dataset, methodology, and variables is publicly available (<http://www.hcup-us.ahrq.gov/databases.jsp>).

We used a validated methodology to identify hospital discharge records for obstetric deliveries.²⁸ We excluded hospitals with fewer than 50 births in 2011, consistent with prior research.²⁹ Our final data set included 508,146 births in 607 hospitals in 45 states.

The University of Minnesota Institutional Review Board exempted this study from review.

Variable measurement

We used a unique hospital identification code to group deliveries by hospital. Hospital teaching status was defined as any hospital with 1) membership of Council of Teaching Hospital of the Association of American Medical Colleges; 2) residency training approval by Accreditation Council for Graduate Medical Education; and 3) 25 or more full-time equivalent resident interns per 100 short-term beds. Classification of hospitals as either urban or rural was based on Core Based Statistical Area codes from Census 2000 data. Using patient-level information on primary payer (private insurance, Medicare, Medicaid, self-pay/uninsured, or other), we also created a measure of a hospital's payer mix, which was categorized as predominantly commercial if more than 50% of a hospital's 2011 births had private insurance listed as the primary payer.

Annual hospital obstetric volume was categorized using tertiles of hospitals for three groups of hospitals: urban teaching, urban non-teaching, and rural hospitals. Hospital type and birth volume are not independent, as shown in Figure 1 (the distribution of birth volume by hospital types), and as such, are analyzed separately. For urban teaching maternity hospitals, the tertile categories were: 50 – 1,700 deliveries per year (Category T1), 1,701 – 3,000 deliveries (Category T2), and 3,001 or more deliveries per year (Category T3). For urban non-teaching maternity hospitals, the categories were: 50 – 650 deliveries per year (Category NT1), 651 – 1,400 deliveries (Category NT2), and more than 1,400 (Category NT3). Rural hospitals were divided using separate categories: 50 – 200 births per year (Category R1), 201 – 400 births (Category R2), and 401 or more births per year (Category R3). Further, we

compared outcomes across the three hospital types among hospitals with 1,000 annual deliveries, to help tease out the effect of low absolute volume versus geography and teaching status.

Low-risk pregnancy was designated based on International Classification of Diseases-9th Revision (ICD-9) diagnosis and procedure codes and excluded women with prior cesarean, chronic hypertension, gestational hypertension, pre-eclampsia, diabetes, abnormal presentation, preterm delivery, fetal death, multiple gestation diagnosis, or breech procedure, consistent with prior literature.¹⁹ All patient-level measures are based on administrative records, ICD-9 diagnosis and procedure codes, and Clinical Classification Software codes, developed by HCUP for use with ICD-9 codes. Exclusions were conducted after calculating hospital obstetric volume.

Using outcomes examined in prior literature, we compared rates of the following outcomes across hospital volume categories separately for urban teaching, urban non-teaching, and rural hospitals: postpartum hemorrhage (overall and stratified by vaginal delivery and cesarean delivery), transfusion of blood products, chorioamnionitis, endometritis, severe perineal lacerations (3rd and 4th degree) in spontaneous vaginal deliveries, and wound infection in cesarean deliveries.

Statistical Analysis

To examine the differential effects of hospital teaching status and geography on the volume-outcome relationship, we conducted analyses separately for urban teaching, urban non-teaching, and rural hospitals. Unadjusted comparisons between volume categories were calculated using the Pearson's chi-square test. We used multivariable logistic regression models to assess the association between obstetric volume category and outcomes, controlling for potential confounding. The highest volume category served as the referent. We controlled for maternal age, maternal race/ethnicity, primary payer for childbirth hospitalization, and state fixed effects. Missing data was not dropped but recoded as a separate group called 'unknown'. We assessed model fit using AIC and BIC values. For the low-volume (< 1000 births) analyses, we considered hospital location and teaching status as the exposure, using the same approach. Urban teaching hospitals served as the referent category. Models adjusted for hospital-level clustering of outcomes using the clustered Huber/White variance estimator, and calculated robust standard errors.³⁰

RESULTS

Patient Characteristics

Urban teaching, urban non-teaching, and rural hospitals made up 45.6% (N=231,756), 43.2% (N=219,696) and 11.2% (N=56,694), respectively, of all births in our sample (N=508,146; Table 1). The highest volume category of urban teaching (T3) and non-teaching (NT3) hospitals cared for a greater proportion of women age 35 and older, while age distribution did not differ across rural hospitals by birth volume. Unlike urban teaching and non-teaching hospitals, more than half of all women giving birth in rural hospitals were

publically-insured; this was consistent across all volume categories. Higher-volume hospitals cared for a larger share of racial/ethnic minority women giving birth in all hospital settings.

Hospital Birth Volume and Maternal Morbidities

In unadjusted analyses, hospital birth volume was significantly associated with multiple maternal morbidities (Table 2). The strength and direction of volume/outcome associations varied by hospital teaching status and geography. In teaching hospitals, higher volume was generally associated with greater risk of morbidity. On the other hand, in non-teaching hospitals higher volume was associated with lower risk of morbidity across many outcomes, except chorioamnionitis, which had a U-shaped association. Among rural hospitals, rates of all outcomes were lowest in high-volume facilities.

After covariate adjustment, the association between hospital birth volume and maternal outcomes was similar to the relationships shown in unadjusted analyses (Table 3). In particular, PPH was consistently associated with birth volume across hospital groups, yet with different patterns in teaching vs. non-teaching urban hospitals. Among urban teaching hospitals, women delivering babies in lower-volume hospitals (categories T1 and T2) had significantly lower odds of PPH than women delivering in T3 hospitals. Overall odds of PPH were 0.86 (95% CI=0.80, 0.93) in T1 and 0.91 (95% CI=0.86, 0.97) in T2, compared with the highest-volume category of teaching hospitals (T3). Women delivering in lower-volume non-teaching hospitals (NT1 and NT2) had significantly higher odds of PPH than women in the highest volume category (NT3). Overall odds of PPH were 1.39 (95% CI=1.26, 1.53) in NT1 and 1.19 (95% CI=1.11, 1.27) in NT2, compared with women giving birth in the highest-volume non-teaching hospitals.

The relationship between birth volume and PPH in rural hospitals was similar to that of urban non-teaching hospitals. Overall odds of PPH were 1.80 (95% CI=1.56, 2.08) in R1 and 1.27 (95% CI=1.12, 1.44) in R2, compared to the odds for women in the highest-volume category (R3). However, unlike urban teaching and non-teaching hospitals, odds of wound infection were elevated in low-volume rural hospitals (AOR=2.74; 95% CI=1.20, 6.21) compared to the odds for women in the high-volume rural hospitals.

Additional outcomes with disproportionately higher odds in lower-volume hospitals included: blood transfusion and severe perineal lacerations in urban non-teaching and rural hospitals, and wound infection in rural hospitals. Odds of blood transfusion were 1.24 (95% CI=1.03, 1.50) in NT1 compared to NT3, and 1.50 (95% CI=1.14, 1.97) in R1 compared to R3. Odds of severe perineal lacerations were 1.08 (95% CI=1.01, 1.15) in NT2 compared to NT3, and 1.22 (95% CI=1.06, 1.39) in R2 compared to R3. Women giving birth in R1 had 2.74 (95% CI=1.20, 6.21) odds of wound infection compared to those giving birth in R3.

Outcomes with decreased odds in lower-volume hospitals were chorioamnionitis and endometritis among teaching hospitals. Overall odds of chorioamnionitis and endometritis were: 0.55 (95% CI=0.51, 0.61) in T1 and 0.68 (95% CI=0.64, 0.72) in T2, compared to T3. Endometritis had overall odds of 0.49 (95% CI=0.41, 0.58) in T1 and 0.58 (95% CI=0.52, 0.65) in T2, compared to T3. This relationship was reversed in non-teaching and rural hospitals, but often not significant.

Maternal Morbidity in Low-Volume Hospitals—We compared outcomes in low-volume hospitals (< 1,000 annual deliveries) across the three hospital types: rural vs. urban teaching, and urban non-teaching vs. urban teaching hospitals (Table 4). In adjusted analyses between rural vs. urban teaching hospitals, results favored rural hospitals in the odds of chorioamnionitis (AOR=0.67; 95% CI=0.52, 0.85) and severe perineal laceration (AOR=0.84; 95% CI=0.73, 0.97). A similar protective association for perineal lacerations was observed in low-volume urban non-teaching hospitals (AOR=0.77; 95% CI=0.67, 0.89). However, adjusted odds of overall PPH (AOR=1.31; 95% CI=1.13, 1.53) and PPH among vaginal deliveries (AOR=1.32; 95% CI=1.12, 1.56), as well as blood transfusion (AOR=1.61; 95% CI=1.20, 2.17) were elevated in low-volume rural hospitals, compared with urban teaching hospitals. These outcomes were the same between low-volume urban hospitals, regardless of teaching status.

COMMENT

In this large retrospective cohort of low-risk births, we observed differences in maternal outcomes by hospital volume, geography, and teaching status. Among urban hospitals, teaching status modified the volume-outcome relationship for maternal morbidity. Among urban non-teaching hospitals, we generally observed higher odds of poor outcomes in low- and mid-volume hospitals. In contrast, urban teaching hospitals had significantly higher rates of poor outcomes in the highest-volume hospitals. These descriptive findings show meaningful variation in maternal morbidity across hospital settings and, in some cases, may highlight opportunities for policymakers, implementing agencies, maternity care clinicians, hospital administrators, and others to improve U.S. maternity care quality and safety.

Hospital teaching status may relate to several factors relevant for maternal morbidity, including modifiable factors (clinician experience level, degree of access to current evidence, hospital cultural norms). Care provided in teaching hospitals involves more clinicians, including trainees. Teaching hospitals are also likely to have greater, more immediate access to current clinical research and administrative practices or cultural norms encouraging utilization of current evidence for clinical decision making. In the general medical literature, teaching status is generally associated with lower rates of adverse outcomes.^{27,31} The association between academic affiliation and quality outcomes is less well-characterized in obstetrics.³² It is also possible that the findings of increased adverse outcomes at high volume is a result of our relative definition of “high volume.” The highest volume category for teaching hospitals has a higher absolute volume (>3000) as compared to non-teaching urban hospitals (>1400). In very high volume settings, clinicians frequently must negotiate the complex needs of multiple patients and may face administrative or clinical capacity strain. More research is needed to understand how the role of birth volume differs in teaching vs. non-teaching hospital settings in order to ameliorate any potential increased vulnerability for mistakes or limited recognition of pending morbidity.

Within rural hospitals, we found an inverse relationship between hospital birth volume and maternal morbidity, with low-risk births in low- and mid-volume hospitals having disproportionately higher odds of poor outcomes. Often-cited challenges in low-volume rural settings include maintaining clinical competency and skills as well as staff recruitment

and retention. Differences in provider workforce composition (e.g., obstetricians vs. family physicians) may also affect outcomes. When we compared maternal outcomes across settings among only low-volume hospitals, we found that women delivering in rural low-volume hospitals had higher odds of PPH than women delivering in low-volume urban teaching hospitals. This finding is consistent with prior research in the state of California, which also found higher odds of PPH in low-volume rural hospitals,¹⁹ implying a need for greater attention to clinical management for PPH in rural low-volume settings. Efforts to address obstetric skill maintenance through continuing medical education and simulation might improve performance for this crucial maternal mortality risk factor.

Limitations

This study used hospital administrative data, which have known limitations for identifying some patient outcomes,^{34,35} as the data do not include comprehensive clinical information and it is possible that coding practices may differ across hospital settings. Also, hospital discharge data do not contain information on parity or specific gestational age, and other important factors, such as infant birthweight, are recorded in the neonatal records and/or birth certificates, which were not linked or available for this analysis. Further, the NIS database lacks information on the clinical management policies, staffing factors, physical space and equipment, and availability of ancillary resources (e.g., blood products) that might explain relationships described. Lastly, differences in patient mix may drive some observed associations, despite multivariable adjustment. For example, it is likely that higher volume (T3) hospitals serve proportionally more patients with higher acuity which may inflate poor maternal morbidity outcomes.

The definition of low-risk used in this analysis excluded preterm deliveries and women with relevant medical conditions. There are varying definitions of “low-risk,” and pregnancies categorized as low-risk may become high-risk during intrapartum care. Additionally, there may be important risks that cannot be captured in our definition of low-risk, such as extreme obesity, which might vary across hospitals but would not exclude a patient from being characterized as low-risk in our study. Defining low-risk is an open question in obstetric/perinatal research; definitions must continue to be refined as research in this area progresses.³⁵

We categorized hospitals using empirically-derived obstetric cutoffs designating volume relative to the hospital category. Cutoffs were chosen to maintain adequate numbers of births and unique hospitals in each category; using another categorization systems may alter results. The lowest-volume rural hospitals may have more year-to-year variability, owing to small numbers, and even the lowest-volume hospitals in our analyses exclude many rural hospitals in remote and frontier areas as well as Critical Access Hospitals, a substantial portion of which have delivery volumes less than 100 births per year.^{12,36} Additionally, our construct of low-volume urban teaching hospital may include teaching hospitals with small obstetric services or no OB/GYN residencies. With regard to maternity services, these facilities would likely be more similar to urban non-teaching hospitals.

Conclusion

This study found that hospital volume, teaching status, and rural setting were significantly associated with several adverse maternal outcomes, after adjusting for maternal characteristics. We note that the associations observed here are likely not all (or even predominantly) causal; birth volume and geography are understood to be markers of other hospital factors, only some of which are modifiable. Still, variation in rates of maternal morbidity highlight room for quality improvement regardless of the underlying etiology. Future research is required to understand the separate and joint impact of academic affiliation and high volume in obstetrics.

Of note, women delivering in urban settings had higher risk of PPH in higher volume teaching hospitals, and in lower volume non-teaching hospitals; while women delivering in rural settings had higher risk of PPH in lower volume hospitals. If future studies corroborate these findings, policymakers and administrators should identify the modifiable hospital-level factors explaining these differences (e.g., staffing models, hospital resources). In addition to volume and hospital resources, it is essential to consider the equitable geographic distribution of obstetric services when evaluating quality of maternity care.³⁷ Quality improvement efforts should be adapted to the challenges unique within each setting. These findings imply a need for enhancing clinical management of PPH in low-volume rural and urban non-teaching hospitals and in high-volume teaching hospitals. Such initiatives may include simulation training, clear steps for referral, inter-professional education, and team communication skill building. Furthering our understanding of the hospital-level drivers of maternal morbidity will help halt and reverse the recent increases in maternal morbidity and mortality in the US.

Acknowledgements

JMS is supported by the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development (grant number K99 HD079658-01). ET is supported by Sigma Theta Tau Beta Psi chapter, the American College of Nurse-Midwives, and the Jonas Doctoral Scholars Program.

References

1. Pfuntner, A.; Wier, LM.; Stocks, C. [Accessed March 24, 2015] Most frequent conditions in US hospitals. Sep. 2011 Available at: <http://www.ncbi.nlm.nih.gov/books/NBK169248/>
2. Callaghan WM, Creanga AA, Kuklina EV. Severe maternal morbidity among delivery and postpartum hospitalizations in the United States. *Obstet Gynecol.* 2012; 120:1029–1036. [PubMed: 23090519]
3. Bateman BT, Berman MF, Riley LE, Leffert LR. The epidemiology of postpartum hemorrhage in a large, nationwide sample of deliveries. *Anesth Analg.* 2010; 110:1368–1373. [PubMed: 20237047]
4. Creanga AA, Berg CJ, Ko JY, et al. Maternal mortality and morbidity in the United States: Where are we now? *J Womens Health.* 2014; 23:3–9.
5. Kassebaum NJ, Bertozzi-Villa A, Coggeshall MS, et al. Global, regional, and national levels and causes of maternal mortality during 1990–2013: A systematic analysis for the global burden of disease study 2013. *The Lancet.* 2014; 384:980–1004.
6. Beard JL, Hendricks MK, Perez EM, et al. Maternal iron deficiency anemia affects postpartum emotions and cognition. *J Nutr.* 2005; 135:267–272. [PubMed: 15671224]

7. Furuta M, Sandall J, Cooper D, Bick D. The relationship between severe maternal morbidity and psychological health symptoms at 6–8 weeks postpartum: A prospective cohort study in one english maternity unit. *BMC Pregnancy Childbirth*. 2014; 14:133. [PubMed: 24708797]
8. Sundaram S, Harman JS, Cook RL. Maternal morbidities and postpartum depression: An analysis using the 2007 and 2008 pregnancy risk assessment monitoring system. *Womens Health Issues Off Publ Jacobs Inst Womens Health*. 2014; 24:e381–e388.
9. Prior E, Santhakumaran S, Gale C, Philipps LH, Modi N, Hyde MJ. Breastfeeding after cesarean delivery: A systematic review and meta-analysis of world literature. *Am J Clin Nutr*. 2012; 95:1113–1135. [PubMed: 22456657]
10. Korst LM, Fridman M, Lu MC, et al. Monitoring childbirth morbidity using hospital discharge data: Further development and application of a composite measure. *Am J Obstet Gynecol*. 2014; 211:268.e1–e268.e16. [PubMed: 24631432]
11. Glance LG, Dick AW, Glantz JC, et al. Rates of major obstetrical complications vary almost fivefold among US hospitals. *Health Aff Millwood*. 2014; 33:1330–1336. [PubMed: 25092833]
12. Kozhimannil KB, Hung P, Prasad S, Casey M, Moscovice IS. Rural-urban differences in obstetric care, 2002–2010, and implications for the future. *Med Care*. 2014; 5:4–9. [PubMed: 24316869]
13. Srinivas SK, Fager C, Lorch SA. Variations in postdelivery infection and thrombosis by hospital teaching status. *Am J Obstet Gynecol*. 2013; 209:567.e1–e567.e7. [PubMed: 23921091]
14. Shahian DM. Improving cardiac surgery quality-volume, outcome, process? *JAMA*. 2004; 291:246–248. [PubMed: 14722153]
15. Phibbs CS, Bronstein JM, Buxton E, Phibbs RH. The effects of patient volume and level of care at the hospital of birth on neonatal mortality. *JAMA*. 1996; 276:1054–1059. [PubMed: 8847767]
16. Phibbs CS, Baker LC, Caughey AB, Danielsen B, Schmitt SK, Phibbs RH. Level and volume of neonatal intensive care and mortality in very-low-birth-weight infants. *N Engl J Med*. 2007; 356:2165–2175. [PubMed: 17522400]
17. Chung JH, Phibbs CS, Boscardin WJ, et al. Examining the effect of hospital-level factors on mortality of very low birth weight infants using multilevel modeling. *J Perinatol*. 2011; 31:770–775. [PubMed: 21494232]
18. Snowden JM, Cheng YW, Kontgis CP, Caughey AB. The association between hospital obstetric volume and perinatal outcomes in California. *Am J Obstet Gynecol*. 2012; 207:478.e1–e7. [PubMed: 23174387]
19. Snowden JM, Cheng YW, Emeis CL, Caughey AB. The impact of hospital obstetric volume on maternal outcomes in term, non-low-birthweight pregnancies. *Am J Obstet Gynecol*. 2014; 212:380.e1–e9. [PubMed: 25263732]
21. Janakiraman V, Lazar J. Hospital volume, provider volume, and complications after childbirth in US hospitals. *Obstet Gynecol*. 2011; 118:521–527. [PubMed: 21826039]
20. Goff SL, Pekow PS, Avrunin J, Lagu T, Markenson G, Lindenauer P. Patterns of obstetric infection rates in a large sample of US hospitals. *Am J Obstet Gynecol*. 2013; 208:456.e1–e456.e13. [PubMed: 23395644]
22. Chang JJ, Stamilio DM, Macones GA. Effect of hospital volume on maternal outcomes in women with prior cesarean delivery undergoing trial of labor. *Am J Epidemiol*. 2008; 167:711–718. [PubMed: 18192674]
23. Kyser KL, Lu X, Santillan DA, et al. The association between hospital obstetrical volume and maternal postpartum complications. *Am J Obstet Gynecol*. 2012; 207:42.e1–e42.e17. [PubMed: 22727347]
24. D'Alton ME, Bonanno CA, Berkowitz RL, et al. Putting the “M” back in maternal–fetal medicine. *Am J Obstet Gynecol*. 2013; 208:442–448. [PubMed: 23211544]
25. [Accessed December 18, 2014] Supporting Healthy and Normal Physiologic Childbirth: A Consensus Statement. Available at: <http://www.midwife.org/ACNM/files/ACNMLibraryData/UPLOADFILENAME/000000000272/Physiological%20Birth%20Consensus%20Statement-%20FINAL%20May%2018%202012%20FINAL.pdf>
26. D'Alton ME, Main EK, Menard MK, Levy BS. The national partnership for maternal safety. *Obstet Gynecol*. 2014; 123:973–977. [PubMed: 24785848]

27. Ayanian JZ, Weissman JS. Teaching hospitals and quality of care: A review of the literature. *Milbank Q.* 2002; 80:569–593. [PubMed: 12233250]
28. Kuklina EV, Whiteman MK, Hillis SD, et al. An enhanced method for identifying obstetric deliveries: Implications for estimating maternal morbidity. *Matern Child Health J.* 2008; 12:469–477. [PubMed: 17690963]
29. Kozhimannil KB, Law MR, Virnig BA. Cesarean delivery rates vary tenfold among US hospitals; Reducing variation may address quality and cost issues. *Health Aff Proj Hope.* 2013; 32:527–535.
30. Williams RL. A note on robust variance estimation for cluster-correlated data. *Biometrics.* 2000; 56:645–646. [PubMed: 10877330]
31. Kupersmith J. Quality of care in teaching hospitals: A literature review. *Acad Med.* 2005; 80:458–466. [PubMed: 15851459]
32. Snyder CC, Wolfe KB, Loftin RW, Tabbah S, Lewis DF, Defranco EA. The influence of hospital type on induction of labor and mode of delivery. *Am J Obstet Gynecol.* 2011; 205:346.e1–e4. [PubMed: 21704962]
33. Goff SL, Pekow PS, Markenson G, Knee A, Chasan-Taber L, Lindenauer PK. Validity of using ICD-9-CM codes to identify selected categories of obstetric complications, procedures and comorbidities. *Paediatr Perinat Epidemiol.* 2012; 26:421–429. [PubMed: 22882786]
34. Lain SJ, Hadfield RM, Raynes-Greenow CH, et al. Quality of data in perinatal population health databases: A systematic review. *Med Care.* 2012; 50:e7–e20. [PubMed: 21617569]
35. Board on Children, Youth, and Families; Institute of Medicine; National Research Council. An update on research issues in the assessment of birth settings: Workshop summary. National Academies Press (US); Washington (DC): Sep 23. 2013 Available at: <http://www.ncbi.nlm.nih.gov/books/NBK201939/> [Accessed February 13, 2015]
36. Kozhimannil KB, Hung P, Prasad S, Casey M, McClellan M, Moscovice IS. Birth volume and the quality of obstetric care in rural hospitals. *J Rural Health.* 2014; 30:335–343. [PubMed: 24483138]
37. Menard MK, Kilpatrick S, Saade G, et al. Levels of maternal care. *Am J Obstet Gynecol.* 2015; 212:259–271. [PubMed: 25620372]

Figure 1.
Distribution of Hospital Birth Volume by Hospital Type

Table 1

Maternal Characteristics By Hospital Obstetric Volume Categories[§] in Urban Teaching, Non-Teaching, and Rural Hospitals

	Urban Teaching Hospital			Urban Non-Teaching Hospital			Rural Hospital		
	T1 50-1700 Births	T2 1701-3000 Births	T3 >3000 Births	NT1 50-450 Births	NT2 451-1400 Births	NT3 >1400 Births	R1 50-200 Births	R2 201-400 Births	R3 >400 Births
Number of Women	32,439	68,597	130,720	22,142	57,082	140,472	6,223	13,875	36,596
Number of Hospitals	46	47	40	88	86	83	74	67	76
Age	Percent of Women								
Unknown	<0.1	<0.1	<0.1	<0.1	0.1	0.1	<0.1	<0.1	<0.1
Age <=20	13.1	14.2	11.1	18.0	15.8	12.6	20.5	20.0	21.3
21<=Age<=25	25.3	25.2	22.1	29.5	27.7	24.3	31.9	33.0	33.0
26<=Age<=30	30.6	30.0	29.0	28.6	29.4	30.2	27.3	26.8	26.8
31<=Age<=35	21.5	21.2	25.5	17.2	19.0	22.5	14.6	14.6	13.9
Age>=36	9.5	9.3	12.2	6.7	8.0	10.3	5.7	5.6	5.0
Primary Payer									
Unknown	<0.1	0.19	<0.1	0.6	0.2	0.1	0.1	0.1	0.9
Medicaid	46.3	42.8	42.5	46.0	46.8	37.8	49.5	52.4	53.2
Private	48.9	51.9	52.9	46.3	47.1	55.7	44.3	39.7	37.5
Self	1.8	1.4	2.0	2.1	2.1	2.5	3.1	3.1	1.8
Other Payments	2.9	3.7	2.5	4.9	3.7	3.9	2.9	4.7	6.5
Race									
Unknown	8.9	14.6	9.3	12.4	6.7	7.3	16.5	18.8	16.6
White	49.5	45.3	38.1	63.0	54.1	45.8	65.9	62.0	55.6
Black	13.7	15.5	15.4	8.2	11.7	8.7	2.8	6.6	11.3
Hispanic	18.0	15.3	25.1	11.2	18.4	27.9	6.9	7.1	11.0
Asian	3.2	3.5	6.4	1.5	3.2	7.0	1.3	1.2	0.9
Other Race	6.6	5.8	5.7	3.6	6.0	3.3	6.7	4.3	4.6
Hospital Characteristics	Percent of Hospitals								
Hospital Proportion of Medicaid Births >50%	39.1	34.0	27.5	40.9	43.0	26.5	52.7	61.2	62.7

Note:

[§] hospital obstetric volume was categorized separately by tertiles of hospitals in urban teaching, urban non-teaching, and rural hospitals.

Table 2
Rates Of Maternal Outcomes across Hospital Volume Categories By Location And Teaching Status

	Urban Teaching Hospital Volume Category			P value [‡]	Urban Non-Teaching Hospital Volume Category			P value [‡]	Rural Hospital Volume Category			P value [‡]
	T1 50-1700 Births	T2 1701-3000 Births	T3 >3000 Births		NT1 50-650 Births	NT2 651-1400 Births	NT3 >1400 Births		R1 50-200 Births	R2 201-400 Births	R3 >400 Births	
Chorioamnionitis	1.7	2.2	3.2	<.001	1.6	1.0	1.6	<.001	0.8	0.8	0.6	<.001
Endometritis	0.5	0.6	1.0	<.001	0.5	0.4	0.4	0.208	0.5	0.5	0.4	0.200
Postpartum Hemorrhage												
Overall	2.9	3.0	3.3	<.001	2.8	2.4	2.1	<.001	4.5	3.6	2.8	<.001
Vaginal Delivery	3.0	3.1	3.2	0.049	2.9	2.5	2.2	<.001	4.9	3.8	2.9	<.001
Cesarean Delivery	2.1	2.7	3.6	<.001	2.0	1.7	1.6	0.277	2.2	2.4	2.1	0.617
Blood Transfusion	0.8	0.9	0.8	0.628	0.7	0.7	0.6	<.001	1.2	0.9	0.9	0.011
Severe Perineal Lacerations (Vaginal)	3.1	3.1	3.2	0.442	2.8	3.0	3.0	0.547	3.2	3.3	2.8	0.004
Wound Infection (Cesarean)	0.6	0.7	0.9	0.017	0.6	0.5	0.7	0.108	1.2	0.9	0.6	0.051

Note: Prolonged length of stay: >3 days for vaginal deliveries; >5 days for cesarean deliveries

[‡] P-value from Pearson's chi-squared tests.

Table 3

Logistic Regression Results Of Maternal Outcomes Based On Volume Categories, Stratified By Location And Teaching Status

	Urban Teaching Hospital			Urban Non-Teaching Hospital			Rural Hospital volume category		
	T1 50-1700 Births	T2 1701-3000 Births	T3 >3000 Births	NT1 50-650 Births	NT2 651-1400 Births	NT3 >1400 Births	R1 50-200 Births	R2 201-400 Births	R3 >400 Births
Chorioamnionitis	0.55 (0.51, 0.61)	0.68 (0.64, 0.72)	Ref	1.13 (0.96, 1.30)	0.68 (0.62, 0.75)	Ref	1.21 (0.86, 1.70)	1.29 (1.01, 1.66)	Ref
Endometritis	0.49 (0.41, 0.58)	0.58 (0.52, 0.65)	Ref	1.08 (0.85, 1.37)	0.97 (0.82, 1.15)	Ref	1.28 (0.83, 1.96)	1.32 (0.96, 1.81)	Ref
Postpartum hemorrhage									
Overall	0.86 (0.80, 0.93)	0.91 (0.86, 0.97)	Ref	1.39 (1.26, 1.53)	1.19 (1.11, 1.27)	Ref	1.80 (1.56, 2.08)	1.27 (1.12, 1.44)	Ref
Vaginal delivery	0.92 (0.85, 1.00) [§]	0.94 (0.89, 1.00)	Ref	1.39 (1.25, 1.54)	1.20 (1.11, 1.29)	Ref	1.90 (1.63, 2.20)	1.32 (1.16, 1.51)	Ref
Cesarean delivery	0.57 (0.46, 0.70)	0.75 (0.64, 0.87)	Ref	1.39 (1.02, 1.89)	1.12 (0.91, 1.39)	Ref	1.10 (0.64, 1.87)	0.86 (0.56, 1.34)	Ref
Blood transfusion	1.04 (0.91, 1.20)	1.11 (0.99, 1.24)	Ref	1.24 (1.03, 1.50)	1.18 (1.04, 1.34)	Ref	1.50 (1.14, 1.97)	0.98 (0.77, 1.23)	Ref
Severe perineal lacerations (Vaginal delivery)	0.98 (0.91, 1.07)	0.95 (0.90, 1.02)	Ref	0.96 (0.87, 1.07)	1.08 (1.01, 1.15)	Ref	1.12 (0.93, 1.34)	1.22 (1.06, 1.39)	Ref
Wound Infection (Cesarean)	0.75 (0.50, 1.1)	0.82 (0.61, 1.11)	Ref	0.90 (0.51, 1.59)	0.84 (0.60, 1.19)	Ref	2.74 (1.20, 6.21)	1.95 (0.96, 3.98)	Ref

Note:

Results are presented as adjusted odds ratio (95% confidence interval), compared to the odds of each outcome in the highest-volume hospitals at each stratified group. Models controlled for maternal age, race/ethnicity, primary payer, and whether proportion of Medicaid births in a delivery hospital is greater than 50%. Models estimated robust standard errors accounting for hospital-level clustering. Significant results are **bold**.

[§] $P_{value} = 0.039$;

Table 4

Comparison Of Maternal Outcomes By Hospital Geography And Teaching Status In Low-Volume Hospitals

	Unadjusted Percentages					P values between rural and urban teaching hospitals χ^2	P values between urban non-teaching and teaching hospitals χ^2	Adjusted Odds Ratio $\S$ (95% Confidence Interval)	
	Rural	Urban Non-Teaching	Urban Teaching	Rural	Urban Non-Teaching				
	N=45,511 births in 203 hospitals	N=48,264 births in 135 hospitals	N=8,917 births in 18 hospitals						
Chorioamnionitis	0.7	1.2	1.1		<.001	0.245	0.67 (0.52, 0.85)	1.12 (0.90, 1.40)	
Endometritis	0.5	0.4	0.4		1.000	0.930	0.97 (0.67, 1.41)	0.93 (0.65, 1.34)	
Postpartum hemorrhage									
Overall	3.3	2.5	2.7		0.003	0.423	1.31 (1.13, 1.53)	0.95 (0.82, 1.11)	
Vaginal delivery	3.5	2.7	2.9		0.006	0.277	1.32 (1.12, 1.56)	0.94 (0.80, 1.10)	
Cesarean delivery	2.0	1.9	1.8		0.670	0.749	1.07 (0.67, 1.69)	1.04 (0.67, 1.61)	
Blood transfusion	1.0	0.7	0.7		0.005	0.834	1.61 (1.20, 2.17)	1.05 (0.79, 1.42)	
Severe perineal lacerations (Vaginal)	3.1	2.9	3.8		0.003	<.001	0.84 (0.73, 0.97)	0.77 (0.67, 0.89)	
Wound Infection (Cesarean)	0.7	0.6	0.6		0.890	0.695	0.92 (0.42, 1.98)	0.78 (0.37, 1.65)	

Note: Hospitals with annual birth volume ≤1000;

[†]P values from Fisher's tests for differences in rates of each outcome between groups of hospitals. P < .05 are **bold**.

[§]Adjusted odds ratios were derived from models with urban teaching hospitals as the reference, controlled for maternal age, race/ethnicity, primary payer, teaching hospital status, and whether proportion of Medicaid births in a delivery hospital is greater than 50%. Models estimated robust standard errors accounting for hospital-level clustering. Significant results are **bold**.