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The association between hospital frequency of labor after cesarean and outcomes in California

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Abstract

Background: Labor after cesarean (LAC) is an alternative to planned repeat cesarean delivery. The effect of hospital-level factors on LAC frequency and vaginal birth after cesarean (VBAC) has been relatively understudied. It was our goal to determine if hospital frequency of LAC (number of women undergoing LAC/ number of women with previous uterine scars) is associated with increased VBAC and associated outcomes among women undergoing LAC.

Materials and Methods: We analyzed n=43,331 term, singleton births to women who experienced LAC in California from 2007–2010. We conducted multivariable logistic regressions of infant and maternal outcomes for women at hospitals with high LAC frequency (≥ median) compared to low LAC frequency (< median), adjusting for maternal and hospital characteristics. We stratified analyses by overall hospital birth volume (categories 1: low, 2: medium, 3: high).

Results: We did not observe an association between high LAC frequency and VBAC in any category of hospital birth volume in regression models. We found that women in hospitals with high LAC frequency had higher odds of infection in Category 1 (low) and 2 (medium) hospitals (Category 1 hospitals adjusted odds ratio [aOR]: 1.61, 95% confidence interval [CI], 1.04–2.48; Category 2 hospitals: aOR, 2.12; 95% CI, 1.34–3.35) and postpartum hemorrhage in Category 2 and 3 hospitals (Category 2 hospitals: aOR 2.49; 95% CI: 1.57–3.94; Category 3 hospitals: aOR, 1.83; 95% CI, 1.24–2.70). We observed that high LAC frequency was associated with more

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Conflicts of interest:

We declare that we have no real or perceived competing interests.

adverse outcomes (e.g., infection, severe perineal lacerations, decreased Apgar scores) in Category 2 than in Category 1 and 3 hospitals.

Conclusions: We did not find that high LAC frequency was associated with more VBAC, nor with many perinatal complications in Category 1 and 3 hospitals. The associations between high LAC frequency and both infection and postpartum hemorrhage are concerning and require further investigation. There may be a sensitive balance between increasing LAC access and determining appropriate LAC candidate selection.

Keywords

Labor after cesarean; hospital volume; perinatal epidemiology; vaginal birth after cesarean; healthcare access

Background

Labor after cesarean in the U.S.

It is a national goal to reduce both primary cesarean delivery and planned repeat cesarean delivery among low-risk women in the United States (American College of Obstetricians and Gynecologists, 2014; Department of Health and Human Services, 2010). Labor after cesarean (LAC)—an alternative to a planned repeat cesarean delivery (PRCD)—is recommended for most women with a single low-transverse uterine scar, and can be a reasonable option for women with two scars depending on other risk factors (American College of Obstetricians and Gynecologists, 2017). Labor after cesarean may either end in vaginal birth after cesarean (VBAC) or unplanned repeat cesarean delivery. Compared to a PRCD, LAC is associated with decreased risk for overall maternal morbidity (secondary to avoiding an additional major abdominal surgery), but also with a small but significantly increased risk for uterine rupture and neonatal mortality (Cahill et al., 2006; Go, Emeis, Guise, & Schelonka, 2011; Guise et al., 2010; American College of Obstetricians and Gynecologists, 2017; Rossi & D'Addario, 2008). Leading national maternity-care professional organizations recommend weighing these risks and benefits, maternal preferences, other risk characteristics, and overall health when counseling women who are considering their delivery options after a previous cesarean (American College of Obstetricians and Gynecologists, 2010; American College of Nurse-Midwives, 2017).

LAC frequency and success in the U.S. over time

Nationwide LAC frequency (i.e., the proportion of women attempting LAC among women with a previous uterine scar) has varied widely since 1990, from a high of 51.8% in 1995 to a low of 15.9% in 2006 (Uddin & Simon, 2013). Nationwide LAC success (i.e., the proportion of LACs that end in VBAC) has also varied in recent decades, reaching a high of 69.8% in 2000 and a low of 38.5% in 2008 (Uddin & Simon, 2013). Both LAC frequency and success are difficult to measure, and these estimates may have some variability. When LAC is attempted, success varies by clinical factors, including obstetric history and maternal weight, as well as hospital and physician characteristics (Dunsmoor-Su, Sammel, Stevens, Peipert, & Macones, 2003; Hashima, Eden, Osterweil, Nygren, & Guise, 2004; Macones et al., 2005; Marchiano, Elkousy, Stevens, Peipert, & Macones, 2004). In contrast with

individual-level clinical factors, there is a relative evidence gap regarding the contribution of institutional factors to VBAC and other LAC outcomes. In addition to directly lowering the overall cesarean rate, a better understanding of the institutional factors that support VBAC among low-risk women may be associated with the additional benefit of reducing the primary cesarean rate: evidence suggests that hospitals with increased LAC success also have lower rates of primary cesarean delivery (Rosenstein et al., 2013).

LAC availability in the U.S.

The stringency of LAC recommendations in the U.S. has changed over time, in turn affecting access to LAC and perhaps outcomes subsequent to LAC, though the latter has not been well studied (Barger, Templeton, Bearman, Delain, & Gates, 2013; Kraemer, Berlin, & Guise, 2004; Roberts RG, Deutchman M, 2007). For example, an earlier American College of Obstetricians and Gynecologists (ACOG) consensus statement (that was in place during the time period of this study) recommended that in order to offer LAC, a hospital should be able to guarantee immediate availability of both a physician capable of performing a cesarean delivery and 24-hour availability of in-hospital anesthesia services (American College of Obstetricians and Gynecologists, 1999). However, ACOG currently recommends that low-risk women undergo labor after cesarean at maternal care level I centers or higher, defined as facilities where physicians with privileges to perform emergency cesarean and anesthesia providers are “readily available at all times,” as opposed to physically present at all times (American College of Obstetricians and Gynecologists 2017; American College of Obstetricians and Gynecologists 2019). A systematic review conducted in 2004 suggested that changing national guidelines regarding VBAC appeared to be associated with changing LAC success (Kraemer et al., 2004).

Facility-level differences such as these are only some of the factors that determine LAC access and outcomes, however. Even the absence of a hospital policy prohibiting LAC does not guarantee LAC access in practice (Barger et al., 2013). Two studies that analyzed LAC attempts among women determined by a nomogram to be good candidates for LAC found 30% and 63% of these women actually attempted to deliver vaginally, respectively (Metz et al., 2013; Sudhof, Has, Rouse, & Hughes, 2018). A recent prospective study of subsequent delivery intentions after a primary cesarean found that 50% of women in the sample desired a VBAC; the discrepancy between this proportion and the proportion of women nationally who actually have a VBAC (12%) is substantial (Attanasio, Kozhimannil, & Kjerulff, 2018). Authors suggested provider counseling as the main reason more women did not attempt LAC, though perhaps other factors were also at play (e.g., billing concerns, patient preference, etc.). Little other prior work explores the complex interrelationships between LAC access (which can further be broken down into official hospital policies vs. actual hospital practice, which might be provider-dependent), LAC frequency, and perinatal outcomes after LAC.

Effects of hospital and LAC/VBAC volume on perinatal outcomes

Prior studies have found hospital characteristics such as low overall birth volume (i.e., overall count of births at a given hospital) and rural geographical location to be associated with increased risk for certain poor birth outcomes, such as increased cesarean risk in low-

volume rural hospitals or increased maternal transfusion risk in medium-volume non-rural hospitals (Kozhimannil et al., 2016; Kyser et al., 2012; Snowden, Cheng, Emeis, & Caughey, 2015; Snowden, Cheng, Kontgis, & Caughey, 2012; Snowden, Darney, Cheng, McConnell, & Caughey, 2013). One study conducted in Canada suggested that lower birth volume hospitals had decreased odds of LAC frequency and increased odds of adverse outcomes compared to higher birth volume hospitals (Wen et al., 2004). A few studies have also examined the effect of LAC or VBAC volume on outcomes. One such prior study from the Northeastern U.S. examined the association between VBAC volume and unsuccessful LAC (i.e., LAC that ends in an unplanned repeat cesarean) and maternal morbidities, finding no significant associations (Chang, Stamilio, & Macones, 2008). Another study conducted in California, however, suggested that both low and high LAC utilization were associated decreased LAC success, suggesting an optimum threshold for utilization (Xu et al., 2019). These few studies leave a substantial evidence gap on the association between a hospital's overall birth volume, its frequency of LAC, and maternal and neonatal outcomes after LAC, including the proportion that end in VBAC.

Informed by these multiple levels of consideration, we sought to analyze the role of LAC frequency on VBAC and relevant morbidities of both the infant and mother. We built on previous research by examining the effect of LAC frequency within the context of overall hospital volume. Further, recognizing the fact that not all hospitals offer LAC, we sought to exclude hospitals not offering LAC from our analysis. Acknowledging that many factors influence LAC access within a given hospital, we compared hospitals of differing LAC frequency within categories of overall hospital volume in order to answer a specific question: after controlling for individual risk factors, how would women delivering at hospitals of similar size but different LAC frequencies compare in their odds of VBAC and outcomes subsequent to LAC? We hypothesized that increased LAC frequency would be associated with better outcomes (i.e., increased VBAC and fewer morbidities), though the magnitude of these associations was hypothesized to vary by overall hospital birth volume.

Materials and Methods

Data source

This study analyzed linked vital statistics/patient discharge data from California hospital deliveries from 2007 – 2010. The California Patient Discharge Data, Vital Statistics Birth Certificate Data, and Vital Statistics Death Certificate data are linked and maintained by the Office of Statewide Health Planning and Development (OSHPD), Healthcare Information Resource Center, under the California Health and Human Services Agency (CHHS). This study focused on the hospital-level exposure of LAC frequency among women who underwent LAC in California during the study period.

The linked dataset includes patient discharge data (International Classification of Disease [ICD]-9 diagnosis and procedure codes) for antepartum hospital admission in the nine months prior to delivery and linked maternal and neonatal admission in the year following delivery. Reporting of births in California is almost 100% comprehensive. CHHS personnel code the data according to uniform specifications, perform rigorous quality checks, and review the birth cohort files before release. This dataset has been described in further detail

elsewhere (Snowden et al., 2015; Snowden et al., 2012; Snowden et al., 2013). We obtained human subjects approval from the California OSHPD Committee for the Protection of Human Subjects and the Institutional Review Board at Oregon Health and Science University.

Determination of patient eligibility for study inclusion

We identified women who labored after a previous cesarean delivery using a combination of markers from birth certificate data and ICD-9 codes from linked discharge data (Appendix Table 1). Specific codes and checkboxes providing evidence that labor occurred were used to identify the presence of labor; this algorithm has been described elsewhere (Biel, Marshall, & Snowden, 2017; Horner-Johnson, Biel, Darney, & Caughey, 2017). For example, any woman who was recorded as having a VBAC from the birth certificate was determined to have labored after cesarean, as well as a woman recorded as having a repeat cesarean from the birth certificate and ICD-9 codes that indicated labor (e.g., labor abnormalities [Henry, Gregory, Hobel, & Platt, 1995]). Analysis was restricted to term, singleton, non-anomalous, vertex-presenting deliveries among women who labored after cesarean.

Determination of institutional study exclusion

Access to LAC is not offered in all California hospitals: one study estimated that only 56% of California hospitals offered LAC during our study period (Barger et al., 2013). Because the main exposure of interest was hospital-level frequency of labor after cesarean, as opposed to the individual-level exposure of labor after cesarean, we aimed to identify hospitals that do not routinely offer LAC. It is possible that hospitals that do not offer LAC may nonetheless contain VBAC/LAC outcomes (e.g., in the case of a woman with a previous uterine scar presenting late in labor and delivering vaginally despite institutional policy prohibiting VBAC [American College of Obstetricians and Gynecologists, 2017]). In our analysis, births in such hospitals would ideally be excluded.

We used two criteria to exclude these hospitals: an implausibly-low proportion of women attempting LAC (i.e., low LAC frequency; number of women laboring with previous uterine scars / number of women with previous uterine scars) or an implausibly low proportion of LAC success (number of vaginal births in women with previous uterine scars/ number of women laboring with previous uterine scars). If (1) fewer than 5% of women with previous uterine scars labored, or if (2) LAC success was less than 20%, we excluded data from these hospitals on the grounds that they do not routinely offer LAC. These values were determined empirically from the distribution of LAC frequency and LAC success in our sample. Given that LAC success varies in the range of 60–80% (Grobman, 2010; Macones et al., 2005), we considered a cutoff of 20% to be relatively conservative. Likewise, national LAC frequency during this time period were around 20% (Uddin & Simon, 2013); thus a criterion excluding hospitals with fewer than 5% of women with a previous cesarean laboring likely excludes hospitals that do not routinely offer this option to women. Hospitals with fewer than 50 annual deliveries were excluded from analysis to avoid including births at unintended locations or hospitals without designated Labor and Delivery units (Snowden et al., 2012).

Exposure: Hospital frequency of labor after cesarean

We collapsed patient-level data to generate our hospital-level exposure of LAC frequency: the number of women laboring with previous uterine scars / total number of women with previous uterine scars. Figure 1 summarizes our study population and key variables. We chose to stratify analyses by overall hospital birth volume to minimize confounding due to hospital characteristics that likely vary by volume (e.g., staffing models, number of labor and delivery rooms) but for which we did not have data. After hospitals were excluded as described above, we divided the remaining (n=153) hospitals offering LAC into categories of overall hospital birth volume defined by tertiles (Snowden et al., 2015; Snowden et al., 2012; Snowden et al., 2013). Category 1 included 93 hospitals with four-year delivery volume <10,506 births; Category 2 included 38 hospitals with four-year delivery volume between 10,584 and 16,063 births; Category 3 included 22 hospitals with four-year delivery volume above 16,063 births. We examined histograms of LAC frequency within categories of hospital volume and determined that the median appeared to be a reasonable cutpoint. Within each category of overall hospital-level birth volume, we determined the median LAC frequency (number of women laboring with a previous uterine scar / number of women with a previous uterine scar) and dichotomized at this point. Hospitals with LAC frequency below the median were classified as *low LAC frequency* and hospitals with LAC frequency at or above the median were classified as *high LAC frequency* (Figure 2).

Outcomes

Our study outcomes included both maternal and neonatal outcomes that are of interest among women who are laboring after a previous cesarean. The first outcome was delivery mode among women undergoing LAC: VBAC or unplanned repeat cesarean delivery. Maternal and infant complications analyzed were: severe perineal lacerations, an obstetric infection composite (including wound infection, chorioamnionitis, endometritis [Snowden et al., 2015]), postpartum hemorrhage (PPH), maternal blood transfusion, uterine rupture, and 5-minute Apgar score <7. A final class of outcomes included service use outcomes potentially indicative of morbidity: prolonged length of stay (>3 days for vaginal deliveries and >5 for cesarean deliveries) and Neonatal Intensive Care Unit (NICU) admission. The sources of outcomes (i.e. birth certificate or ICD-9 codes) can be found in Appendix Table 2. Asphyxia and neonatal death could not be analyzed because of small cell sizes.

Statistical analysis

To assess associations between hospital-level factors, we determined the correlation between both 1) overall hospital birth volume and volume of women with previous uterine scars and 2) overall hospital birth volume and LAC volume. Multiple hospital-level factors were of interest, so we conducted descriptive analyses of demographic factors by two different categorizations: first, by categories of hospital birth volume and, second, by LAC frequency (high/low).

We conducted multivariable logistic regression to assess adjusted associations between hospital LAC frequency (high/low) and outcomes. Stratified models were fit within categories of overall hospital birth volume (1: low/2: medium/3: high). These regression models controlled for maternal race/ethnicity (Non-Hispanic White [referent], Non-Hispanic

Black, Hispanic, Asian, and Other), advanced maternal age (age 35 years or older), maternal education (some college or greater [referent], high school/ GED, < high school) maternal insurance (public, private [referent], self), gestational hypertension, chronic hypertension, gestational diabetes, chronic diabetes, augmentation of labor, induction of labor, and teaching hospital status. Hospital geography was initially evaluated, but there were no rural hospitals in the two upper categories of overall birth volume, so this hospital characteristic was dropped from all analyses. Robust standard errors were calculated accounting for clustering at the hospital level. All analyses were conducted in Stata 15 (StataCorp. 2017. Stata Statistical Software: Release 15. College Station).

Results

After applying our exclusion criteria, this study included 43,331 births to women who labored after cesarean in 153 (of the available 279) hospitals in California from 2007–2010. While we found a very strong linear correlation between overall hospital birth volume and volume of women with previous uterine scars ($r=0.97$), we found a lower, but still strong, linear correlation between overall hospital birth volume and LAC volume ($r=0.70$) (Appendix Figure 1). Most maternal characteristics differed by overall hospital birth volume and all characteristics differed by hospital LAC frequency (Table 1). Higher proportions of women delivering in Category 1 hospitals received augmentations compared to other categories (24.3% vs 19.7% in Category 2 and 8.8% in Category 3), though there were similar frequencies of induction across overall hospital birth volume categories (Category 1: 11.8%; Category 2: 12.5%; Category 3: 12.7%). Category 3 hospitals had the highest proportion of births at teaching hospitals (43.9%) and Category 2 hospitals had the lowest (10.1%). Compared to low-LAC frequency hospitals, women in high-LAC frequency hospitals were more likely to have less than a high school education, were more likely to be publicly insured, more frequently had risk factors such as diabetes or hypertension, and were more likely to receive augmentation or induction of labor ($p<0.001$ for all associations).

Table 2 presents bivariable (unadjusted) associations between hospital LAC frequency (high/low) and maternal/infant outcomes, stratified by category of overall hospital birth volume. In category 1 and 2 of overall birth volume, more women delivered vaginally in high-LAC frequency hospitals (e.g., Category 1: 52.9% of women in high-LAC frequency hospitals vs 50.6% of women in low-LAC frequency hospitals, $p=0.004$). Across all categories of overall hospital birth volume, there were consistent associations between high-LAC frequency hospitals and increased occurrence of extended length of stay, postpartum hemorrhage, infection, and NICU admissions (e.g., Category 3: 5.2% of women in high-LAC frequency hospitals experienced PPH vs 2.7% of women in low-LAC frequency hospitals, $p<0.001$; see Table 2).

After adjustment for maternal and hospital characteristics, some of the observed bivariable associations persisted in Category 1 and Category 2 hospitals but were attenuated or did not reach statistical significance in Category 3 hospitals (Table 3). Associations between high LAC frequency and extended length of stay and infection persisted in Category 1 and 2 hospitals (e.g., Category 1 infection aOR, 1.61; 95% CI, 1.04–2.48). In Categories 2 and 3 of overall hospital volume, increased LAC frequency remained associated with increased PPH

after confounder adjustment (e.g., Category 2 aOR, 2.49; 95% CI, 1.57–3.94; Category 3 aOR, 1.83; 95% CI: 1.24–2.70). High LAC frequency was associated with the most adverse outcomes in Category 2 hospitals, with associations with PPH, severe perineal lacerations, extended length of stay, low 5-minute Apgar, and infection. We did not observe an association between high LAC frequency and VBAC in any of the hospital birth volume categories (e.g., Category 3 aOR, 0.98; 95% CI, 0.57–1.70).

Discussion

We sought to understand how two hospitals of similar size, but different LAC frequencies, compare in both VBAC and outcomes subsequent to LAC. Our study confirms the findings of previous work on low LAC volume and adverse outcomes, while also adding the new context of overall hospital birth volume. Similar to a previous study by Chang et al. that investigated the effect of VBAC volume on subsequent outcomes, we found no association between increased LAC frequency and uterine rupture, although this differs from the Xu et al. study that found that hospitals with both greater than median LAC utilization and LAC success had increased occurrence of uterine rupture (Chang et al., 2008; Xu et al., 2019). Our study period (2007–2010) occurred immediately before 2010 ACOG recommendations and the Xu et al. study period occurred immediately after (2010–2012), but recommendations that staff be “immediately available” for emergency cesarean (likely the most important factor influencing decreased VBAC) were not updated until 2017 (American College of Obstetricians and Gynecologists, 1999; American College of Obstetricians and Gynecologists, 2010; American College of Obstetricians and Gynecologists, 2017). A major difference between our study and the Xu et al. study is that we excluded hospitals we considered to be implausible data points based on proportions of LAC frequency and success. For example, hospitals that appeared to have high (sometimes around 98%) LAC frequency but had very low LAC success (as low as 2%) raised questions about whether LAC was in fact offered at these hospitals. As previously mentioned, literature around this time period suggested only 56% of California hospitals offered LAC and LAC success proportions were between 60–80% (Barger et al., 2013; Grobman et al., 2010; Macones et al., 2005).

We found no differences in VBAC between low and high frequency LAC hospitals. We observed generally low proportions of VBAC (~50% for all categories), but these were within the range of what has been previously observed (Barger et al., 2013; Xu et al., 2019). Across categories of hospital birth volume, we found associations between increased LAC frequency and postpartum hemorrhage (Category 2 and 3 hospitals), extended length of stay (Category 1 and 2 hospitals), and infection (Category 1 and 2 hospitals). We hypothesized that associations may differ by overall hospital birth volume, but found that high LAC frequency was associated with the fewest adverse outcomes in Category 3 hospitals and the most adverse outcomes in Category 2 hospitals.

While some associations between high LAC frequency and outcomes were attenuated in adjusted analyses (e.g., associations with VBAC that were null in the regression models), we found other associations that persisted across categories of overall hospital birth volume. For instance, the positive associations between high LAC frequency and both infection and

postpartum hemorrhage are concerning, especially given the recent national policy focus on maternal morbidity and mortality (Creanga, Syverson, Seed, & Callaghan, 2017). When LAC is successful, it generally carries fewer risks than PRCDs (Cahill et al., 2006; Go et al., 2011; Guise et al., 2004; Guise et al., 2010; Macones et al., 2005). LAC resulting in unplanned cesarean delivery, however, represents the highest-risk scenario of the three groups (American College of Obstetricians and Gynecologists, 2017; Gregory et al., 2008).

Previous studies suggest that the excess of adverse events accompanying a trial of labor after cesarean can be attributed to the complications arising during labor that require an unscheduled repeat cesarean rather than the labor itself (Landon et al., 2004; McMahon, 1996). Therefore, accurately assessing a woman's suitability for LAC is paramount. It is possible that some factor of patient counseling for mode of delivery after previous cesarean is not currently optimized in higher-LAC frequency hospitals (e.g., not considering the indication for the previous CD). This could explain our finding that high-LAC frequency hospitals have poorer outcomes on some measures. Although we lack data to assess this possibility, if true, this might result in worse outcomes including unsuccessful LAC, increased PPH, and infection. Research has suggested that women are accurately able to recall their own indication for previous cesarean; this information, if not available on health record, could be used to determine if a subsequent vaginal delivery is appropriate (Attanasio, Kozhimannil, Srinivas, & Kjerulff, 2017).

We had hypothesized that hospitals with increased LAC frequency, regardless of overall hospital birth volume, would be associated with better outcomes based on the "practice makes perfect" paradigm commonly considered in volume-outcome research (Birkmeyer et al., 2002; Halm, 2002). However, we did not find evidence to support this hypothesis, finding instead that hospitals with high LAC frequency did no better than hospitals with low LAC frequency at achieving VBAC. It is worth noting, however, that they also did no worse, which has positive implications when considering potential strategies to reduce the overall cesarean rate in the U.S. If 50% of women achieve VBAC in a hospital where more total women are attempting LAC, then the absolute number of VBACs is higher than in a comparably large hospital where 50% of women achieve VBAC but fewer total women attempt LAC (Kaufman, 2012; King, Harper, & Young, 2012).

The volume-outcome relationship has been shown to be inconsistent in obstetrics, with some studies finding no association between hospital volume and outcomes (Chang et al., 2008; Janakiraman, Lazar, Joynt, & Jha, 2011) and others finding a protective effect of higher hospital volume (Snowden et al., 2015; Snowden et al., 2012; Snowden et al., 2013). While we did not directly compare outcomes across categories of hospital birth volume, we did observe that high LAC frequency was associated with the most adverse outcomes in Category 2 hospitals. This finding does not follow the generally observed pattern that lower volume is most commonly associated with increased frequency of poor outcomes, in which case the association might be strongest in Category 1 hospitals. That said, the nature of the volume-outcome association is more complex here than for many procedures, given that it reflects both selection into the population at risk (i.e., both a hospital offering and a patient choosing LAC), and also management of labor and associated outcomes. We observed that higher proportions of Category 1 and 3 hospitals were teaching hospitals and that teaching

hospital status appeared to be associated with higher LAC frequency. Differential clinical policies and care among teaching hospitals could help explain our results, and have been noted previously (Korst et al., 2011; Xu et al., 2019). We also observed variation in the proportion of women receiving augmentations across categories of birth volume, providing some evidence of differential practice. There are likely many other ways in which hospital practice differs that were not measured in our analysis, and it is this complex mix of patient, provider, and hospital-level factors that contributes to LAC success and incidence of subsequent outcomes.

The relative novelty of analyzing both LAC frequency and overall hospital birth volume as well as the large sample analyzed are strengths of our study. We acknowledge our limitations, however. Our data sources, birth certificates linked to claims data, can provide a large amount of information, but are still administrative data whose utility is predicated on the assumption that information was accurately recorded. Some of the claims data used to determine exposures or outcomes (i.e., indicators of labor) have been shown to have good sensitivity and specificity when compared to a chart review (Gregory, Korst, Gornbein, & Platt, 2002; Henry et al., 1995; Korst, Gregory, & Gornbein, 2004), but we also used this information in a novel way to determine if a hospital offered LAC. Regardless of method, it is difficult to determine whether a hospital offers LAC or not; a 2012 survey of hospitals in California listed as a limitation that while a hospital could have a policy in place that allowed LAC, the actual day-to-day availability of LAC was driven by individual provider preferences (Barger et al., 2013). We lacked the data to account for provider-level effects on LAC, and these can have important effects on both availability and success (Fore, Allshouse, Carlson, & Hurt, 2020; Korst et al., 2011; Wells, 2010). As described in the methods section, using LAC frequency and LAC success to designate a hospital as “offering LAC” remains a limitation of this study. This likely resulted in the inclusion of hospitals that did not formally offer LAC, perhaps explaining the lower-than-expected VBAC proportion we observed in our study, though we almost certainly did not miss including any hospitals that *do* offer LAC routinely (Chang et al., 2008; Grobman, 2010). Our decision to use tertiles of hospital volume and a median cutpoint of LAC frequency was arbitrary. Our study is also an observational study with the attendant limitations, but observational studies remain a reasonable option for studying characteristics where randomization is unfeasible, such as hospital LAC frequency. We also note that we do not consider the population of women undergoing a PRCD, and our results cannot be generalized to that population, even though many of them are potentially good candidates for LAC.

Implications for Practice and Policy

Future work is needed to refine current understandings of hospital-level LAC availability (e.g., ban, de facto unavailable, available), and to collect data on this factor. There may be a sensitive balance between expanding LAC access (a commonly-used cesarean reduction strategy) and optimizing LAC outcomes. To the extent that future research confirms our findings and identifies mechanisms through which they act (e.g., potentially counseling women in their decision to pursue LAC and the role of obstetric history in this discussion), practice and policy should be modified to improve outcomes after LAC. Additional research

will inform evidence-based policies to achieve optimal outcomes for the majority of women with a previous cesarean delivery.

Conclusions

Our study findings provide new information on hospital-level LAC frequency and its association with maternal and neonatal outcomes. This analysis included all women laboring after cesarean, but future analyses could stratify by risk profiles to see if this affects the observed associations (Gregory et al., 2008). Our consistent finding of an association between LAC frequency and both infection and postpartum hemorrhage warrants concern, and these associations should be examined in future research.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Women with prior cesarean scar (A+B+C)

Labor after cesarean (LAC) terminology			
Term	LAC frequency	LAC volume	LAC success
Definition	A proportion: the number of births to women who labor after cesarean, over the total number of births to women with a prior cesarean scar $(A+B) / (A+B+C)$	A count: the absolute number of births to women who labor after cesarean A+B	A proportion: the number of births that result in a vaginal birth, over the total number of births to women who labor after cesarean $A / (A+B)$

Figure 1:
Description of study population and key variables.

Figure 2:

Definition of main exposure variable: The sample was divided into hospital birth volume tertiles, and the proportion of women attempting labor after cesarean (LAC) was calculated within each tertile. The main exposure variable (high/low LAC frequency) was defined using the median of this proportion. Percentages reflect median proportion of women attempting LAC in each tertile.

Table 1: Maternal characteristics by overall hospital birth volume and labor after cesarean frequency (No. (%)), California 2007–2010

	Overall hospital birth volume category (deliveries over 4 study years)				LAC frequency category		
	Category 1 n=15,179	Category 2 n=14,593	Category 3 n=13,559	P Value	Low (LAC frequency <28%) n=22,260	High (LAC frequency ≥28%) n=21,071	P Value
Race/ethnicity				<0.001			<0.001
Non-Hispanic White	4385 (29.1)	4116 (28.3)	2894 (21.4)		6015 (27.2)	5380 (25.6)	
Non-Hispanic Black	1063 (7)	716 (4.9)	1040 (7.7)		1229 (5.6)	1590 (7.6)	
Hispanic	7689 (51)	7341 (50.5)	7689 (56.9)		12178 (55)	10541 (50.2)	
Asian	1564 (10.4)	2099 (14.4)	1548 (11.5)		2243 (10.1)	2968 (14.1)	
Other	378 (2.5)	260 (1.8)	342 (2.5)		477 (2.2)	503 (2.4)	
Maternal age							<0.001
<35 years	4385 (29.1)	4116 (28.3)	2894 (21.4)	0.986	16480 (74)	15164 (72)	
35 years	1063 (7)	716 (4.9)	1040 (7.7)		5780 (26)	5907 (28)	
Maternal education							<0.001
< High school	3987 (27.1)	2907 (20.9)	4430 (34.1)	<0.001	5675 (26.7)	5649 (27.8)	
High school/GED	3648 (24.8)	3443 (24.8)	2971 (22.9)		5379 (25.3)	4683 (23)	
Some college +	7074 (48.1)	7549 (54.3)	5585 (43)		10219 (48)	9989 (49.2)	
Insurance							<0.001
Private	6640 (43.7)	5411 (37.1)	7964 (58.7)	<0.001	10210 (45.9)	9805 (46.5)	
Public	8308 (54.7)	8924 (61.2)	5407 (39.9)		11606 (52.1)	11033 (52.4)	
Self	231 (1.5)	258 (1.8)	187 (1.4)		444 (2)	232 (1.1)	
Diabetes							<0.001
	179 (1.2)	122 (0.8)	151 (1.1)	.009	172 (0.8)	280 (1.3)	
Gestational diabetes	1657 (10.9)	1499 (10.3)	1358 (10)	0.035	1991 (8.9)	2523 (12)	<0.001
Hypertension	292 (1.9)	234 (1.6)	179 (1.3)	<0.001	266 (1.2)	439 (2.1)	<0.001
Gestational hypertension/ preeclampsia	589 (3.9)	507 (3.5)	547 (4)	0.038	682 (3.1)	961 (4.6)	<0.001
Augmentation	3681 (24.3)	2878 (19.7)	1187 (8.8)	<0.001	2399 (10.8)	5347 (25.4)	<0.001
Induction	1790 (11.8)	1821 (12.5)	1722 (12.7)	0.048	2254 (10.1)	3079 (14.6)	<0.001
Teaching hospital	3462 (22.8)	1474 (10.1)	5957 (43.9)	<0.001	4189 (18.8)	6704 (31.8)	<0.001

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Hospital category definitions (all hospital births, LAC or other): Category 1: N=93 hospitals with 10,506 total deliveries over 4 study years; Category 2: N=38 hospitals with 10,584–16,063 deliveries; Category 3: N=22 hospitals with 16,281 deliveries

Abbreviations: LAC, labor after cesarean

Table 2.

Maternal outcomes by hospital frequency of labor after cesarean (high/low) (No.(%)), stratified by category of overall hospital birth volume

Overall hospital birth volume category (deliveries over 4 study years)									
	Category 1 n=15,179			Category 2 n=14,593		Category 3 n=13,559			
	Low LAC frequency (<33% LAC)	High LAC frequency (33% LAC)	p Value †	Low LAC frequency (<27% LAC)	High LAC frequency (27% LAC)	p Value †	Low LAC frequency (<24% LAC)	High LAC frequency (24% LAC)	p Value †
VBAC	3993 (50.6)	3857 (52.9)	0.004 *	3813 (48.4)	3395 (50.6)	0.006 *	3724 (51)	3134 (50.2)	0.354
Postpartum hemorrhage	370 (4.7)	539 (7.4)	<0.001 *	179 (2.3)	414 (6.2)	<0.001 *	200 (2.7)	326 (5.2)	<0.001 *
Uterine rupture	68 (0.9)	57 (0.8)	0.588	66 (0.8)	56 (0.8)	0.990	67 (0.9)	45 (0.7)	0.208
Severe perineal lacerations	210 (2.7)	182 (2.5)	0.524	134 (1.7)	189 (2.8)	<0.001 *	165 (2.3)	164 (2.6)	0.166
Maternal transfusion	80 (1.0)	134 (1.8)	<0.001 *	66 (0.8)	89 (1.3)	0.004 *	71 (1)	51 (0.8)	0.340
Extended length of stay	100 (1.3)	225 (3.1)	<0.001 *	69 (0.9)	108 (1.6)	<0.001 *	133 (1.8)	160 (2.6)	0.003 *
NICU admission	234 (3.0)	747 (10.3)	<0.001 *	238 (3.0)	227 (3.4)	0.209	256 (3.5)	133 (2.1)	<0.001 *
5-minute Apgar <7	58 (0.8)	80 (1.1)	0.027 *	28 (0.4)	44 (0.7)	0.011 *	40 (0.5)	38 (0.6)	0.638
Infection composite	255 (3.2)	474 (6.5)	<0.001 *	190 (2.4)	409 (6.1)	<0.001 *	179 (2.4)	360 (5.8)	<0.001 *

[†] p Value from chi-squared test comparing individuals at high-LAC volume hospitals to those at low-LAC volume hospitals within each category of overall hospital birth volume

* p Value<0.05

Abbreviations: LAC, labor after cesarean; VBAC, vaginal birth after cesarean; NICU: Neonatal Intensive Care Unit

Hospital category definitions (all hospital births, LAC or other): Category 1: N=93 hospitals with 10,506 total deliveries over 4 study years; Category 2: N=38 hospitals with 10,584–16,063 deliveries; Category 3: N=22 hospitals with 16,281 deliveries

Table 3:

Adjusted associations[‡] between hospital frequency of labor after cesarean (high compared to low) and maternal/infant outcomes by Category of overall hospital birth volume

	Overall hospital birth volume category (deliveries over 4 study years)					
	Category 1 n=15,179		Category 2 n=14,593		Category 3 n=13,559	
	Low LAC frequency (<33% LAC) (referent)	High LAC frequency (33% LAC)	Low LAC frequency (<27% LAC) (referent)	High LAC frequency (27% LAC)	Low LAC frequency (<24% LAC) (referent)	High LAC frequency (24% LAC)
VBAC	ref	1.06 (0.85–1.32)	ref	1.06 (0.77–1.46)	ref	0.98 (0.57–1.70)
Postpartum hemorrhage	ref	1.11 (0.55–2.23)	ref	2.49 (1.57–3.94)*	ref	1.83 (1.24–2.70)*
Uterine rupture	ref	0.90 (0.60–1.35)	ref	0.91 (0.6–1.37)	ref	0.80 (0.42–1.54)
Severe perineal lacerations	ref	0.93 (0.65–1.34)	ref	1.42 (1.03–1.94)*	ref	1.08 (0.57–2.03)
Maternal transfusion	ref	1.45 (0.98–2.17)	ref	1.36 (0.83–2.24)	ref	0.80 (0.4–1.61)
Extended length of stay	ref	1.61 (1.01–2.59)*	ref	1.57 (1.09–2.26)*	ref	1.12 (0.47–2.71)
NICU admission	ref	2.90 (1.09–7.68)*	ref	0.97 (0.57–1.64)	ref	0.51 (0.22–1.17)
5-minute Apgar <7	ref	1.18 (0.76–1.83)	ref	1.64 (1.12–2.42)*	ref	1.11 (0.66–1.86)
Infection composite	ref	1.61 (1.04–2.48)*	ref	2.12 (1.34–3.35)*	ref	2.11 (0.98–4.51)

[‡](Odds ratio (95% CI)) All regressions adjusted for: maternal race/ethnicity (Non-Hispanic White [referent], Non-Hispanic Black, Hispanic, Asian, and Other), advanced maternal age (age 35 years or older), maternal education (some college or greater [referent], high school/ GED, < high school) maternal insurance (public, private [referent], self), gestational hypertension, chronic hypertension, gestational diabetes, chronic diabetes, augmentation of labor, induction of labor, and teaching hospital status. Robust standard errors were calculated accounting for clustering at the hospital level.

*
p<0.05

Abbreviations: LAC, labor after cesarean; VBAC, vaginal birth after cesarean; NICU, Neonatal Intensive Care Unit

Hospital category definitions (all hospital births, LAC or other): Category 1: N=93 hospitals with 10,506 total deliveries over 4 study years; Category 2: N=38 hospitals with 10,584–16,063 deliveries; Category 3: N=22 hospitals with 16,281 deliveries