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ORIGINAL RESEARCH

Evaluating the Safety and Efficacy of Intraoperative Cell Salvage in Cesarean Delivery for Placenta Accreta Spectrum: A Propensity Score-Matched Retrospective Study

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Purpose: The Placenta Accreta Spectrum (PAS) poses a significant obstetric challenge, often leading to life-threatening hemorrhage during delivery. Intraoperative Cell Salvage (IOCS) is a promising but insufficiently studied blood conservation approach.

Patients and Methods: This retrospective cohort investigation employed propensity score matching to analyze 102 PAS cases diagnosed through combined preoperative MRI and ultrasound at a tertiary referral center between 2018 and 2022, comparing outcomes between the IOCS (n=53) and non-IOCS (n=49) groups, while utilizing inverse probability weighting to address potential selection bias.

Results: The analysis revealed that although the IOCS group experienced significantly greater median blood loss (2500 mL versus 1200 mL, $p<0.0001$), they required fewer allogeneic red blood cell transfusions (2 units versus 1 unit, $p<0.0001$) without experiencing severe complications such as amniotic fluid embolism. Weak but statistically significant correlations were observed between autologous blood recovery volume and PAS ultrasound scores ($r=0.29$, $p=0.034$), whereas total transfusion requirements showed a strong correlation with bleeding severity ($r=0.81$, $p<0.0001$). High-risk patients with ultrasound scores ≥9 yielded greater volumes of salvaged blood (715.0 mL vs.484.5 mL, $p=0.093$) than lower-risk patients. Multivariate regression analysis identified both elevated PAS scores (adjusted OR 1.44, 95% CI 1.06–1.95, $p=0.020$) and MRI-detected placental vascular abnormalities (adjusted OR 11.11, 95% CI 3.18–38.78, $p=0.0002$) as independent predictors of transfusion requirements. Comparative analyses showed equivalent hysterectomy rates (16.98% vs.10.20%, $p=0.32$) and neonatal outcomes, including birth weight ($p=0.81$), between the two groups.

Conclusion: These findings demonstrate that IOCS safely decreases dependence on allogeneic blood products in PAS management, particularly benefiting high-risk patients with vascular anomalies or severe imaging scores, while integrating effectively within comprehensive perioperative care protocols. This technology is particularly valuable in well-resourced clinical environments; however, multicenter prospective studies are warranted to standardize the implementation protocols and fully evaluate the cost-benefit ratios across diverse healthcare settings.

Keywords: placenta accreta spectrum, intraoperative cell salvage, postpartum hemorrhage, allogeneic blood transfusion

Introduction

Placenta Accreta Spectrum (PAS) is a potentially life-threatening pregnancy complication with a rising incidence rate.[1] It encompasses conditions such as accreta, increta, and percreta, in which the placenta abnormally attaches to and invades the uterine wall.[2] These conditions are frequently associated with previous cesarean deliveries, uterine surgeries, or placenta previa. A meta-analysis reported an overall PAS incidence rate of 0.17% (95% Confidence Interval (CI) 0.14–0.19), while in Germany, the rate was higher at 0.59%.[3] PAS can result in significant postpartum hemorrhage,

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which may necessitate emergency hysterectomy and pose substantial risks to maternal health,[4] with a maternal mortality rate of up to 7%.[5,6] Studies by Miller et al have demonstrated an average of 5.19 red blood cell (RBC) transfusions per PAS patient (95% CI 4.12–6.26).[7] Although timely blood volume replenishment is crucial for improving maternal survival, allogeneic blood transfusions carry risks such as acute lung injury, circulatory overload, viral infection transmission, and immunosuppression.

Intraoperative Cell Salvage (IOCS) is a procedure introduced to reduce the reliance on allogeneic blood transfusions, particularly during obstetric surgery. This technique involves collecting the patient's lost blood during surgery, processing it through anticoagulation, filtration, and washing, and subsequently re-infusing it into the patient's body. IOCS has been shown to reduce transfusion-related complications, such as immune responses and the risk of infectious diseases.[8] Furthermore, it helps alleviate the pressure on blood supply, especially for rare blood types, avoids incompatibility issues, and reduces overall transfusion-related costs. Historically, IOCS has been limited in obstetrics because of concerns regarding the potential risk of amniotic fluid embolism and maternal immune reactions. However, advancements in technology, including the use of Leukocyte Depletion Filters (LDF), have enhanced its safety by effectively eliminating contaminants such as amniotic fluid and fetal cells.[9]

Recent studies have shown that autologous transfusion using IOCS with LDF can significantly reduce transfusion-related hypotensive reactions and remove pro-inflammatory cytokines, thereby minimizing postoperative immune suppression.[10] Cost-effectiveness analyses have also indicated that IOCS is a more economical option than allogeneic blood transfusion.[11]

Given that PAS management requires optimal strategies to mitigate severe bleeding and preserve the uterus, exploring effective perioperative management approaches is essential.

This study aimed to assess the safety and effectiveness of IOCS in patients with PAS undergoing cesarean delivery, focusing on its impact on maternal and neonatal outcomes and associated complications. By providing insights into the clinical utility of IOCS, we hope to contribute to improved management strategies for PAS and better maternal care.

Materials and Methods

Study Design

This retrospective study included patients diagnosed with PAS via prenatal ultrasound and MRI, and the diagnoses were confirmed postoperatively by pathologists at Beijing Obstetrics and Gynecology Hospital, Capital Medical University. The study period spanned from January 1, 2018, to May 31, 2022, at a tertiary referral institution specializing in complex and high-risk obstetric cases in Northern China.

The inclusion criteria were as follows: 1) singleton pregnancies of at least 28 weeks of gestation.2) Confirmed PAS through preoperative ultrasound and MRI.

The exclusion criteria were as follows: 1) multiple pregnancies or gestation < 28 weeks.2) Severe internal conditions (eg, advanced heart disease, severe liver or kidney dysfunction, and coagulopathy). 3) Cases with incomplete medical records. 4) Multiple pregnancies. 5) unpredicted by ultrasound and MRI.

This retrospective study was approved by the Institutional Review Board of Beijing Obstetrics and Gynecology Hospital (approval no. 2024-KY-012-01). The requirement for informed consent was waived by the Institutional Review Board due to the retrospective nature of the study, which involved anonymized data analysis without direct patient involvement. All patient data were de-identified and processed in strict accordance with the Personal Information Protection Law of China and the Measures for Security Management of Medical Data to ensure patient confidentiality.

The hospital has a multidisciplinary team comprising obstetricians, anesthesiologists, oncologists, interventional radiologists, neonatologists, ultrasound specialists, and intensive care unit personnel to support the diagnosis and management of PAS. Postpartum hemorrhage (PPH) was defined as blood loss of at least 1000 mL during the cesarean section.

Ultrasound Sign Scoring

Ultrasound images of the patients were evaluated using a modified prenatal ultrasound grading system derived from Chen.[12] This system involves nine specific ultrasound indicators, including placental previa status, bladder integrity, vascularity at the uterine-bladder interface, and the presence of lacunae in the placenta. Each ultrasound feature was assigned a score of 0–2, and a cumulative score of 3 or higher indicated PAS.[13] Ultrasound evaluation is essential for the preoperative planning and management of patients with PAS.

MRI Examination

MRI scans were performed with the patients in the supine position and moderate bladder filling. A Discovery™ MR750 3.0T scanner with an 8-channel phased-array abdominal coil was used for the imaging. The sequences included T1-weighted axial, T2-weighted coronal and sagittal, fat-suppressed T2-weighted axial, and diffusion-weighted images. The evaluations were performed independently by two experienced imaging specialists using a double-blind approach. Indicators such as intraplacental dark bands, uterine-placental bulge, myometrial thinning signals, bladder wall interruption, focal exophytic mass, loss of T2-hypointense retroplacental line, abnormal vascularization of the placental bed, and placental heterogeneity are indicative of placental implantation.[14]

Surgical Methods

Management approaches for PAS include planned cesarean hysterectomy, conservative uterine reconstruction, and management of placental retention. In this study, a combination of conservative treatment and uterine reconstruction was used to minimize transfusion requirements and associated complications. Ureteral stents were placed in cases of suspected invasive placental growth. The type of anesthesia used was determined based on each patient's medical status.[15]

When there were signs of deep placental invasion, abdominal aortic balloons were placed before uterine incisions were made. Blood conservation measures, such as intraoperative cell salvage, were performed as required. The IOCS protocol adhered to standardized operational parameters, with the suction pressure maintained at 150–190 mmHg in accordance with the manufacturer's specifications (Sorin). A designated surgical assistant systematically managed suctioning to preserve intraoperative visualization, and no procedures required interruption because of the compromised field visibility. Postoperative comparative analysis of hemoglobin levels and hemolytic markers between the groups revealed no statistically significant differences ($p > 0.05$ for all comparisons), confirming the absence of clinically meaningful erythrocyte injury attributable to the salvage process. For hemostasis, methods such as uterine compression sutures, cavity packing, intrauterine balloon tamponade, and ligation of the uterine arteries are used. If all conservative measures failed, the decision to perform a hysterectomy was made by at least two experienced surgeons. Tissue samples obtained during surgery, including placental fragments or hysterectomy specimens, were sent for histopathological analysis. Based on the assessment of venous thromboembolism and postpartum hemorrhage risks, prophylactic low-molecular-weight heparin was administered within 24 h postoperatively.

Study Outcomes

The primary end point was maternal morbidity, defined as intraoperative and postoperative complications. Maternal baseline characteristics, ultrasound findings, MRI findings, pregnancy complications, and surgical details were obtained from the medical records.

Statistical Analysis

This study adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines. Data were extracted from electronic medical records and manually entered by the researchers for analysis. SPSS 27.0 software was used for statistical analysis. Continuous variables are expressed as mean ± standard deviation (SD) and were analyzed using independent *t*-tests. Categorical variables are presented as counts and percentages, and chi-square tests were used for the comparisons. Spearman's rank correlation analysis was employed to evaluate the statistical relationships between intraoperative salvaged blood volume and two clinical parameters EBL and PAS ultrasound severity scores. Propensity score matching in a 1:1 ratio was applied to minimize selection bias between the two groups. Variables with $p<0.2$ were included in the univariate analysis, and a significance level of $p<0.05$ was considered statistically significant.

Results

Patient Baseline Data and Diagnosis of Placenta Accreta Spectrum

Between January 1, 2018, and May 31, 2022, 55,432 pregnant women were admitted for childbirth. Among these, 1243 patients were diagnosed with PAS after cesarean section, resulting in an incidence rate of 2.24%. The high incidence of PAS at our center is associated with its role as a critical care center for pregnant and postpartum women in Northern China. In this study, 102 patients were selected based on preoperative ultrasound and MRI evaluations and were subsequently confirmed during surgery (Figure 1). The average age of these patients was 34.86 years, and 81.37% had a history of cesarean section. The PAS cases comprised 18.6% accreta, 44.1% increta, and 37.3% percreta.

Owing to differences in baseline characteristics between the groups (Table 1), we used propensity score matching to create comparable cohorts.

Patient Enrollment and Group Characteristics

Of the 102 eligible patients included in this study, 53 (51.9%) received Intraoperative Cell Salvage (IOCS) during cesarean section, while the remaining 49 patients formed the non-IOCS group. Table 1 shows the characteristics of the entire cohort before and after propensity score matching (PSM). In the original cohort, factors such as gestational age at delivery (35.00 ± 1.63 weeks vs 35.80 ± 1.78 weeks, p=0.0203), parity ≥ 2 (96.23% vs 73.47%, p=0.0012), and in vitro fertilization (IVF) usage (1.89% vs 12.24%, p=0.0387) were associated with different outcomes in the IOCS and non-IOCS groups ($P < 0.005$). Compared to the control group, the IOCS group also had higher rates of abnormal vascularization of the placental bed identified by MRI (73.58% vs 36.73%, p=0.0002) and higher ultrasound scores

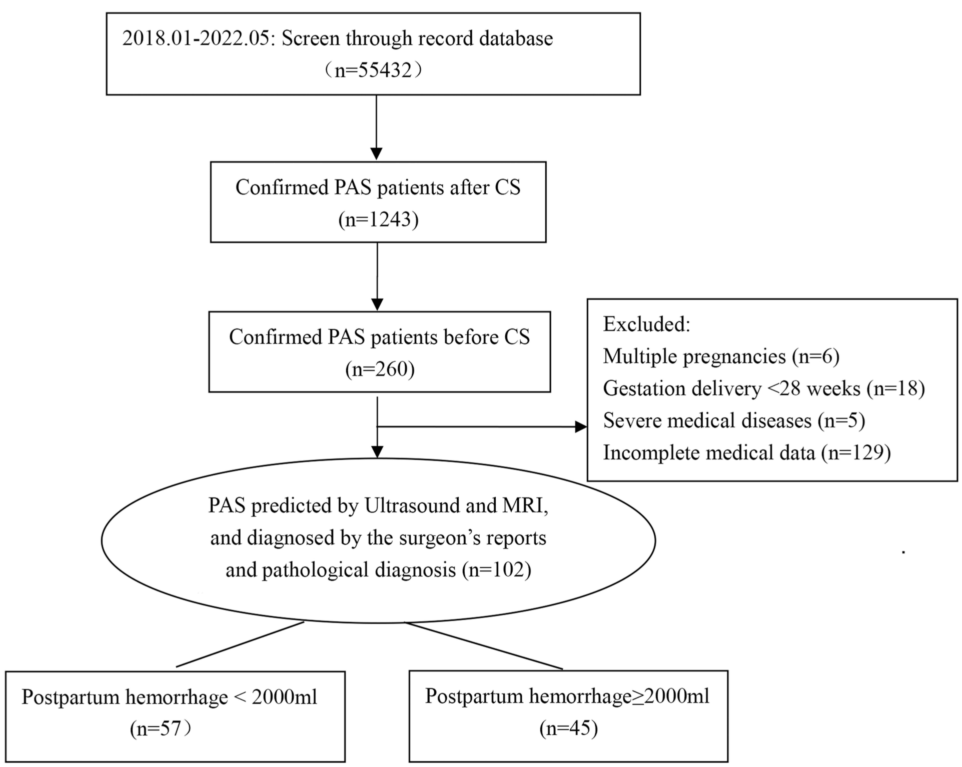

Figure 1 Flowchart of Patient Enrollment and Exclusion Criteria.

Table 1 Propensity Score Matching Analysis of Baseline Information Between IOCS Group and Non-IOCS Group

Variables	**Entire Cohort**			**Propensity Score-Matched Cohort**		
	IOCS (N=53)	**No IOCS (N=49)**	***p*-value**	**IOCS (N=28)**	**No IOCS (N=28)**	***p*-value**
Age, yr	34.42±3.77	35.35±4.42	0.2540	34.07±3.95	35.11±4.50	0.3642
BMI, kg/m2	25.04±4.10	26.38±5.38	0.1597	24.91±4.52	25.72±6.19	0.5802
Gestational age at delivery, weeks	35.00±1.63	35.80±1.78	0.0203*	35.07±2.00	35.25±2.05	0.7425
Gravidity			0.7086			0.7891
≤3	24 (45.28)	24 (48.98)		15 (53.57)	14 (50.00)	
≥4	29 (54.72)	25 (51.02)		13 (46.43)	14 (50.00)	
Parity			0.0012*			0.6393
≤1	2 (3.77)	13 (26.53)		2 (7.14)	3 (10.71)	
≥2	51 (96.23)	36 (73.47)		26 (92.86)	25 (89.29)	
Prior cesarean delivery			0.3312			0.5148
≤1	39 (73.58)	40 (81.63)		23 (82.14)	21 (75.00)	
≥2	14 (26.42)	9 (18.37)		5 (17.86)	7 (25.00)	
Prior uterine curettage			0.4871			0.4450
≤2	44 (83.02)	38 (77.55)		23 (82.14)	25 (89.29)	
≥3	9 (16.98)	11 (22.45)		5 (17.86)	3 (10.71)	
History of antepartum hemorrhage			0.1045			1.0000
≤1	46 (86.79)	47 (95.92)		26 (92.86)	26 (92.86)	
≥2	7 (13.21)	2 (4.08)		2 (7.14)	2 (7.14)	
IVF			0.0387*			1.0000
0	52 (98.11)	43 (87.76)		27 (96.43)	27 (96.43)	
1	1 (1.89)	6 (12.24)		1 (3.57)	1 (3.57)	
Hypomenorrhea			0.4998			1.0000
Yes	44 (83.02)	43 (87.76)		24 (85.71)	24 (85.71)	
No	9 (16.98)	6 (12.24)		4 (14.29)	4 (14.29)	
PAS ultrasound scoring	9.98±2.76	7.08±2.75	<0.0001*	9.00±2.49	8.75±2.38	0.7028
Placental heterogeneity			0.2730			1.0000
0 (No)	4 (7.55)	7 (14.29)		2 (7.14)	2 (7.14)	
1 (Yes)	49 (92.45)	42 (85.71)		26 (92.86)	26 (92.86)	
Bladder wall interruption			0.0749			0.5671
0 (No)	30 (56.60)	36 (73.47)		20 (71.43)	18 (64.29)	
1 (Yes)	23 (43.40)	13 (26.53)		8 (28.57)	10 (35.71)	
Myometrial thinning/disruption			0.1691			1.0000
0 (No)	4 (7.55)	8 (16.33)		1 (3.57)	1 (3.57)	
1 (Yes)	49 (92.45)	41 (83.67)		27 (96.43)	27 (96.43)	
Abnormal vascularization of the placental bed			0.0002*			0.7859
0 (No)	14 (26.42)	31 (63.27)		11 (39.29)	12 (42.86)	
1 (Yes)	39 (73.58)	18 (36.73)		17 (60.71)	16 (57.14)	
Placenta is located on a lateral uterine wall			0.2758			0.5892
0 (No)	29 (54.72)	32 (65.31)		17 (60.71)	15 (53.57)	
1 (Yes)	24 (45.28)	17 (34.69)		11 (39.29)	13 (46.43)	
Placenta located in the lower uterine segment			0.1776			0.4853
0 (No)	12 (22.64)	17 (34.69)		4 (14.29)	6 (21.43)	
1 (Yes)	41 (77.36)	32 (65.31)		24 (85.71)	22 (78.57)	
Placenta located on the posterior uterine wall			0.3290			0.7825
0 (No)	23 (43.40)	26 (53.06)		11 (39.29)	10 (35.71)	
1 (Yes)	30 (56.60)	23 (46.94)		17 (60.71)	18 (64.29)	
Placenta in the cervix			0.0548			0.3424
0 (No)	37 (69.81)	42 (85.71)		20 (71.43)	23 (82.14)	
1 (Yes)	16 (30.19)	7 (14.29)		8 (28.57)	5 (17.86)	

Note: *Represents statistical significance ($p < 0.05$).
Abbreviations: IOCS, Intraoperative Cell Salvage; PAS, Placenta Accreta Spectrum.

(9.98 ± 2.76 vs 7.08 ± 2.7, $p<0.0001$). Propensity score matching was performed using a caliper of 0.02, resulting in 28 matched pairs, with the resulting IOCS and non-IOCS groups being comparable in terms of their baseline characteristics.

Maternal and Neonatal Outcomes

In the propensity score-matched cohort, patients in the IOCS group experienced significantly greater blood loss during delivery (2500 vs 1200 mL, $p<0.0001$), longer operation times (115 vs 70 min, $p< 0.0001$), and increased instances of estimated blood loss (EBL) ≥ 1500 mL (79.25% vs 40.82%, $p<0.0001$) (Table 2). They also required a higher volume of transfused RBCs (2 vs 1 unit, $p<0.0001$) and more plasma (500 vs 400 mL, $p<0.0001$) than the non-IOCS group. The IOCS group also had significantly longer postoperative hospital stays (6 days vs 4.5 days, $p=0.0003$) and higher rates of abdominal aortic balloon use (43.4% vs 22.45%, $p=0.0250$). Conversely, neonatal birth weight was lower in the IOCS group (2595 ± 389 g vs 2803 ± 572 g, $p=0.0361$). Despite these differences, there were no significant differences in the rates of hysterectomy or neonatal outcomes, and no maternal deaths were reported in either group. Additionally, the IOCS group did not report any severe complications, such as allergies, amniotic fluid embolism, or disseminated intravascular coagulation, whereas three cases of allergy were observed in the non-IOCS group.

Stratified Analysis of IOCS Efficacy by PAS Severity

To assess differential outcomes based on disease severity, we stratified patients with PAS into high-risk (ultrasound score ≥9, n=33) and low-risk (score <9, n=20) subgroups (Table 3). The high-risk group demonstrated greater volumes of salvaged

Table 2 Maternal and Neonatal Outcomes of Two Groups

Variables	**Entire Cohort**			**Propensity Score-Matched Cohort**		
	IOCS (N=53)	**No IOCS (N=49)**	***p*-value**	**IOCS (N=28)**	**No IOCS (N=28)**	***p*-value**
Surgical time, min	115 (80–140)	70 (55–90)	<0.0001	105.0 (60.0–138.0)	86.5 (67.5–117.0)	0.6458
Total estimated blood loss at delivery (mL)	2500 (1700–3650)	1200 (800–1800)	<0.0001	2110 (1200–3575)	1700 (1000–2900)	0.1603
EBL≥1500 mL	42 (79.25)	20 (40.82)	<0.0001	20 (71.43)	17 (60.71)	0.3972
EBL≥2000 mL	34 (64.15)	11 (22.45)	<0.0001	16 (57.14)	11 (39.29)	0.1812
EBL≥2500 mL	28 (52.83)	8 (16.33)	0.0001	13 (46.43)	8 (28.57)	0.1675
RBC, U	2 (2–4)	1 (0–2)	<0.0001	2 (2–6)	2 (0–4)	0.0572
Plasma, mL	500 (400–1100)	400 (0–400)	<0.0001	400 (400–1000)	400 (0–700)	0.0852
Hysterectomy, %	9 (16.98)	5 (10.20)	0.3204	3 (10.71)	5 (17.86)	0.4450
Length of hospitalization, day	6.0 (5.0–8.0)	4.5 (4.0–6.0)	0.0003	5.0 (4.0–8.0)	5.5 (4.0–6.5)	0.7200
Bladder injury, %	5 (9.43)	0	0.0573	1 (3.57)	0	1.0000
Intrauterine gauze packing, %	16 (30.19)	9 (18.37)	0.1655	10 (35.71)	9 (32.14)	0.7778
Intrauterine balloon tamponade, %	7 (13.21)	3 (6.12)	0.3848	4 (14.29)	2 (7.14)	0.6657
Abdominal aortic balloon, %	23 (43.40)	11 (22.45)	0.0250	8 (28.57)	11 (39.29)	0.3972
Uterine artery embolization after surgery, %	10 (18.87)	3 (6.12)	0.0538	7 (25.00)	3 (10.71)	0.1628
Intraoperative uterine compression suture, %	17 (32.08)	15 (30.61)	0.8736	11 (39.29)	6 (21.43)	0.1462
Ligation of internal iliac artery, %	8 (15.09)	3 (6.12)	0.1444	3 (10.71)	3 (10.71)	1.0000
Neonatal Birth Weight, g	2595±389	2803±572	0.0361	2604±451	2639±611	0.8102

Abbreviations: IOCS, Intraoperative Cell Salvage; EBL, estimated blood loss.

Table 3 The Relationship Between the PAS Ultrasound Score, IOCS and Allogeneic Blood Transfusion

	Low-Risk (score <9, n=20)	**High-Risk (score ≥ 9, n=33)**	***P* value**
IOCS, mL	484.5 (243.0–804.5)	715.0 (381.0–1221.0)	0.0932
Allogeneic transfusion, mL	400 (400–800)	600 (400–1200)	0.2175
Plasma, mL	400 (400–1200)	600 (400–1000)	0.3408
IOCS/IOCS+allogeneic transfusion, %	52.87±24.88	50.62±19.57	0.7161

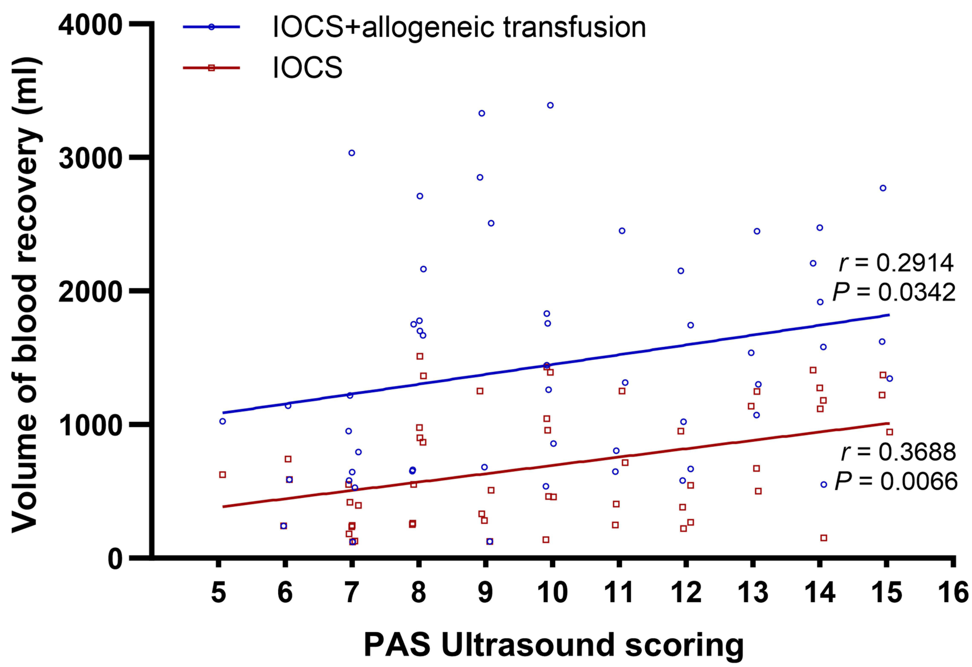

Figure 2 Relationship between PAS ultrasound score and blood recovery volume. The blue line represents the total volume of autologous plus allogeneic blood transfused, and the red line indicates the volume of intraoperative cell salvage (IOCS) blood.

blood (715 vs 484.5 mL, p=0.093) and allogeneic transfusion (600 vs 400 mL, p=0.218), although these differences did not reach statistical significance. Plasma transfusion volumes showed no significant intergroup difference (p>0.05).

The proportion of autologous blood in total transfusion was comparable between the groups (low-risk: 52.87% vs high-risk: 50.62%, p=0.716), suggesting consistent application of IOCS across risk strata. The total transfusion volume exhibited a significant positive correlation with the PAS score (r=0.369, p=0.007) (Figure 2), with more pronounced increases at higher scores. This likely reflects the greater transfusion requirements in severe PAS cases due to increased intraoperative hemorrhage.

Autologous blood salvage volume showed a weaker but still significant correlation with the PAS score (r=0.29, p=0.034). The attenuated response compared to total transfusion may reflect technical limitations in blood salvage efficiency during massive hemorrhage or inter-patient variability in the salvageable blood volume.

Among the 53 IOCS-treated patients, the salvaged blood volume correlated significantly with the EBL (p<0.0001) (Figure 3). The total transfusion volume demonstrated an even stronger correlation (r=0.808, p<0.0001), indicating that while autologous salvage increases with blood loss, substantial additional allogeneic support is required to meet transfusion demands in cases of significant hemorrhage.

Univariate and Multivariate Analysis

Univariate analysis revealed that PAS severity and IOCS use were potentially linked to PAS ultrasound scoring, myometrial thinning, abnormal vascularization of the placental bed, placental location, and cervical involvement (*p*<0.02; Table 4). Multivariate logistic regression analysis further indicated that PAS ultrasound scoring (adjusted odds ratio [OR], 1.437; 95% CI, 1.058–1.952; *p*=0.0202) and MRI-detected abnormal vascularization of the placental bed (adjusted odds ratio, 11.109; 95% CI, 3.183–38.777; *p*=0.0002) were associated with the primary outcome.

Comparison of Clinical Data for PAS Patients with Different Blood Loss Levels

A total of 62 patients with PAS experienced severe postpartum hemorrhage (EBL ≥ 1500 mL), whereas 40 patients had an EBL < 1500 mL. The detailed baseline data are shown in Table 5. The data showed no significant association between severe PPH and age, BMI, gravidity, parity, or gestational age at delivery. The median intraoperative blood loss in the

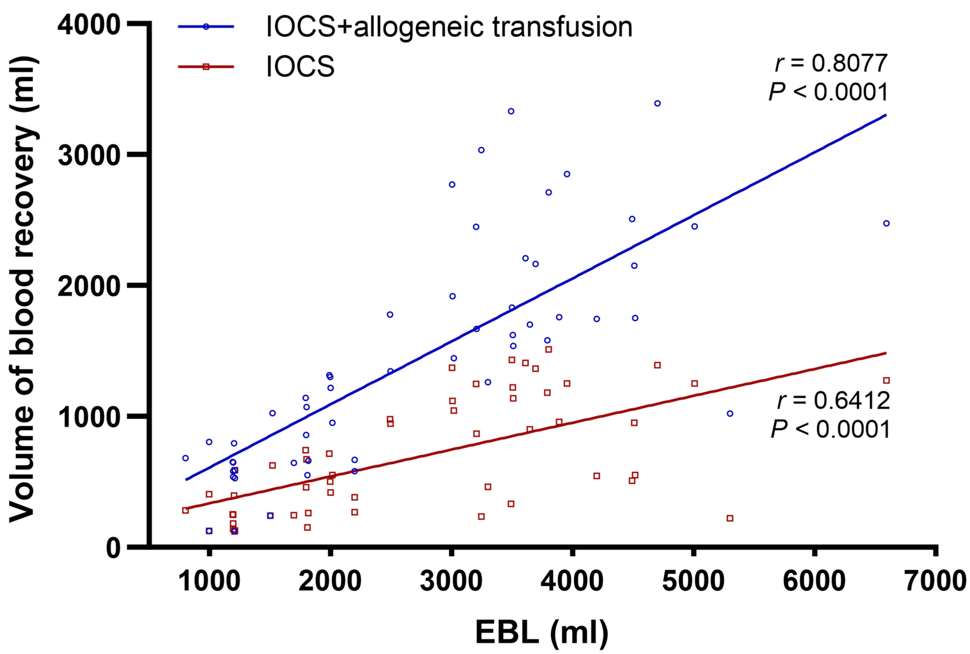

Figure 3 Relationship between estimated blood loss (EBL) and blood recovery volume among patients reinfused with IOCS blood (n=53). The blue line represents the combined volume of autologous and allogeneic blood, and the red line represents the IOCS volume.

≥1500 and <1500 mL groups was 1800 mL (1500–6600 mL) and1127 mL (800–1200 mL), respectively, with the higher group requiring a greater volume of transfused blood (806 mL vs 260 mL, *p*<0.01). The use of IOCS was more frequent in the ≥1500 mL group (67.7%, n=42). However, the difference in overall expenditure between the groups was not statistically significant.

Table 4 Univariate and Multivariate Logistic Analysis of the Entire Cohort for the Primary Outcome

Variables	**Univariate Analysis**		**Multivariate Logistic Analysis**	
	OR (95% CI)	***p*-value**	**OR (95% CI)**	***p*-value**
PAS ultrasound scoring	1.740 (1.384–2.187)	<0.0001*	1.437 (1.058–1.952)	0.0202*
Bladder wall interruption				
0 (No)	1	Reference	1	Reference
1 (Yes)	5.312 (1.953–14.449)	0.0011*	2.458 (0.607–9.951)	0.2074
Myometrial thinning/disruption				
0 (No)	1	Reference	1	Reference
1 (Yes)	5.708 (1.440–22.620)	0.0132*	1.196 (0.176–8.137)	0.8546
Abnormal vascularization of placental bed				
0 (No)	1	Reference	1	Reference
1 (Yes)	19.643 (7.008–55.054)	<0.0001*	11.109 (3.183–38.777)	0.0002*
Placenta is located on a lateral uterine wall				
0 (No)	1	Reference	1	Reference
1 (Yes)	3.000 (1.255–7.174)	0.0135*	2.163 (0.600–7.804)	0.2385
Placenta in cervix				
0 (No)	1	Reference	1	Reference
1 (Yes)	9.732 (2.137–44.319)	0.0033*	4.648 (0.677–31.903)	0.1180
IOCS				
No	1	Reference	1	Reference
Yes	5.536 (2.308–13.278)	0.0001*	1.593 (0.450–5.630)	0.4701

Note: *Represents statistical significance (p < 0.05).
Abbreviations: IOCS, Intraoperative Cell Salvage; PAS, placenta accreta spectrum.

Table 5 Comparison of Clinical Data of PAS Patients with Blood Loss Of<1500 mL and ≥1500 mL

Variables	<1500 mL (N=40)	≥1500 mL (N=62)	*p*-value
Age(year)	35.25±4.41	34.61±3.91	0.4469
BMI(kg/m2)	26.80±4.92	24.96±4.58	0.0574
Gravida	4.00(2.00–5.00)	4.00(3.00–5.00)	0.7620
Para	2.00(2.00–2.00)	2.00(2.00–3.00)	0.2247
Gestational age(week)	35.65±1.93	35.16±1.50	0.1540
EBL at delivery (mL)	1127 mL (800–1200 mL)	1800 mL (1500–6600 mL)	<0.001
RBC (mL)	260 mL (126–588 mL)	806 mL (151–1512 mL)	<0.001
Operation time	62.68±21.47	162.29±297.44	<0.001
Hysterectomy	0	14	<0.001

Note: Statistical significance was set at p<0.05.
Abbreviations: SD, Standard Deviation; N, Number of patients; BMI, Body Mass Index; RBC, Red Blood Cell; EBL, Estimated blood loss.

Women with EBL ≥ 1500 mL required greater perioperative blood product usage, had longer operation times, and had higher hysterectomy rates than those with lower blood loss. Notably, no cases of amniotic fluid embolism, severe transfusion reactions, shock, or maternal death were reported in either group.

Discussion

The diagnosis of PAS primarily depends on imaging modalities such as ultrasonography and MRI. Regardless of the surgical intervention, PAS is often associated with severe intraoperative hemorrhage. The primary treatment for PAS involves surgical management, which may include cesarean section or hysterectomy. Effective control of intraoperative hemorrhage is crucial. Methods such as uterine compression sutures, intrauterine packing, and vascular ligation are commonly employed alongside Intraoperative Cell Salvage (IOCS) to minimize intraoperative hemorrhage and reduce the need for allogeneic transfusion. Our findings indicated that women with PAS had a significantly higher incidence of intraoperative hemorrhage than those without PAS (98.03% vs 10.9%; P<0.0001). A retrospective study found that the median number of red blood cell units transfused in patients with PAS was 4 units (range: 0–10).[16] Moreover, a recent study highlighted that cell salvage is more commonly used in hospitals handling over 1337 births annually.[17] In our study, 92.45% of patients who received IOCS required allogeneic red blood cell transfusions, compared with 53.06% in the non-IOCS group.

The IOCS technique involves the use of a heparinized suction tube to collect blood from the surgical site, followed by filtration through LDF to remove white blood cells and other components from the amniotic fluid. The blood is then washed, concentrated, and reinfused into the patient, maintaining a final hematocrit between 0.45 and 0.55. Although there is a theoretical risk of amniotic fluid embolism associated with IOCS, only two cases of suspected amniotic fluid embolism have been reported since its introduction.[18,19] In our study, 53 patients underwent IOCS without severe adverse obstetric outcomes, indicating that IOCS is relatively safe for use in cesarean sections. A meta-analysis of 24 studies and 5872 patients (11 RCTs and 13 observational studies) found that patients who used IOCS had higher postoperative hemoglobin levels and fewer transfusion-related adverse events.[20]

Implementation of Autologous Blood Transfusion Technology

During the study period, 53 (51.9%) and 49 patients were in the IOCS and non-IOCS groups, respectively. The procedures performed during cesarean sections included abdominal aortic balloon placement in 34 cases (33.3%), internal iliac artery ligation in 11 cases (10.8%), uterine artery embolization in 13 cases (12.7%), and hysterectomy in 14 cases (13.7%).

The average intraoperative blood loss in the IOCS group was 2500 mL, with a mean transfusion of 2 units, and all recovered blood was successfully reinfused after leukoreduction filtration. Comparatively, the non-IOCS group required fewer transfusions (one unit on average). The use of IOCS was associated with a higher need for allogeneic blood, likely due to the more severe conditions in this group, as reflected by the higher ultrasound scores. Our study showed that IOCS recovered less than 50% of the estimated blood loss in PAS cases. This limited recovery efficiency suggests that patients experiencing substantial (>1500 mL) or rapid hemorrhage remain at a higher risk of requiring allogeneic blood products. In such clinical scenarios, the implementation of additional suction systems may enhance IOCS yield during acute massive hemorrhage; however, this requires prospective validation.

Intraoperative Blood Loss and Allogeneic Transfusion Requirements

The average intraoperative blood loss was significantly higher in the IOCS group (2500 mL) than in the non-IOCS group (1200 mL). Propensity score matching revealed that IOCS significantly reduced blood loss, with an average of 2110 mL in the IOCS group. A total of 53 patients in the IOCS group had an intraoperative salvage volume of 36,748 mL, equating to 183.7 units of red blood cells (mean 693±215 mL per patient). The total blood loss in the IOCS group was 145,230 mL, with an average of 13.7 units per patient. Due to higher preoperative ultrasound scores (9.98 ± 2.76), the demand for transfusions was greater in the IOCS group than in the non-IOCS group. Based on our findings, we recommend preoperative preparation of adequate allogeneic blood products (packed red blood cells and fresh frozen plasma) for patients with higher ultrasound scores (≥9), along with optimization of IOCS protocols to maximize autologous blood recovery. For low-risk cases (ultrasound score <9), IOCS may serve as the primary blood conservation strategy with continuous intraoperative monitoring of bleeding dynamics. The modest correlation coefficients (autologous salvage volume r=0.29, p=0.034; total transfusion volume r=0.369, p=0.007) indicate that while ultrasound scoring shows statistically significant associations with transfusion requirements, other clinical factors, including surgical technique variations and precise placental invasion topography, likely contribute substantially to the overall transfusion volume.

Importantly, IOCS helped reduce the incidence of complications such as disseminated intravascular coagulation (DIC), hemorrhagic shock, and hysterectomy. No patient experienced related complications, supporting the safety of this technique for PAS management.[20–22] The salvaged blood volume was converted to equivalent allogeneic blood units using established methods.[11] In the Chinese clinical setting, one unit of allogeneic packed red blood cells is typically derived from 200 mL of whole blood with a hematocrit range of 0.45–0.6. This conversion ratio indicates that 200 mL of processed salvaged blood corresponds to approximately one unit of allogeneic packed red cells with a hematocrit value between 0.45 and 0.55. While Miller et al reported a median transfusion requirement of four units in PAS patients,[7] our inverse probability-weighting adjusted analysis revealed that the IOCS reduced this transfusion requirement by 50%, even in cases involving greater blood loss, more complex surgical procedures, and higher ultrasound severity scores, a quantitative relationship not previously demonstrated in the literature.

Surgical and Hospital Stay Duration

Patients in the IOCS group had longer surgical times (approximately 45 min more) than those in the non-IOCS group. The average hospital stay was also longer in the IOCS group (7 vs 5.7 days). This difference was attributed to more severe preoperative conditions, as indicated by ultrasound scoring and MRI, and the additional time required for blood recovery and processing. A meta-analysis of 17 studies involving 235,779 surgical patients showed that a multimodal blood management program, including IOCS, reduced transfusion rates, hospital stays, and overall complications.[23]

Cost-Effectiveness Analysis

Although the initial cost of autologous transfusion technology is relatively high, our study found no significant difference in costs between patients with <1500 mL and ≥1500 mL of blood loss. However, the use of IOCS reduced overall medical expenses because the need for allogeneic blood decreased. On average, the medical costs for patients in the IOCS group were 10% lower than those for patients in the non-IOCS group. The routine use of cell salvage during cesarean sections is estimated to increase costs by $223.8.[24]

Delivery Gestational Age and Long-Term Follow-Up Results

The average delivery time for PAS patients in our study was 35 weeks, which aligns with the guidelines of the American College of Obstetricians and Gynecologists and the Society for Maternal-Fetal Medicine, recommending delivery between 34 and 35 weeks for PAS.[25] Delivery timing must consider PAS severity, risk of antenatal bleeding, and preterm complications and should be customized based on the available resources.[26] Our analysis also found that preoperative ultrasound scoring, parity, IVF use, and vascular abnormalities were associated with increased surgical difficulty, leading to a higher risk of intraoperative bleeding.

No maternal mortality was observed in either the IOCS or non-IOCS group. All 102 enrolled patients successfully completed their hospitalizations and were subsequently discharged. Furthermore, a review of the excluded cases found no mortality during the study period. This safety profile was maintained across the entire patient cohort, regardless of treatment allocation. These mortality data align with the study's broader safety findings regarding IOCS use in this high-risk obstetric population.

Clinical Significance

The results of our study add valuable information to the existing literature, demonstrating the effectiveness of IOCS in reducing the need for allogeneic transfusions and minimizing the risks of DIC, hemorrhagic shock, and hysterectomy. Accurate prenatal PAS diagnosis using tools such as MRI and ultrasound helps assess the feasibility of IOCS application, allowing for better preoperative planning.[27] The current study found that while IOCS implementation did not lead to a decrease in hysterectomy rates, it resulted in a significant reduction in the need for allogeneic blood transfusions. This reduction consequently diminished the potential risks associated with transfusion-transmitted infections while simultaneously preserving valuable blood bank resources. These findings corroborate evidence from recent meta-analyses that have similarly demonstrated the efficacy of IOCS in decreasing allogeneic transfusion requirements for obstetric hemorrhage cases.[20,28] Furthermore, our data on the economic benefits of IOCS supports previous cost-effectiveness analyses. The observed outcomes collectively suggest that IOCS provides measurable clinical and operational advantages, despite not affecting surgical outcomes such as hysterectomy rates. This pattern of benefits has been consistently documented in multiple studies examining blood conservation strategies in obstetric practice.[11]

Advantages and Limitations

This study benefited from methodological strengths, including a substantial sample size and rigorous inclusion criteria that maintained diagnostic consistency through multimodal assessment combining ultrasound and MRI with subsequent intraoperative and histopathological confirmation. The application of inverse probability weighting with propensity score adjustment effectively controlled for potential confounding variables, while supplementary sensitivity analyses using conventional propensity score-matching reinforced the robustness of our findings. The comprehensive evaluation of both maternal and neonatal outcomes aligns with the growing clinical evidence regarding the benefits of IOCS in managing obstetric hemorrhage.

Several limitations warrant consideration when interpreting the results of this study. The retrospective design introduces potential selection bias due to non-random allocation of subjects, such as surgeon experience and institutional protocols, which represent a key limitation, despite our use of propensity score-matching to address baseline differences. As a single-center study conducted at a specialized PAS referral center, the findings may not be generally applicable to resource-limited settings or institutions with less IOCS experience. Although the current sample size was substantial, it may have been insufficient to detect rare adverse outcomes. Additional investigations are needed to optimize technical parameters, such as suction pressure thresholds and red blood cell preservation, during salvage procedures.

These limitations highlight the need for future multicenter prospective studies to confirm our findings. Such research should incorporate standardized protocols across diverse clinical settings to enhance generalizability while maintaining the diagnostic rigor demonstrated in this study. The consistent alignment of our findings with the existing literature suggests that despite these limitations, this study provides valuable insights into the application of IOCS for PAS management.

Study Significance

Despite its limitations, our study enhances the understanding of IOCS and its implementation in PAS management. Prospective randomized controlled trials with larger cohorts are needed to confirm the effectiveness and safety of IOCS, and further research should explore the optimal protocols for its use. The cost-effectiveness and practicality of applying IOCS in different healthcare settings must also be assessed, considering PAS severity and local medical conditions.

Conclusion

In conclusion, IOCS is a safe, effective, and cost-efficient strategy that reduces but does not eliminate the need for allogeneic blood transfusion, especially in severe PAS cases. By decreasing the reliance on allogeneic blood, IOCS helps avoid transfusion-related complications from allogeneic transfusions and requires integration with multidisciplinary strategies to optimize outcomes.

With ongoing technological advancements, IOCS has the potential to become an important tool in the multidisciplinary treatment of PAS, particularly in patients with vascular abnormalities detected by MRI or those with high placental scores. However, IOCS use requires specialized equipment and expertise, making it unsuitable for all patients. A careful assessment is essential to balance the benefits and risks of this approach.

Data Sharing Statement

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Ethics Approval

The study was approved by the Ethics Committee of Beijing Obstetrics and Gynecology Hospital, Capital Medical University on 8th January, 2024 (no. 2024-KY-012-01) and conducted in accordance with the 1964 helsinki Declaration and its later amendments or comparable ethical standards.

Consent to Participate

The requirement for informed consent was waived by the Institutional Review Board because of the retrospective nature of this study.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

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