Utilizations and outcomes of intra-arterial balloon occlusion at cesarean hysterectomy for placenta accreta spectrum

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Abstract
Introduction: This study examined national-level trends, characteristics, and perioperative outcomes of women who had intra-arterial balloon occlusion at cesarean hysterectomy for placenta accreta spectrum (PAS).

Material and methods: This was a population-based retrospective observational study that queried the National Inpatient Sample from October 2015 to December 2018. Study population was women who underwent hysterectomy at cesarean delivery for PAS (n = 6440 in 806 centers). Exposure allocation was the use of intra-arterial balloon occlusion. Main outcome measures were (a) characteristics associated with intra-arterial balloon occlusion use, and (b) perioperative outcome including hemorrhage, blood transfusion, coagulopathy, shock, urinary tract injury, intra-arterial balloon occlusion-related complication (arterial injury, arterial thrombosis, and lower extremities ischemia), and death, assessed in multivariable analysis.

Results: Intra-arterial balloon occlusion was used in 420 (6.5%) women in 64 (7.9%) centers. Utilization of intra-arterial balloon occlusion during cesarean hysterectomy for placenta accreta decreased significantly over time (from 6.3% to 3.1%, p < 0.001), but not in placenta increta (from 12.8% to 9.3%, p = 0.204) or placenta percreta (from 21.3% to 17.5%, p = 0.344). In a multivariable analysis, patient factors (younger age, earlier year, obesity, diabetes mellitus), pregnancy factors (placenta increta/percreta, previous cesarean delivery, placenta previa, and early gestational age), and facility factors (large bed capacity, urban teaching status, and Northeast/West regions) represented the independent characteristics for using the intra-arterial balloon occlusion (all, p < 0.05). In a classification-tree model, the absolute difference in intra-arterial balloon occlusion use among 18 utilization patterns was 48% (range, 0%–48%). In perioperative outcome analysis, women who received intra-arterial balloon occlusion...
INTRODUCTION

Placenta accreta spectrum (PAS) is the disease in which trophoblastic tissue is abnormally and morbidly adherent to the surrounding structures/organs. Depending on the extent of placental invasion, PAS is classified into the following three categories: placenta accreta (being adherent to the myometrium without decidual layer), placenta increta (invading into the myometrium), and placenta percreta (invading into surrounding organs).

The optimal treatment approach for PAS remains undetermined, but pregnant women with suspected PAS commonly undergo cesarean delivery. Frequently, hysterectomy is performed at cesarean delivery because the placenta is inseparable from the uterus. Due to the nature of pathology, surgery for PAS is associated with significantly increased risk of maternal morbidity and mortality, particularly surgical bleeding. For this reason, any technique or intervention to reduce the risk of bleeding is useful in the surgical management of this patient population.

One such consideration to control surgical bleeding for PAS is devascularization through preoperative placement of a balloon into the internal iliac artery. Upon completion of the cesarean delivery, the intra-arterial balloon is inflated to internally occlude the arteries supporting the uterus. The use of this technique to reduce surgical bleeding is currently under active investigation, particularly for placenta percreta. However, many of these past studies were limited by small sample size, making their results challenging to interpret. At present, population-level data on the utilization and outcome of intra-arterial balloon occlusion for cesarean hysterectomy is not available.

The objective of this study was to examine national trends and perioperative outcomes of women who underwent cesarean hysterectomy using intra-arterial balloon occlusion for PAS in the USA.

MATERIAL AND METHODS

This is a retrospective observational cohort study querying the population-based hospitalization data platform, the National Inpatient Sample (NIS). The NIS program is an all-payer inpatient database developed for the Healthcare Cost and Utilization Project that is sponsored by the Agency for Healthcare Research and Quality in the USA. The NIS program is publicly available and de-identified. The program collects randomly 20% of inpatient data in each center. The information captured represents over 35 million admissions a year, which when weighted for national estimates, represents 90% of the US population.

The study population consisted of women who underwent hysterectomy at cesarean delivery for PAS from October 2015 to December 2018. The starting date of October 2015 was chosen based on the introduction of International Classification of Disease 10th revision (ICD-10) codes for PAS to the NIS. The codes used throughout the study period.

The key study codes are shown in Table S1. Cesarean section codes were identified per the Healthcare Cost and Utilization Project (HCUP) Statistical Brief #254, which examined the obstetric deliveries in the NIS program. PAS was based on the ICD-10 code O432, and hysterectomy was identified per the Center for Disease Control and Prevention (CDC) Severe Maternal Morbidity definition.

The eligible cases for analysis were grouped based on the presence of ICD-10 codes for intra-arterial balloon occlusion. This study searched intra-arterial balloon occlusion for internal iliac artery, common iliac artery, and abdominal aorta (Table S1). Cases with any of these codes were grouped into the intra-arterial balloon occlusion group. Cases without these codes were allocated into the non-balloon group.
The main outcome measures were (a) the trends and characteristics of intra-arterial balloon occlusion use at cesarean hysterectomy for PAS type, and (b) surgical outcome measures (hemorrhage, blood transfusion, coagulopathy, shock, urinary tract injury, and death). These morbidities were preselected because they are pertinent to intra-arterial balloon occlusion or hysterectomy outcome evaluation in PAS. The ICD-10 codes for outcome measures are based on the CDC definitions and a recent study for PAS.

For study covariates, patient baseline demographics, hospital information, and pregnancy characteristics were abstracted from the program for the study covariates, which were grouped similarly to previous studies from the database. Patient demographics included age (continuous), year (trisected to every 13-month interval as October 2015 to October 2016, November 2016 to November 2017, and December 2017 to December 2018), admission type (elective vs non-elective), race/ethnicity (white, black, Hispanic, Asian/Pacific Islander, Native American, and others) grouped per the program, median household income (every quartile), primary expected payer (Medicaid, private including Health Maintenance Organization, and others), obesity (grouped per CDC classification: non-obesity, class I–II, and class III), and tobacco use (yes or no).

Hospital information included hospital bed capacity (small, medium, and large), hospital location-teaching status (rural, urban non-teaching, and urban teaching), and hospital region (Northeast, Midwest, South, and West), determined by the HCUP program. Pregnancy characteristics included gestational age at delivery (<28, 28–31, 32–33, 34–36, and ≥37 weeks). The following pregnancy factors were dichotomized (yes or no): previous cesarean section, placenta previa, multiple gestations, breech presentation, grand multiparity, diabetes mellitus, and hypertensive disorder of pregnancy.

The first step of analysis was to examine the trend of intra-arterial balloon occlusion use at cesarean hysterectomy for PAS. Utilization was examined in each trisected time period, and the Cochran–Armitage trend test was used for statistical analysis.

The second step of analysis was to identify the independent characteristics related to intra-arterial balloon use during the cesarean hysterectomy for PAS. A binary logistic regression model was fitted for multivariable analysis (intra-arterial balloon occlusion use vs non-use). Conditional backward method was used for the analysis because of the relatively limited number for intra-arterial balloon occlusion cases. The initial selection criteria included the covariates with a p value less than 0.05 among the baseline characteristics on univariable analysis, and the final stopping rule was also set at a p value less than 0.05 across the covariates. The effect size for the intra-arterial balloon occlusion use was estimated with odds ratio (OR) and corresponding 95% CI. A classification-tree was further constructed to examine the utilization pattern of intra-arterial balloon occlusion. A recursive partitioning model with chi-squared automatic interaction detector approach was used to determine the nodes with a stopping rule at levels of 3. All the independent factors for intra-arterial balloon occlusion use were entered in the modeling.

The last step of the analysis was to assess the independent association between the exposure and outcome measures. As the sample size for intra-arterial balloon occlusion was limited, a parsimonious adjustment model was used for analysis in the presence of statistically significant association in univariable analysis (cut-off, p < 0.05). Adjusting factors were stringently selected before analysis, and limited to age and PAS type to avoid overfitting. Effect size for the intra-arterial balloon occlusion use on the outcome measures was expressed with OR and corresponding 95% CI.

Various sensitivity analyses were performed to assess the robustness of the study findings. First, outcome measures were assessed per subtype of PAS (accreta, increta, and percreta). Second, the procedure-related adverse event related to intra-arterial balloon occlusion was examined: (a) arterial injury in internal iliac arterial, common iliac artery, and abdominal aorta; (b) lower extremity ischemia; and (c) arterial thrombosis in lower extremity, iliac artery, and abdominal aorta (Table S1). Third, composite end point was assessed by combining the hysterectomy-related and the intra-arterial balloon-related adverse events. Last, hospital-level cluster analysis was performed based on the practice for intra-arterial balloon occlusion.

All the analyses were based on weighted value for national estimates provided by the program. Two-tailed hypothesis was used for statistical evaluation, and a p value less than 0.05 was considered statistically significant. Cases with unknown information were grouped as one category in each variable. IBM SPSS Statistics version 27.0 (IBM Corp., Armonk, NY, USA) and R statistics version 3.5.3 (R Foundation for Statistical Computing, Vienna, Austria) were used for statistical analysis. This study followed the STROBE guidelines for an observational study.

2.1 | Ethical approval

The University of Southern California Institutional Review Board deemed this study exempt because of the use of publicly available de-identified data (6HS-16-00481). There was no patient or public involvement in this study. The study team did not have patient and public involvement in this study, but the database used in the study was developed with patient and public involvement that was organized and managed by the HCUP by the Agency for Healthcare Research and Quality.

3 | RESULTS

A total of 3,895,707 cesarean deliveries were performed during the study period. Among them, 11,840 cesarean sections were performed for PAS, of which 6,505 cases had a concurrent hysterectomy. After excluding 65 cases with no time information, 6,440 cases of cesarean hysterectomy for PAS represented the study population. The most common type of PAS was placenta accreta (n = 4,910, 76.2%) followed by placenta percreta (n = 790, 12.3%), and placenta...
intra-arterial balloon occlusion, all in the internal iliac artery, was performed in 420 (6.5%) women.

During the study period, utilization of intra-arterial balloon occlusion decreased in the whole cohort (8.8% in the first-third study period, 5.3% in the mid-third study period, and 5.7% in the last-third study period, p < 0.001; Figure 1). This association remained independent in multivariable analysis (Tables 1 and 2). In addition, women with obesity, diabetes, earlier gestational age, previous cesarean delivery, placenta previa, and placenta increta/accreta were more likely to undergo intra-arterial balloon occlusion at cesarean hysterectomy, and large urban-teaching centers in West region were more likely to utilize this procedure (all, p < 0.05). Of those, placenta percreta exhibited the largest effect size (adjusted odds ratio [aOR] 3.83, 95% CI 2.99–4.90, p < 0.001). Conversely, older age, and centers in Midwest and South regions were the factors associated with decreased utilization of intra-arterial balloon occlusion (all, p < 0.05; Table 2).

Utilization pattern of intra-arterial balloon occlusion was examined (Figure S1 and Table S2). Among 18 patterns identified, 6 (33.3%) patterns exhibited at least a 20% utilization rate of the balloon occlusion, of which 3 (50.0%) patterns had placenta percreta. White or Hispanic women with placenta percreta who had cesarean hysterectomy in West region had the highest rate of intra-arterial balloon occlusion use (48.0%). This was followed by women with placenta percreta in Northeast region who had cesarean hysterectomy in the last-third of the study period (36.4%). In contrast, even in percreta cases, there were no cases of intra-arterial balloon occlusion use among centers in Midwest and South regions in the last-third of the study period. Ultimately, the absolute difference in the utilization rate of the balloon occlusion was 48 percentage points (range 0%–48.0%).

When sensitivity analysis was performed per the placenta accreta subtypes, intra-arterial balloon occlusion use decreased significantly in placenta accreta (6.3% to 3.1%, 50.7% relative-decrease, p < 0.001; Figure 1) and this association remained independent in multivariable analysis (aOR for last-third vs first-third 0.46, 95% CI 0.32–0.66, p < 0.001; Tables S3). The utilization of intra-arterial balloon occlusion was statistically unchanged over time in placenta increta (12.8% to 9.3%, p = 0.204) and placenta percreta (21.3% to 17.5%, p = 0.344) (Figure 1).

Among the assessed outcome measures, hemorrhage was the most common (n = 3850, 59.8%), followed by blood transfusion (n = 2415, 37.5%). There were 20 (0.3%) women who had arterial thrombosis, but there were no cases of arterial injury of lower extremity ischemia. A total of 25 (0.4%) women died during the admission for cesarean hysterectomy. As a whole, nearly three-quarters of the study population had a measured surgical complication (n = 4705, 73.1%).

For the entire cohort (Table 3), the incidence of hemorrhage (56.0% vs 60.0%), blood transfusion (34.5% vs 37.7%), shock (7.1% vs 8.0%) and urinary tract injury (6.0% vs 8.1%) were similar between the intra-arterial balloon occlusion group and the non-balloon group (all, p > 0.05). Women in the intra-arterial balloon occlusion group were more likely to develop coagulopathy (8.3% vs 5.3%, aOR 1.68, 95% CI 1.16–2.44, p = 0.006) and arterial thrombosis (aOR 5.25, 95% CI 1.87–14.7, p = 0.002) compared with those in the non-balloon group. There was no fatality in the balloon group whereas 25 (0.4%) women died in the non-balloon group. In composite end-point analysis, women in the intra-arterial balloon occlusion group were less likely to have the measured outcomes compared with those in the non-balloon group (66.7% vs 73.5%, aOR 0.69, 95% CI 0.56–0.86, p < 0.001).

Outcome measures were examined per the exposure subgroups (Table 4). In the placenta accreta group, intra-arterial balloon occlusion was not associated with decreased risk of hemorrhage, blood transfusion, shock, or urinary tract injury compared with non-balloon occlusion (all, p > 0.05). Composite end points were also statistically similar between the two exposure groups (p > 0.05). In the placenta increta group, the intra-arterial balloon occlusion group had the lower incidence of hemorrhage compared with the non-balloon group (30.8% vs 63.7%, aOR 0.25, 95% CI 0.15–0.44, p < 0.001).

In the placenta percreta group, the use of intra-arterial balloon occlusion was associated with a decreased likelihood of blood transfusion (30.8% vs 43.2%, aOR 0.60, 95% CI 0.40–0.90, p = 0.014) and a decreased risk of urinary tract injury (aOR 0.28, 95% CI 0.11–0.71, p=0.008) compared with non-use (both, p < 0.05). Intra-arterial balloon occlusion was not associated with
### TABLE 1 Patient demographics (N = 6440)

|                      | No balloon | Balloon | p value |
|----------------------|------------|---------|---------|
| **Number**           | n = 6020   | n = 420 |         |
| **Age (y)**          |            |         |         |
| <35                  | 3430 (57.0%) | 270 (64.3%) | 0.004  |
| ≥35                  | 2590 (43.0%) | 150 (35.7%) |         |
| **Year**             |            | <0.001  |         |
| First-third          | 1815 (30.1%) | 175 (41.7%) |         |
| Middle-third         | 1970 (32.7%) | 110 (26.2%) |         |
| Last-third           | 2235 (37.1%) | 135 (32.1%) |         |
| **Admission type**   |            | 0.478   |         |
| Non-elective         | 3030 (50.3%) | 215 (51.2%) |         |
| Elective             | 2970 (49.3%) | 205 (48.8%) |         |
| Unknown              | 20 (0.3%) |          |         |
| **Race/ethnicity**   |            | <0.001  |         |
| White                | 2465 (40.9%) | 170 (40.5%) |         |
| Black                | 1055 (17.5%) | 75 (17.9%) |         |
| Hispanic             | 1535 (25.5%) | 100 (23.8%) |         |
| Asian<sup>a</sup>    | 340 (5.6%) | 20 (4.8%) |         |
| Others               | 340 (5.6%) | 50 (11.9%) |         |
| Unknown              | 285 (4.7%) |          |         |
| **Median household income** | 0.275 |         |         |
| 1st QT (lowest)      | 1765 (29.3%) | 140 (33.3%) |         |
| 2nd QT               | 1510 (25.1%) | 110 (26.2%) |         |
| 3rd QT               | 1355 (22.5%) | 80 (19.0%) |         |
| 4th QT (highest)     | 1295 (21.5%) | 85 (20.2%) |         |
| Unknown              | 95 (1.6%) |          |         |
| **Primary expected payer** | 0.009  |         |         |
| Medicaid             | 3045 (50.6%) | 225 (52.9%) |         |
| Private including Health Maintenance Organization | 2585 (42.9%) | 185 (44.0%) |         |
| Other/unknown        | 385 (6.4%) |          |         |
| Unknown              | b | 0 |         |
| **Obesity**          |            | <0.001  |         |
| No                   | 4935 (82.0%) | 305 (72.6%) |         |
| Class I–II           | 545 (9.1%) | 55 (13.1%) |         |
| Class III            | 540 (9.0%) | 60 (14.4%) |         |
| **Tobacco use**      |            | 0.489   |         |
| No                   | 5450 (90.5%) | 385 (91.7%) |         |
| Yes                  | 570 (9.5%) | 35 (8.3%) |         |
| **Hospital bed capacity** | <0.001  |         |         |
| Small                | 540 (9.0%) | 15 (3.6%) |         |
| Medium               | 1280 (21.3%) | 65 (15.5%) |         |
| Large                | 4200 (69.8%) | 340 (81.0%) |         |

Notes: Median (IQR) or number (percentage per column) is shown. Chi-squared test, Fisher exact test, for p values. Abbreviations: HDP, hypertensive disorders of pregnancy; IQR: interquartile range; QT, quartile.<sup>a</sup> Including Pacific Islanders.<sup>b</sup> Suppressed per the Healthcare Cost and Utilization Project requirement.

### TABLE 1 (Continued)

|                      | No balloon | Balloon | p value |
|----------------------|------------|---------|---------|
| Hospital teaching status |            |         |         |
| Rural                | 150 (2.5%) | 0       | <0.001  |
| Urban Non-teaching   | 680 (11.3%) | 25 (6.0%) |         |
| Urban teaching       | 5190 (86.2%) | 395 (94.0%) |         |
| Hospital region      |            | <0.001  |         |
| Northeast            | 1145 (19.0%) | 110 (26.2%) |         |
| Midwest              | 1130 (18.8%) | 40 (9.5%) |         |
| South                | 2255 (37.5%) | 115 (27.4%) |         |
| West                 | 1490 (24.8%) | 155 (36.9%) |         |
| Gestational age (wk) |            | <0.001  |         |
| <32                  | 1060 (17.6%) | 80 (19.0%) |         |
| 32–33.9              | 840 (14.0%) | 70 (16.7%) |         |
| 34–36.6              | 2630 (43.7%) | 205 (48.8%) |         |
| >37                  | 1300 (21.6%) | 40 (9.5%) |         |
| Unknown              | 190 (3.2%) | 25 (6.0%) |         |
| Previous cesarean delivery |            |         | <0.001  |
| No                   | 1530 (25.4%) | 75 (17.9%) |         |
| Yes                  | 4490 (74.6%) | 345 (82.1%) |         |
| Placenta previa      |            | <0.001  |         |
| No                   | 2850 (47.3%) | 160 (38.1%) |         |
| Yes                  | 3170 (52.7%) | 260 (61.9%) |         |
| Multiple gestations  |            | 0.178   |         |
| No                   | 5795 (96.3%) | 410 (97.6%) |         |
| Yes                  | 225 (3.7%) |          |         |
| Breech presentation  |            | 0.136   |         |
| No                   | 4910 (81.6%) | 330 (78.6%) |         |
| Yes                  | 1110 (18.4%) | 90 (21.4%) |         |
| Grand multiparity    |            | 0.337   |         |
| No                   | 5915 (98.3%) | 410 (97.6%) |         |
| Yes                  | 105 (1.7%) |          |         |
| Diabetes Mellitus    |            | <0.001  |         |
| No                   | 5080 (84.4%) | 315 (75.0%) |         |
| Yes                  | 940 (15.6%) | 105 (25.0%) |         |
| HDP                  |            | 0.058   |         |
| No                   | 5025 (83.5%) | 335 (79.8%) |         |
| Yes                  | 995 (16.5%) | 85 (20.2%) |         |
| PAS type             |            | <0.001  |         |
| Accreta              | 4685 (77.8%) | 225 (53.6%) |         |
| Increta              | 675 (11.2%) | 65 (15.5%) |         |
| Percreta             | 660 (11.0%) | 130 (31.0%) |         |

Notes: Median (IQR) or number (percentage per column) is shown. Chi-squared test, Fisher exact test, for p values. Abbreviations: HDP, hypertensive disorders of pregnancy; IQR: interquartile range; QT, quartile.<sup>a</sup> Including Pacific Islanders.<sup>b</sup> Suppressed per the Healthcare Cost and Utilization Project requirement.
hemorrhage (57.7% vs 59.1%, \( p = 0.767 \)) but was associated with decreased risk of any measured morbidity, although it did not reach statistical significance (69.2% vs 77.3%, aOR 0.66, 95% CI 0.44–1.00, \( p = 0.051 \)).

Among 806 centers, 64 (7.9%) centers performed intra-arterial balloon occlusion at cesarean hysterectomy during the study period and 742 (92.1%) centers did not. The centers performing intra-arterial balloon occlusion were more likely to have large bed capacity (76.6% vs 69.7%), be urban teaching hospitals (93.8% vs 85.8%), and manage placenta percreta (24.1% vs 10.8%) compared with the non-performing centers (all, \( p < 0.05 \)). When stratified by the PAS subtypes (Tables S4 and S5), the intra-arterial balloon occlusion-performing centers and non-performing centers had similar composite outcome measures in placenta accreta (72.6% vs 72.8%) and placenta percreta (74.3% vs 76.4%) (both, \( p > 0.05 \)).

Surgical outcomes were then examined in 725 cases in the intra-arterial balloon occlusion-performing centers (Tables S6–S7). Notable findings included that women who had intra-arterial balloon occlusion were less likely to have the measured perioperative outcomes compared with those who did not in placenta percreta (69.2% vs 88.9%, aOR 0.28, 95% CI 0.10–0.76, \( p = 0.012 \)).

4 | DISCUSSION

The principal results of this study are threefold. First, cesarean hysterectomy for PAS is associated with significant surgical morbidity and mortality. Second, utilization of intra-arterial balloon occlusion at cesarean hysterectomy for PAS significantly varies based on patient, pregnancy, and facility factors; and less than 10% of US centers used this interventional procedure. Third, perioperative outcomes related to intra-arterial balloon occlusion at cesarean hysterectomy differed based on the severity of PAS.

This study confirmed the results of other studies reporting considerable surgical morbidities for cesarean hysterectomy performed for PAS.3–5 Many of these patients experienced surgical complications, with the most common being hemorrhage, urinary tract injury, and the need for blood products. Surgical mortality in this study
population was markedly high as one in 258 patients died during the admission. Of note, surgical mortality rate in elective repeat cesarean section was reported as one in 7692 in the USA.25 The large sample size of this study corroborates previous studies on this topic and reaffirms the importance of research into ways to reduce morbidity and mortality in PAS requiring cesarean hysterectomy.

The decreasing trend of intra-arterial balloon occlusion use at cesarean hysterectomy for placenta accreta found in this analysis has not been previously reported. The rate of decline is rather rapid. Even though this study only examined a 3-year span, the use of intra-arterial balloon occlusion declined by half over that short time period. It is likely that several recent trials, which showed no benefits of intra-arterial balloon occlusion on surgical outcome of PAS, may have influenced the recent practice.9,10

The most compelling data impacting the decline of intra-arterial balloon use for placenta accreta is likely from the 2015 trial (NCT01373255).10 In this trial, a total of 27 women with a prenatal diagnosis of placenta accreta from January 2009 to March 2015 were randomized to two groups: preoperative placement of balloon at the anterior division of internal iliac artery (n = 13) or no-balloon (n = 14).10 Estimated blood loss (1600 mL vs 1614 mL, p = 0.56) and number of packed red blood cell products needed (5.2 units vs 4.1 units, p = 0.90) were similar between the two groups. The authors concluded that the data demonstrated a lack of benefit of intra-arterial balloon occlusion for placenta accreta. The results of the trial were reported in November 2015. Hence, the decrease in the use of intra-arterial balloon placement during the time period of our national study may be due in part to the results of this trial. A more recent trial in May 2020 reported similar results (5.3 units vs 4.7 units of red blood cell products needed, p = 0.54), which may further contribute to a decrease in use moving forward.9

The results of our study demonstrating the lack of improvement in the risk of hemorrhage in placenta accreta are consistent with the aforementioned two trials. Increased likelihood of coagulopathy in the placenta accreta group was unexplained, and merits further investigation. Risk of arterial thrombosis in the intra-arterial balloon group is also a concern. At a minimum, it is reasonable to state that intra-arterial balloon occlusion may be not necessary for cesarean hysterectomy performed for the less severe form of PAS (placenta accreta).

An interesting and important result of this study is the finding in the severe form of PAS (placenta increta/percreta). Women who underwent intra-arterial balloon occlusion in these subgroups specifically were less likely to experience hemorrhage, require a blood transfusion, and have a urinary tract injury. The magnitude of risk reduction is clinically compelling as surgical morbidity for placenta increta/percreta is generally devastating.26,27 Our observation partly validates a previous study demonstrating reduced surgical blood loss and blood product use with intra-arterial balloon use.13 As their study was limited in sample size (n = 18 for balloon vs n = 13 for non-balloon), the larger sample size of our study provides more robust and generalizable information.

An explanation for the discrepancy between our results for placenta percreta and the aforementioned two trials is that the majority of the trial patients in the previous papers had placenta accreta. Placenta percreta accounted for 1 of 27 participants in the 2015 trial and 31 of 100 in the 2020 trial.9,10 Placenta percreta-specific analysis was not performed in the 2020 trial. The reason for improved surgical outcome with intra-arterial balloon occlusion for placenta increta/percreta observed in this study is likely multifactorial, and until more data are available, interpretation of our results requires special caution. Routine use of intra-arterial balloon occlusion at

### Table 3: Association between intra-arterial balloon occlusion use and outcome measures (whole cohort)

| Characteristic          | Intra-arterial balloon occlusion | Unadjusted | Adjusted† |
|-------------------------|---------------------------------|------------|-----------|
|                         | No (n = 6020) | Yes (n = 420) | OR (95% CI) | p value       | OR (95% CI) | p value       |
| Lower limb ischemia     | 0 | 0 | 0.994 | 0.994 |
| Arterial thrombosis     | 0.2% | 4.82 (1.74–13.3) | 0.002 | 5.25 (1.87–14.7) | 0.002 |
| Death                   | 0.4% | 0 | n/a       | 0.994 |
| Any                     | 73.5% | 66.7% | 0.72 (0.58–0.89) | <0.001 | 0.69 (0.56–0.86) | <0.001 |

Note: Binary logistic regression model for analysis.
Abbreviation: OR, odds ratio.
*Adjusted for age and placenta accreta spectrum type when the association in univariable analysis exhibited statistical significance of p < 0.05 level.
cesarean hysterectomy for placenta percreta is not recommended per the recent expert panel consensus.\(^6\)

Kingdom et al recently released an expert review on the state of play in 2020 for the management of placenta increta and percreta.\(^6\) Their review notes that some of the institutions represented in their expert panel have shifted from routine intra-arterial balloon occlusion to selective arterial ligation. Furthermore, the panel emphasized an evolving team-based surgical approach that includes five constructive steps that are key to reduce major blood loss in PAS. This shift may also inadvertently reduce the use of balloon occlusion by reducing surgical bleeding in PAS overall. Therefore, institutions managing women with suspected PAS should be highly encouraged to organize a multidisciplinary team and follow the proposed five-step surgical technique outlined.\(^6\)

### TABLE 4

Association between intra-arterial balloon occlusion use and outcome measures (PAS type-specific)

| Cohort | Characteristic | Intra-arterial balloon occlusion | Unadjusted | Adjusted* |
|--------|----------------|--------------------------------|------------|-----------|
|        |                | No | Yes | OR (95% CI) | p value | OR (95% CI) | p value |
| Accreta| Hemorrhage     | 59.7% | 62.2% | 1.11 (0.85–1.47) | 0.444 | 3.43 (2.34–5.04) | <0.001 |
|        | Blood transfusion | 37.2% | 33.3% | 0.84 (0.63–1.12) | 0.236 | 0.84 (0.63–1.12) | 0.236 |
|        | Coagulopathy   | 5.2% | 15.6% | 3.34 (2.28–4.90) | <0.001 | 3.34 (2.28–4.90) | <0.001 |
|        | Shock          | 7.8% | 6.7% | 0.85 (0.50–1.44) | 0.538 | 0.85 (0.50–1.44) | 0.538 |
|        | Urinary tract injury | 7.8% | 8.9% | 1.16 (0.72–1.85) | 0.550 | 1.16 (0.72–1.85) | 0.550 |
|        | Arterial injury | 0 | 0 | 0 | | 0 | |
|        | Arterial thrombosis\(^a\) | 0 | 0 | 0 | | 0 | |
|        | Lower limb ischemia | 0 | 0 | 0 | | 0 | |
|        | Death          | 0.3% | 0 | n/a | 0.995 | | |
|        | Any            | 73.0% | 68.9% | 0.82 (0.61–1.09) | 0.177 | 0.82 (0.61–1.09) | 0.177 |
| Increta| Hemorrhage     | 63.7% | 30.8% | 0.25 (0.15–0.44) | <0.001 | 0.25 (0.15–0.44) | <0.001 |
|        | Blood transfusion | 35.6% | 46.2% | 1.55 (0.93–2.59) | 0.092 | 1.55 (0.93–2.59) | 0.092 |
|        | Coagulopathy   | 4.4% | 0 | n/a | 0.997 | | |
|        | Shock          | 7.4% | 0 | n/a | 0.997 | | |
|        | Urinary tract injury | 7.4% | 0 | n/a | 0.997 | | |
|        | Arterial injury | 0 | 0 | 0 | | 0 | |
|        | Arterial thrombosis\(^a\) | 0 | 0 | n/a | 0.997 | | |
|        | Lower limb ischemia | 0 | 0 | n/a | 0.997 | | |
|        | Death          | 0.3% | 0 | n/a | 0.997 | | |
|        | Any            | 73.3% | 53.8% | 0.42 (0.25–0.71) | 0.001 | 0.42 (0.25–0.71) | 0.001 |
| Percreta| Hemorrhage     | 59.1% | 57.7% | 0.94 (0.65–1.38) | 0.767 | | |
|        | Blood transfusion | 43.2% | 30.8% | 0.59 (0.39–0.88) | 0.009 | 0.59 (0.39–0.88) | 0.009 |
|        | Coagulopathy   | 6.8% | 0 | n/a | 0.996 | | |
|        | Shock          | 9.8% | 11.5% | 1.19 (0.66–2.17) | 0.560 | 1.19 (0.66–2.17) | 0.560 |
|        | Urinary tract injury | 11.4% | 0 | n/a | 0.014 | | |
|        | Arterial injury | 0 | 0 | 0 | | 0 | |
|        | Arterial thrombosis | 0 | 0 | 0 | | 0 | |
|        | Lower limb ischemia | 0 | 0 | 0 | | 0 | |
|        | Death          | 0.3% | 0 | n/a | 0.996 | | |
|        | Any            | 77.3% | 69.2% | 0.66 (0.44–1.00) | 0.051 | | |

Note: Binary logistic regression model for analysis.
Abbreviations: OR, odds ratio; PAS, placenta accreta spectrum.
\(^a\)Suppressed per the Healthcare Cost and Utilization Project requirement.
*Adjusted for age when the association in univariable analysis exhibited statistical significance of \(p < 0.05\) level.
Last, intra-arterial balloon occlusion for cesarean hysterectomy appears to be a highly selective procedure that only 8% of centers performed. Interventional radiology sub-specialists are likely required for this procedure and these centers are likely tertiary referral centers, dealing with the most complex cases of PAS. Hence, comparison of the intra-arterial balloon occlusion performing and non-performing centers may have an inherent selection bias (Table S4 and S5). When the cohort was restricted to balloon-performing centers (Table S6), intra-arterial balloon occlusion was associated with decreased measured outcomes. Further study with a large sample size is needed to investigate if this association is also seen in more invasive forms of PAS.

The major strengths of this study are its population-based approach, large sample size, and robust sensitivity analysis. This type of national database is useful to examine relatively rare procedures or diseases, such as intra-arterial balloon occlusion use for PAS.

However, there are several limitations. First, surgical complications were only measured in a qualitative fashion (yes vs no) in the database, and therefore a quantitative assessment was not possible. As the exact amount of blood loss and surgical time are both salient outcome measures for a study examining the control of surgical bleeding, this lack of quantitative information limits interpretation of the results. Likewise, the ICD-10 codes do not specify the amount of blood loss for defining hemorrhage.

Second, there is unmeasured bias inherent to retrospective studies. For instance, decision-making regarding the placement of the intra-arterial balloon, indication for hysterectomy (preplanned vs unplanned), surgeon type and experience, number of uterine surgeries including cesarean section, use/results of imaging modality such as ultrasonography, surgery type (emergency vs non-emergency), and antenatal diagnosis and severity of PAS (clinical vs histological) were not available in the database but may confound the analysis. Likewise, information on intra-arterial balloon placement (routine use vs selective use) was not available. As the decision to perform intra-arterial balloon placement was presumably made before surgery based on these factors, the results of this study would not be directly applicable unless these factors are assessed.

Finally, the accuracy of exposure allocation and outcome measures is unknown as this study relied on ICD-10 codes without actual medical record review and histopathological results of the uterine specimen. For instance, as a result of the limitation in the ICD-10 codes with lack of specific procedure description, use of uterine arterial embolization was not distinguishable in this study, but this procedure is generally less likely to be performed at cesarean hysterectomy.

5 | CONCLUSION

There is a substantial variability in the utilization of intra-arterial balloon occlusion at cesarean hysterectomy for PAS based on patient, pregnancy, and facility factors. Moreover, a limited number of US centers offer intra-arterial balloon occlusion. These observations imply that there is no universal treatment approach in this surgical procedure, warranting the development of society-based practice consensus and guidelines. The observed exposure–outcome association of intra-arterial balloon occlusion use and improved surgical outcome in severe forms of PAS is clinically important and warrants further investigation in future studies.

CONFLICT OF INTEREST

KMatsuo declares honorarium from Chugai, textbook editorial expense from Springer, and investigator meeting attendance expense from VBL Therapeutics; SM declares a research grant from Merck, both outside the current study. The other authors have no conflicts of interest to declare.

AUTHOR CONTRIBUTION

KM designed the study, initiated the collaborations, cleaned and analyzed the data, created the figures and tables, interpreted the results, and drafted and revised the manuscript with others. SM, NLV, and RNS contributed to study concept and design, interpreted the data, and reviewed the manuscript. RSM accessed the data source, generated/cleaned the dataset, interpreted the results and revised the manuscript. KM and MK contributed to the study discussion and intellectual inputs, interpreted the results, and edited the manuscript. JGO contributed to the study concept, interpreted the results, supervised the study team, and revised the manuscript.

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SUPPORTING INFORMATION
Additional supporting information may be found in the online version of the article at the publisher’s website.

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