Research Square

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Effects of tranexamic acid on maternal outcomes among women stratified by placenta accreta spectrum grade: A 10-year single-centre retrospective cohort study

Deng huimin
Shanghai Jiao Tong University
kai Zhang
Rizhao Central Hospital
Nannan Pan
Shanghai Jiao Tong University
Lili Wang
Shanghai Jiao Tong University
Xiao Wang
Shanghai Jiao Tong University
Jun Zheng
Shanghai Jiao Tong University
Sicheng Wu
Shanghai Jiao Tong University
Jun Zhang
Shanghai Jiao Tong University
chenshao heng
chenshaoheng@sjtu.edu.cn
Shanghai Jiao Tong University

Research Article

Keywords: placenta accreta spectrum, tranexamic acid, allogeneic blood transfusion, blood conservation measures, maternal outcomes

Posted Date: November 18th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11314352/v1

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Additional Declarations: No competing interests reported.

Abstract

Background

To evaluate whether tranexamic acid (TXA) administration improves maternal outcomes by reducing postpartum estimated blood loss (EBL) and shortening the postpartum length of stay among women with different placenta accreta spectrum (PAS) grades.

Methods

This retrospective cohort study included 451 patients with PAS who delivered at a municipal critical maternity care centre from January 2015 to January 2026. Propensity score matching (PSM) based on TXA administration yielded 215 matched pairs in the overall cohort. The 451 patients were further stratified by whether they had an abnormally adherent or abnormally invasive placenta, yielding 87 and 108 matched pairs, respectively. The primary outcomes were 2- and 24-hour postpartum EBL; the secondary outcomes included severe postpartum haemorrhage (sPPH), postpartum length of stay, the need for allogeneic blood transfusion and the need for blood conservation measures. Subgroup analyses were performed to evaluate the effects of TXA across patients with PAS of different grades, and interaction effects between the PAS grade and TXA administration were assessed.

Results

In the overall matched cohort, TXA administration was associated with significantly lower 2- and 24-hour postpartum EBL and a lower incidence of EBL > 1500 mL ($P < 0.05$). The rates of arterial embolization, intrauterine balloon tamponade, and salvaged autologous blood transfusion were also lower with TXA administration ($P < 0.05$), whereas the rates of red blood cell and fresh frozen plasma transfusions did not significantly differ ($P > 0.05$). In patients with an abnormally adherent or abnormally invasive placenta, TXA administration reduced 2-hour EBL (mean difference [MD], − 203.45 and − 347.22 mL, respectively) and 24-hour EBL (MD, − 290.35 and − 442.59 mL, respectively). Furthermore, among patients with an abnormally invasive placenta, TXA administration was associated with a lower incidence of EBL > 1500 mL (odds ratio [OR], 0.53; 95% confidence interval [CI], 0.31 to 0.91; $P = 0.021$) and a shorter postpartum length of stay (MD, − 0.93; 95% CI, − 1.49 to − 0.29; $P = 0.004$). A significant interaction was observed between the PAS grade and TXA administration for the postpartum length of stay (P for interaction = 0.041).

Conclusions

In parturients with PAS, intrapartum TXA administration is associated with reduced postpartum EBL and sPPH incidence. Moreover, the depth of placental invasion significantly modifies the effect of TXA administration on the postpartum length of stay, with high-risk patients with an abnormally invasive placenta requiring a significantly shorter postpartum length of stay.

Background

Tranexamic acid (TXA), a synthetic lysine analogue, competitively blocks lysine binding sites on plasminogen, preventing its activation to plasmin and attenuating hyperfibrinolysis. TXA is indicated for the treatment of bleeding disorders associated with increased fibrinolytic activity [1]. Multiple randomized controlled trials (RCTs) have established the widespread application of TXA in both medical and surgical settings. For example, TXA has exhibited well-defined efficacy in reducing the incidence of bleeding-related complications among patients with traumatic brain injury, those undergoing orthopaedic or major cardiac surgery, and critically ill people with trauma [2–5]. Concurrently, TXA has gained increasing attention in the field of obstetrics and gynaecology, and the World Health Organization (WHO) has issued an updated recommendation endorsing the use of intravenous TXA for the treatment of postpartum haemorrhage (PPH) [6]. Previous studies have demonstrated that TXA administration, as a routine obstetric haemostatic measure, does not reduce the incidence of bleeding-related outcomes in low-risk parturients [7, 8]. Notably, TXA administration tends to reduce the risk of PPH and allogeneic blood transfusion requirements in high-risk patient populations, including women with placenta previa, prolonged labour, anaemia or maternal haemodynamic instability [9–11]. Accordingly, we speculate that TXA administration yields greater benefit in women with a high risk of PPH.

Placenta accreta spectrum (PAS) disorders are severe and life-threatening obstetric complications. As the depth of trophoblast invasion progressively increases in patients with PAS, the risks of severe PPH (sPPH), massive transfusion, hysterectomy, shock, disseminated intravascular coagulation (DIC), and even maternal mortality increase significantly, with a concomitant increase in the rates of adverse maternal outcomes [12, 13]. According to the available data, the overall incidence of PAS disorders is 0.17%, with a maternal case fatality rate of 0.05% [14]. The most significant risk in women with PAS is PPH. The WOMAN trial demonstrated that early TXA administration reduces the risk of bleeding-related mortality by nearly one-third, further confirming that TXA decreases the risk of life-threatening PPH [15, 16]. Accordingly, the aim

of this study was to stratify patients with PAS to analyse whether TXA administration can provide additional clinical benefits during delivery in a population at high risk for PPH.

Methods

Study design and population

This retrospective cohort study was conducted at a municipal tertiary critical obstetric care center in Shanghai, China. All findings were reported in line with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [17]. The study protocol was approved by the Institutional Review Board and Medical Ethics Committee of Shanghai General Hospital (Ethics approval number: 2026/381). Individual informed consent was waived, given the retrospective design and utilization of deidentified clinical data.

We reviewed the electronic medical records of all the women who delivered in our hospital from January 2016 to January 2026 and identified those who were clinically diagnosed with PAS. In all cases, PAS was diagnosed according to the 2019 International Federation of Gynaecology and Obstetrics (FIGO) classification system [18]. For patients who underwent hysterectomy, the diagnosis was pathologically confirmed after surgery, whereas for participants who did not undergo hysterectomy, the diagnosis was made using a combination of clinical data and intraoperative findings.

Eligibility criteria

The inclusion criteria were a diagnosis of PAS and all of the following: (1) age ≥ 18 years; (2) gestational age at delivery ≥ 32 weeks; (3) in-hospital delivery; and (4) normal antenatal coagulation before delivery. The exclusion criteria were (1) hospitalization without subsequent delivery, (2) severe haemostatic disorders, and (3) incomplete clinical data related to primary outcomes.

Exposure classification

In treated patients, a 1 g dose of TXA (Shandong Ruiyang Pharmaceutical Co., Ltd., National Medicine Approval No. H20043103, specification: 10 mL:1.0 g) was administered via intravenous injection within 30 minutes following foetal delivery. Throughout the study period, intravenous TXA administration was not standardized, and whether the drug was administered was determined by the attending obstetricians on the basis of real-time blood loss. As this was a retrospective cohort study of patients with PAS, TXA administration was guided by clinical judgement rather than a predefined research-driven protocol.

Data collection and definitions

Clinical data were extracted from the laboratory information system (LIS) and hospital information system (HIS) of our institute. Maternal demographic characteristics included maternal age and body mass index (BMI, kg/m²). Baseline clinical variables included total gravidity, history of prior caesarean delivery and abortion, myomectomy history, antecedent postpartum haemorrhage status, gestational type (singleton/multifoetal), delivery mode, placenta previa status, uterine leiomyoma status, preeclampsia/eclampsia status, gestational diabetes mellitus status and gestational anaemia status. Perinatal outcomes included perioperative blood conservation measures, postpartum estimated blood loss (EBL), postpartum length of stay and intensive care unit (ICU) admission length; routine laboratory tests included coagulation panels and complete blood counts. Additionally, all transfusion-related data, including the type and number of units of transfused blood products, were obtained from our institutional electronic transfusion medical records system.

Gestational anaemia was diagnosed using a haemoglobin (Hb) level cutoff of < 110 g/L across all trimesters per the WHO's 2025 consolidated PPH guidelines [19]. sPPH was defined as cumulative EBL > 1500 mL within 24 hours after delivery, corresponding to Stage 3 severe haemorrhage per the 2022 SOGC Clinical Practice Guideline No. 431 (Postpartum Haemorrhage and Haemorrhagic Shock) [20]. The institutional massive transfusion protocol was activated for patients with an EBL exceeding 1500 mL, accompanied by haemodynamic instability or shock, and all transfusion regimens for parturients followed the 2023 AABB International Clinical Guidelines for Red Blood Cell (RBC) Transfusion [21].

Outcome measures

The primary outcome was postpartum EBL at 2 and 24 hours. Regardless of delivery modality (vaginal or caesarean section), total postpartum EBL was quantified using a combined gravimetric method (weighing all blood-soaked drapes, gauze and absorbent pads after subtracting the baseline dry weight) and volumetric collection of aspirated blood per relevant clinical guidelines. Secondary outcomes included the incidence of sPPH, postpartum length of stay, transfer to the ICU, allogeneic blood transfusion, the decrease in peripartum Hb concentration, blood conservation measures, posttransfusion laboratory parameters, and adverse transfusion reactions. Adverse transfusion reactions included

febrile nonhaemolytic transfusion reactions, urticarial or anaphylactic allergic reactions, intravascular and extravascular haemolytic transfusion reactions, transfusion-associated circulatory overload, and citrate-induced hypocalcaemia secondary to rapid massive plasma transfusion.

Statistical analysis

Given that this was a retrospective study including all eligible parturients over a predefined timeframe, an a priori sample size calculation was not performed. However, a post hoc power calculation revealed that with our propensity score-matched (PSM) sample size of 215 matched pairs, the study had greater than 99% power to detect the observed between-group difference in the outcome of 2-hour postpartum EBL (1420.1 vs. 1178.5 mL) at an alpha level of 0.05. A two-sided P value of < 0.05 was considered to indicate statistical significance. Missing data were handled using multiple imputation with a chained equation. All the statistical analyses were performed using R statistical software (version 4.1.1; https://www.r-project.org/).

Categorical variables are presented as counts and frequencies, whereas continuous variables are expressed as either means (standard deviations [SDs]) or medians (with interquartile ranges [IQRs]), depending on the normality of the data distribution. A 1:1 greedy nearest-neighbour PSM algorithm was used to match women to balance baseline confounders across groups. All prespecified covariates, including baseline demographic characteristics, obstetric variables and antenatal laboratory indicators, were adjusted in the model, with a calliper width of 0.1 set to limit the maximum permissible difference in propensity scores between paired individuals. For intergroup comparisons of categorical data, the chi-square test or Fisher's exact test was applied accordingly; continuous variables were compared using the independent-samples t test or Wilcoxon (Mann–Whitney U) rank-sum test on the basis of data normality. Binary endpoints were assessed via conditional logistic regression to obtain odds ratios (ORs) and corresponding 95% confidence intervals (CIs); continuous outcomes were quantified using the mean difference (MD) and its 95% CI. Multiplicative interaction was assessed by incorporating product interaction terms of primary predictors into logistic regression models; regression coefficients and covariance matrices were calculated to verify the presence of multiplicative interaction effects.

Results

Baseline characteristics

From the initial cohort of 27680 parturients, 497 patients had a clinical diagnosis of PAS. After excluding 46 patients for various reasons, 451 patients met the eligibility criteria for the study. Following PSM of patients stratified by intrapartum TXA administration status, 215 matched case–control pairs were generated, consisting of 196 patients with an abnormally adherent placenta and 234 patients with an abnormally invasive placenta. The original cohort (n = 451) was stratified according to PAS severity into an abnormally adherent placenta group (n = 211) and an abnormally invasive placenta group (n = 240). Independent PSM was performed within each stratum, yielding 87 and 108 matched pairs, respectively (Fig. 1).

The post–matching covariate balance was assessed via standardized MDs (SMDs), with all variables presenting a satisfactory balance (SMD < 0.1). Prior to matching, significant intergroup differences were observed in baseline characteristics, including BMI, previous abortion history, myomectomy history, use of in vitro fertilization with embryo transfer (IVF-ET), placenta previa status, uterine leiomyoma status, hypertensive disorder complicating pregnancy (HDCP) status, activated partial thromboplastin time (APTT) and D-dimer level. After PSM, these covariates were well balanced between groups. All demographic and clinical characteristics before and after matching are presented in Table 1.

Table 1

Baseline characteristics of parturients in the control and TXA groups

Characteristics	Before PSM					After PSM				
	Total (N = 451)	TXA (N = 218)	Control (N = 233)	*P* value	SMD	Total (N = 430)	TXA (N = 215)	Control (N = 215)	*P* value	SMD
Age (years), mean (SD)	32.0 (5.1)	32.0 (4.8)	32.0 (5.3)	0.901	0.002	31.94 (5.0)	31.99 (4.8)	31.90 (5.3)	0.856	0.018
Age ≥ 35 years, n (%)	128 (28.4)	62 (28.4)	66 (28.3)	0.979	0.081	122 (21.9)	62 (28.8)	60 (27.9)	0.831	0.021
BMI ($kg.m^{-2}$), mean (SD)	27.4 (3.4)	27.6 (3.6)	27.2 (3.2)	0.169	0.135	27.41 (3.4)	27.6 (3.6)	27.3 (3.2)	0.362	0.088
Gravidity				0.817	0.022				0.473	0.069
Primiparous, n (%)	91 (20.2)	43 (19.7)	48 (20.6)			88 (20.5)	41 (19.1)	47 (21.9)		
Multiparous, n (%)	360 (79.8)	175 (80.3)	185 (79.4)			342 (79.5)	174 (80.9)	168 (78.1)		
Prior obstetric and intrauterine surgical history										
Previous caesarean delivery, n (%)	240 (53.2)	123 (56.4)	117 (50.2)	0.187	0.018	236 (54.9)	123 (57.2)	113 (52.6)	0.332	0.093
Abortion history, n (%)	288 (63.9)	137 (62.8)	151 (64.8)	0.665	0.227	270 (62.8)	136 (63.3)	134 (62.3)	0.842	0.018
Myomectomy history, n (%)	63 (14.0)	29 (13.3)	34 (14.6)	0.335	0.693	59 (13.7)	29 (13.5)	30 (14.0)	0.889	0.013
IVF-ET, n (%)	82 (18.2)	28 (12.8)	54 (23.2)	0.004	0.278	63 (14.7)	28 (13.0)	35 (16.3)	0.340	0.092
Current pregnancy				0.502	0.063				0.520	0.066
Singleton pregnancy, *n* (%)	427 (94.7)	208 (95.4)	219 (94.0)			407 (94.7)	202 (94.0)	205 (95.3)		
Multifoetal pregnancy, *n* (%)	24 (5.3)	10 (4.6)	14 (6.0)			23 (5.4)	13 (6.1)	10 (4.7)		
Mode of delivery				0.471	0.068				0.682	0.041
Caesarean delivery, *n* (%)	379 (84.0)	186 (85.3)	193 (82.8)			367 (85.4)	185 (86.1)	182 (84.7)		
Vaginal delivery, *n* (%)	72 (16.0)	32 (14.7)	40 (17.2)			63 (14.7)	30 (14.0)	33 (15.4)		
Uterine and placental abnormalities										
Placenta previa, *n* (%)	240 (53.2)	127 (58.3)	113 (48.5)	0.038	0.135	225 (52.3)	117 (54.4)	108 (50.2)	0.385	0.084
Uterine leiomyoma, n (%)	35 (7.8)	14 (6.4)	21 (9.0)	0.304	0.163	33 (7.7)	14 (6.5)	19 (8.8)	0.365	0.083
Antenatal comorbidities										
HDCP, *n* (%)	52 (11.5)	21 (9.6)	31 (13.3)	0.222	0.163	49 (11.4)	21 (9.8)	28 (13.0)	0.288	0.084
GDM, *n* (%)	134 (29.7)	66 (30.3)	68 (29.2)	0.800	0.063	127 (29.5)	66 (30.7)	61 (28.4)	0.597	0.050
Anaemia (Hb < 110 g/L), *n* (%)	193 (42.8)	95 (43.6)	98 (42.1)	0.745	0.085	188 (43.7)	95 (44.2)	93 (43.3)	0.846	0.018

Note: Data are reported as numbers (percentages), means (SDs) or medians (Q1–Q3).

Characteristics	Before PSM					After PSM				
	Total (N = 451)	TXA (N = 218)	Control (N = 233)	*P* value	SMD	Total (N = 430)	TXA (N = 215)	Control (N = 215)	*P* value	SMD
Antenatal laboratory parameters										
Hb (g/dL), mean (SD)	110.9 (16.2)	110.4 (15.8)	111.4 (16.6)	0.630	0.064	110.7 (15.9)	110.4 (15.8)	111.1 (16.0)	0.654	0.043
Hct (%), mean (SD)	33.1 (5.0)	33.1 (4.6)	33.2 (5.3)	0.987	0.016	33.1 (4.9)	33.1 (4.6)	33.1 (5.2)	0.956	0.006
PT, mean (SD)	11.6 (1.1)	11.6 (0.9)	11.8 (1.3)	0.001	0.037	11.6 (1.0)	11.6 (0.9)	11.6 (1.1)	0.803	0.027
APTT (s), mean (SD)	27.9 (4.3)	27.6 (3.6)	28.1 (4.6)	0.246	0.112	27.6 (3.1)	27.6 (2.7)	27.6 (3.5)	0.984	0.002
INR, mean (SD)	1.0 (0.2)	1.0 (0.3)	1.0 (0.2)	0.109	0.078	1.0 (0.3)	1.0 (0.3)	1.0 (0.3)	0.981	0.002
TT, mean (SD)	17.0 (2.7)	17.1 (2.4)	16.9 (2.9)	0.206	0.059	17.0 (2.2)	17.0 (2.3)	16.9 (2.0)	0.631	0.046
Fibrinogen level (g/L), mean (SD)	3.9 (1.1)	3.9 (1.0)	3.9 (1.2)	0.807	0.037	3.9 (1.1)	3.9 (1.0)	3.9 (1.2)	0.703	0.037
D-dimer level, median (Q1 ~ Q3)	2.8 (1.6–5.7)	2.5 (1.4–5.3)	3.2 (1.7–6.2)	0.715	0.416	2.7 (1.5–5.5)	2.6 (1.5–6.1)	2.8 (1.5–5.1)	0.719	0.098
Note: Data are reported as numbers (percentages), means (SDs) or medians (Q1–Q3).										

Treatment of established PPH

After 1:1 PSM, a total of 215 matched case–control pairs were included for subsequent statistical analysis (Table 2). Stratification by TXA administration status revealed that the primary outcomes, 2- and 24-hour postpartum EBL, were significantly lower in the TXA group than in the control group (1178.5 ± 105.4 mL vs. 1420.1 ± 109.9 mL, $P = 0.037$; 1228.5 ± 109.6 mL vs. 1577.5 ± 119.3 mL, $P = 0.020$). With respect to secondary outcomes, the risk of sPPH was significantly lower in the TXA group than in the control group (76 [35.4%] vs. 97 [45.1%]; OR 0.67, 95% CI, 0.45 to 0.98; $P = 0.039$). The mean decrease in Hb concentration was also significantly lower among women who received TXA (26.4 ± 19.9 vs. 31.4 ± 19.3 g/dL; $P = 0.007$). With respect to intrapartum blood conservation measures, arterial embolization (OR 0.54, 95% CI, 0.31 to 0.94; $P = 0.030$), intrauterine balloon tamponade (OR 0.45, 95% CI, 0.30 to 0.67; $P < 0.001$) and cell salvage (OR 0.29, 95% CI, 0.15 to 0.58; $P < 0.001$) were utilized significantly less frequently in the TXA group than in the control group. With respect to blood product transfusions, the rates of cryoprecipitate (OR 0.43, 95% CI, 0.23 to 0.80; $P = 0.007$) and platelet (OR 0.40, 95% CI, 0.17 to 0.93; $P = 0.029$) transfusions were significantly lower in the TXA group than in the control group. No significant between-group differences were noted in the use (proportion or volume) of RBCs or fresh frozen plasma (FFP).

Table 2.Comparison of the two groups after PSM in terms of blood conservation measures and allogeneic blood transfusion.

	Total (N=430)	TXA (N=215)	Control (N=215)	*OR/MD (95%CI)*	P value
Blood loss and haematological parameters					
2-h EBL (mL), means (SDs)	1299.3 (108.3)	1178.5 (105.4)	1420.1 (109.9)	−241.58 (−445.34, −37.83)	0.037
24-h EBL (mL), means (SDs)	1403.0 (115.3)	1228.5 (109.6)	1577.5 (119.3)	−349.07 (−566.59, −131.55)	0.020
24-h EBL (mL) (> 1 500 mL), n (%)	173 (40.2)	76 (35.4)	97 (45.1)	0.67 (0.45,0.98)	0.039
Peripartum decrease in Hb level (g/dL), means (SDs)	28.9 (19.7)	26.4 (19.9)	31.4 (19.3)	−5.07 (−8.78, −1.36)	0.007
Peripartum decrease in Hct level (%), means (SDs)	8.6 (5.9)	8.0 (5.9)	9.2 (6.0)	−1.18 (−2.30, −0.06)	0.039
Blood conservation measures					
Arterial embolization, n (%)	62 (14.4)	23 (10.7)	39 (18.1)	0.54 (0.31,0.94)	0.030
Hysterectomy, n (%)	39 (9.1)	15 (7.0)	24 (11.2)	1.68 (0.85,3.29)	0.131
Intrauterine balloon tamponade, n (%)	151 (35.1)	56 (26.1)	95 (44.2)	0.45 (0.30,0.67)	<0.001
Cell salvage, n (%)	48 (11.2)	12 (5.6)	36 (16.7)	0.29 (0.15,0.58)	<0.001
Volume for cell salvage (mL), medians (Q1–Q3)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.00 (0.00,0.00)	0.087
Allogeneic blood transfusion					
RBC transfusion, n (%)	324 (75.4)	156 (72.6)	168 (78.1)	0.74 (0.48,1.15)	0.179
Number of RBC units transfused, means (SDs)	3.40 (3.8)	3.17 (3.9)	3.64 (3.7)	−0.47 (−1.19,0.25)	0.201
FFP transfusion, n (%)	208 (48.4)	94 (43.7)	114 (53.0)	0.69 (0.47,1.01)	0.054
Number of FFP units transfused, means (SDs)	2.09 (3.2)	1.83 (3.2)	2.34 (3.1)	−0.52 (−1.11,0.08)	0.090
Cryoprecipitate transfusion, n (%)	50 (11.6)	16 (7.4)	34 (15.8)	0.43 (0.23,0.80)	0.007
Number of cryoprecipitate units transfused, medians (Q1–Q3)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.00 (0.00,0.00)	0.033
PLT transfusion, n (%)	27 (6.3)	8 (3.7)	19 (8.8)	0.40 (0.17,0.93)	0.029
Number of PLT units transfused, means (SDs)	0.2 (1.3)	0.2 (1.4)	0.2 (1.0)	−0.05 (−0.28,0.19)	0.699

Note: Data are reported as numbers (percentages), means (SDs) or medians (Q1–Q3).

Abbreviations: OR:odds ratio; MD: mean difference; 95% CI: 95% confidence interval; EBL: estimated blood loss; Hb: haemoglobin; Hct: haematocrit; RBC: red blood cell; FFP: fresh frozen plasma; PLT: platelet.

Maternal outcomes

According to the overall matched cohort analysis, the incidence of adverse transfusion reactions was significantly lower in the TXA group than in the control group (0 [0.0%] vs. 4 [1.9%]; *P* = 0.044); the TXA group also had a significantly higher discharge Hb level than the control group (median [IQR]: 101.0 [90.0–115.0] vs. 98.5 [89.0–107.0]; *P* = 0.041), as presented in Table 3. There were no significant between-group differences in the ICU admission rate, duration of postpartum ICU stay, postpartum length of stay, total length of hospital stay, or posttransfusion laboratory parameters. No maternal deaths occurred in either group during the study.

Table 3.Comparison of the two groups after PSM in terms of maternal outcomes.

	Total (N=430)	TXA (N=215)	Control (N=215)	*0R/MD (95%CI)*	P value
Postpartum outcomes					
Postpartum length of ICU stay (d), means (SDs)	0.6 (1.9)	0.5 (1.4)	0.7 (2.2)	−0.27 (−0.63,0.09)	0.137
Transfer to ICU, n (%)	60 (14.0)	28 (13.0)	32 (14.9)	0.86 (0.50,1.48)	0.578
Postpartum length of stay (d), means (SDs)	5.9 (3.3)	5.6 (2.9)	6.2 (3.7)	−0.61 (−1.24,0.01)	0.054
Total length of hospital stay (d), means (SDs)	13.8 (11.4)	14.0 (12.1)	13.5 (10.7)	0.51 (−1.65,2.67)	0.556
Mortality, n (%)	0 (0.0)	0 (0.0)	0 (0.0)	NA	NA
Adverse transfusion reactions, n (%)	4 (0.9)	0 (0.0)	4 (1.9)	0.00 (0.00, /)	0.044
Post-transfusion laboratory parameters					
Hb level (g/dL), means (SDs)	102.1 (16.3)	102.6 (17.4)	101.6 (15.2)	1.03 (−2.53,4.59)	0.569
Hct (%), means (SDs)	30.4 (4.8)	30.5 (5.0)	30.3 (4.6)	0.22 (−0.54,1.28)	0.676
PLT count (× 10^9/L), means (SDs)	141.7 (54.2)	142.9 (51.0)	139.7 (59.2)	3.20 (−7.53,13.93)	0.558
PT, means (SDs)	11.9 (1.4)	11.83 (1.0)	12.0 (1.8)	−0.15 (−0.42,0.12)	0.286
APTT (s), medians (Q1–Q3)	28.5 (26.8-30.6)	28.6 (26.9-30.7)	28.4 (26.7-30.6)	0.20 (0.15,0.32)	0.444
INR, medians (Q1–Q3)	1.0 (1.0-1.1)	1.0 (1.0-1.0)	1.0 (1.0-1.1)	0.00 (−0.08,0.05)	0.445
TT, means (SDs)	16.9 (3.1)	17.1 (2.5)	16.6 (3.)	0.44 (−0.14,1.02)	0.139
Fibrinogen (g/L) level, means (SDs)	3.8 (1.7)	3.7 (1.1)	3.9 (2.1)	−0.16 (−0.48,0.16)	0.329
D-Dimer level, medians (Q1–Q3)	4.27 (2.2-8.0)	4.1 (2.3-8.0)	4.4 (2.1-8.1)	−0.27 (−0.33,0.13)	0.740
Discharge haemoglobin level (g/dL), medians (Q1–Q3)	99.0 (90.0-110.0)	101.0 (90.0-115.0)	98.5 (89.0-107.0)	2.50 (1.00,8.00)	0.041

Note: Data are reported as numbers (percentages), means (SDs) or medians (Q1–Q3).

Abbreviations: PSM: propensity score matching; OR: odds ratio; MD: mean difference; 95% CI: 95% confidence interval; ICU: intensive care unit; Hb: haemoglobin; Hct: haematocrit; PLT: platelet; PT: prothrombin time; APTT: activated partial thromboplastin time; INR: international normalized ratio; TT: thrombin time.

Treatment of established PPH in patients with PAS of different grades

Patients were classified into abnormally adherent placenta and abnormally invasive placenta subgroups on the basis of the depth of placental invasion into the uterine myometrium. In both subgroups, 2- and 24-hour postpartum EBL were significantly lower in the TXA group than in the control group (2-hour loss [918.1 ± 594.3 mL vs. 1121.5 ± 688.6 mL, *P* = 0.038; 1400.9 ± 1246.7 mL vs. 1748.2 ± 1322.4 mL, *P* = 0.047]; 24-hour loss [963.5 ± 597.6 mL vs. 1253.8 ± 754.4 mL, *P* = 0.006; 1459.3 ± 1304.4 mL vs. 1901.9 ± 1456.4 mL, *P* = 0.023]). Similarly, within the abnormally invasive placenta subgroup, the control group had a higher incidence of 24-hour postpartum EBL > 1500 mL than the TXA group (43 [39.8%] vs. 60 [55.6%]; OR 0.53, 95% CI, 0.31 to 0.91; *P* = 0.021). Moreover, within the abnormally invasive placenta subgroup, TXA administration resulted in lower postpartum EBL, accompanied by a lower rate of blood conservation measures, as shown in Table 4. Although the incidence of hysterectomy was lower in the TXA group than in the control group (15 [13.9%] vs. 21 [19.4%]; OR = 0.67, 95% CI, 0.32 to 1.38; *P* = 0.273), no significant between-group difference was detected. With respect to the transfusion of blood products, compared with patients with an abnormally adherent placenta in the TXA group, those in the control group received more packed RBCs (PRBCs) and cryoprecipitate. In the abnormally invasive placenta subgroup, no significant intergroup differences were observed regarding blood-product transfusion.

There was no significant interaction between TXA administration and the above outcomes in the abnormally adherent placenta subgroup or the abnormally invasive placenta subgroup (*P* for interaction > 0.05; Table 4).

Table 4. Comparison of blood conservation measure and allogeneic blood transfusion rates among parturients with PAS of different grades

Variables	Abnormally adherent placenta				Abnormally invasive placenta				
	TXA (N=87)	Control (N=87)	*OR/MD (95% CI)*	*P* value	TXA (N=108)	Control (N=108)	*OR/MD (95% CI)*	*P* value	*P* for interaction
Blood loss and haematological parameters									
2-h EBL (mL), mean (SD)	918.1 (594.3)	1121.5 (688.6)	−203.45 (−395.82,−11.08)	0.038	1400.9 (1246.7)	1748.2 (1322.4)	−347.22 (−703.41,8.96)	0.047	0.311
24-h EBL (mL), mean (SD)	963.5 (597.6)	1253.8 (754.4)	−290.35 (−494.29,−86.40)	0.006	1459.3 (1304.4)	1901.9 (1456.4)	−442.59 (−824.43,−60.76)	0.023	0.361
24-h EBL (mL) (> 1500 mL), n (%)	26 (29.9)	29 (33.3)	0.85 (0.45,1.62)	0.625	43 (39.8)	60 (55.6)	0.53 (0.31,0.91)	0.021	0.265
Peripartum decrease in Hb level (g/dL), mean (SD)	24.5 (15.6)	28.4 (15.7)	−3.87 (−8.60,0.86)	0.108	29.2 (22.1)	30.5 (21.1)	1.30 (−7.28,4.68)	0.668	0.523
Peripartum decrease in Hct level (%), mean (SD)	7.3 (4.8)	8.6 (4.8)	−1.21 (−2.65,0.22)	0.098	8.7 (6.5)	9.0 (6.6)	−0.30 (−2.11,1.50)	0.741	0.213
Blood conservation measures									
Arterial embolization, n (%)	2 (2.3)	7 (8.0)	0.27 (0.05,1.33)	0.168	17 (15.7)	31 (28.7)	0.46 (0.24,0.90)	0.022	0.537
Hysterectomy, n (%)	0 (0.0)	1 (1.1)	0.00 (0.00)	0.500	15 (13.9)	21 (19.4)	0.67 (0.32,1.38)	0.273	0.997
Intrauterine balloon tamponade, n (%)	16 (18.4)	36 (41.4)	0.32 (0.16,0.64)	0.001	33 (30.6)	58 (53.7)	0.38 (0.22,0.66)	0.001	0.703
Cell salvage, n (%)	0 (0.0)	2 (2.3)	0.00 (0.00)	0.155	11 (10.2)	32 (29.6)	0.27 (0.13,0.57)	<0.001	0.997
Volume for cell salvage (mL), median (Q1~Q3)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	39.08 (−93.31,15.15)	0.156	97.2 (223.3)	160.7 (343.0)	−63.43 (−167.06,40.21)	0.229	0.702
Allogeneic blood transfusion									
RBC transfusion, n (%)	59 (67.8)	69 (79.3)	0.55 (0.28,1.09)	0.086	83 (76.9)	86 (79.6)	0.85 (0.44,1.62)	0.621	0.366
Number of RBC units transfused, mean (SD)	2.2 (2.0)	3.3 (2.6)	−1.06 (−1.74, −0.38)	0.003	4.1 (4.7)	4.2 (4.5)	−0.18 (−1.47,1.12)	0.789	0.267
FFP transfusion, n (%)	34 (39.1)	41 (47.1)	0.72 (0.39,1.31)	0.284	54 (50.0)	61 (56.5)	0.77 (0.45,1.32)	0.340	0.868
Number of FFP units transfused, median (Q1~Q3)	0.0 (0.0-2.0)	0.0 (0.0-4.0)	−0.64 (−1.32,0.03)	0.166	2.5 (3.9)	2.7 (3.2)	−0.23 (−1.22,0.76)	0.645	0.519
Cryoprecipitate transfusion, n (%)	1 (1.1)	7 (8.0)	0.13 (0.02,1.10)	0.030	14 (13.0)	22 (20.4)	0.58 (0.28,1.21)	0.144	0.196

Number of cryoprecipitate units transfused, median (Q1~Q3)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.00 (0.00,0.00)	0.032	1.1 (3.6)	1.6 (3.8)	−0.60 (−1.60,0.40)	0.236	0.759
PLT transfusion, n (%)	1 (1.1)	3 (3.4)	0.33 (0.03,3.19)	0.312	7 (6.5)	10 (9.3)	0.68 (0.25,1.86)	0.448	0.563
Number of PLT units transfused, median (Q1~Q3)	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.00 (0.00,0.00)	0.310	0.4 (2.0)	0.3 (1.0)	0.11 (−0.32,0.54)	0.611	0.553

Note: Data are reported as numbers (percentages), means (SDs) or medians (Q1–Q3).

Abbreviations: OR: odds ratio; MD: mean difference; 95% CI: 95% confidence interval; EBL: estimated blood loss; Hb: haemoglobin; Hct: haematocrit; RBC: red blood cell; FFP: fresh frozen plasma; PLT: platelet.

Maternal outcomes in patients with PAS of different grades

In the subgroup of patients with an abnormally adherent placenta, the postpartum length of stay was comparable between the TXA group and the control group (4.9 ± 2.0 vs. 5.0 ± 1.6 days; MD = −0.11; 95% CI, −0.89 to 0.57; *P* = 0.746). In contrast, TXA administration resulted in a significantly shorter postoperative length of stay among those with an abnormally invasive placenta (6.0 ± 2.1 vs. 6.9 ± 2.6 days; MD = −0.93; 95% CI, −1.49 to −0.29; *P* = 0.004). A significant interaction between the severity of the PAS score and TXA administration was identified for the postpartum length of stay (*P* for interaction = 0.041). There were no significant intergroup differences in the ICU admission rate, duration of postpartum ICU stay, total length of hospital stay, or posttransfusion laboratory parameters. No maternal deaths were reported in either study group (Table 5).

Table 5. Comparison of maternal outcomes among groups with PAS of different grades

Variables	Abnormally adherent placenta				Abnormally invasive placenta				
	TXA (N=87)	Control (N=87)	*OR/MD (95% CI)*	*P* value	TXA (N=108)	Control (N=108)	*OR/MD (95% CI)*	*P* value	*P* for interaction
Postpartum outcomes									
Postpartum length of ICU stay (d), mean (SD)	0.2 (0.9)	0.4 (1.6)	−0.17 (−0.57,0.22)	0.391	0.7 (1.8)	0.8 (2.5)	−0.16 (−1.69,2.41)	0.703	0.385
Transfer to ICU, n (%)	5 (5.7)	7 (8.0)	0.70 (0.21,2.29)	0.550	21 (19.4)	19 (17.6)	1.13 (0.57,2.25)	0.726	0.490
Postpartum length of stay (d), mean (SD)	4.9 (2.0)	5.0 (1.6)	−0.11 (−0.89,0.57)	0.746	6.0 (2.1)	6.9 (2.6)	−0.93 (−1.49, −0.29)	0.004	0.041
Total length of hospital stay (d), mean (SD)	9.1 (7.3)	10.5 (9.3)	−1.43 (−3.93,1.06)	0.259	16.4 (11.6)	16.8 (12.4)	−0.38 (−4.65,9.21)	0.517	0.628
Mortality, n (%)	0 (0.0)	0 (0.0)	NA	NA	0 (0.0)	0 (0.0)	NA	NA	NA
Adverse transfusion reactions, n (%)	1 (1.1)	3 (3.4)	0.00 (0.00)	0.081	0 (0.0)	1 (0.9)	0.00 (0.00)	0.316	1.000
Posttransfusion laboratory parameters									
Hb level (g/dL), mean (SD)	95.8 (17.3)	95.7 (14.1)	0.13 (−5.26,5.53)	0.961	107.0 (16.0)	104.9 (15.5)	2.28 (−4.65,9.21)	0.517	0.726
Hct (%), mean (SD)	28.7 (4.8)	28.4 (4.1)	0.30 (−1.24,1.83)	0.703	31.66 (4.8)	31.41 (4.9)	0.36 (−1.69,2.41)	0.730	0.934
PLT count (× 10^9/L), mean (SD)	139.5 (58.5)	133.9 (51.4)	5.60 (−9.84,21.04)	0.454	146.8 (59.6)	141.8 (51.0)	5.00 (−10.53,20.53)	0.552	0.380
PT, mean (SD)	11.9 (0.88)	11.7 (0.91)	0.19 (−0.05,0.44)	0.126	11.8 (1.03)	12.1 (2.36)	−0.29 (−0.77,0.19)	0.238	0.103
APTT (s), mean (SD)	29.2 (3.02)	28.8 (10.42)	0.44 (−0.48,1.37)	0.343	29.4 (4.52)	30.1 (9.23)	−0.72 (−2.67,1.22)	0.464	0.322
INR, mean (SD)	1.0 (0.1)	1.0 (0.1)	0.02 (−0.01,0.04)	0.157	1.0 (1.0-1.0)	1.0 (0.9-1.1)	−0.04 (−0.11,0.03)	0.249	0.160
TT, mean (SD)	16.4 (1.8)	16.4 (1.9)	0.07 (−0.44,0.58)	0.797	17.6 (2.9)	17.0 (4.7)	0.63 (−0.39,1.65)	0.224	0.365
Fibrinogen level (g/L), mean (SD)	3.9 (1.1)	3.7 (1.2)	0.24 (−0.08,0.56)	0.140	3.6 (2.9-4.4)	3.6 (3.2-4.6)	−0.03 (−0.18,0.26)	0.344	0.052
D-Dimer level, median (Q1~ Q3)	6.2 (9.5)	6.9 (13.3)	−0.66 (−4.00,2.69)	0.700	4.7 (2.5-8.4)	5.1 (3.2-11.8)	−0.44 (−3.38, −0.78)	0.058	0.145
Discharge haemoglobin level (g/dL), mean (SD)	98.4 (14.5)	95.9 (12.4)	2.51 (−1.27,2.70)	0.192	105.0 (14.9)	102.5 (13.2)	2.58 (−1.09,6.24)	0.168	0.981

Note: Data are reported as numbers (percentages), means (SDs) or medians (Q1–Q3).

Abbreviations: OR: odds ratio; MD: mean difference; 95% CI: 95% confidence interval; ICU: intensive care unit; Hb: haemoglobin; Hct: haematocrit; PLT: platelet; PT: prothrombin time; APTT: activated partial thromboplastin time; INR: international normalized ratio; TT: thrombin time.

Discussion

During the 10-year study period, the overall incidence of PAS disorders was 1.63% (451/27680), which was markedly higher than the 0.29% rate derived from a nationwide population-based analysis of U.S. deliveries performed by Matsuzaki et al.; however, it was consistent with the 1.20% overall PAS incidence documented in a 2018 Chinese cohort study led by Chan-Juan Zeng [22, 23]. With the sustained global increase in

caesarean delivery rates and changes in China's national fertility policies, the proportion of reproductive-age women with a history of caesarean delivery, including multiple repeat caesarean sections, who subsequently conceive has continued to increase, contributing to the year-on-year increase in the incidence of PAS disorders [24,25]. Additional predisposing clinical factors that increase the risk of PAS include multiparity, a uterine curettage history, myomectomy history, uterine artery embolization history, advanced maternal age, and assisted reproductive technology use [26,27]. Pregnancies complicated by PAS confer substantially elevated risks of sPPH, which critically threatens maternal safety in high-risk obstetric cohorts.

Our primary study findings revealed that intrapartum administration of TXA reduced postpartum EBL and the incidence of sPPH (OR 0.67, 95% CI 0.45 to 0.98; *P* = 0.039), with MDs of −241.58 mL and −349.07 mL at 2 and 24 hours, respectively. These findings were consistent with the core conclusions reported by Francis et al., who reported a 48.7% reduction in mean blood loss after TXA administration, corresponding to an MD of approximately −166.20 mL [28]. Findings from another trial align with our results: Among parturients at high risk of PPH, postpartum EBL was substantially lower among participants receiving TXA than among those receiving placebo (442.94 vs. 801.28 mL) [10].

Notably, an analysis of subgroups stratified by clinical PAS grade was performed to assess sPPH incidence. In the placental adherence subgroup, sPPH rates were similar between the control and TXA groups (29.9% [26/87] vs. 33.3% [29/87]). Conversely, in the high-risk abnormally invasive placenta subgroup, sPPH rates differed markedly between the control and TXA arms, with significant differences in OR and CI values (39.8% [43/108] vs. 55.6% [60/108]; OR = 0.53, 95% CI, 0.31 to 0.91; *P* = 0.021). TXA has stronger haemostatic effects in high-risk patients with invasive placental pathology. In contrast, a placebo-controlled randomized trial including exclusively low-risk women undergoing elective caesarean delivery reported comparable PPH rates of 7.3% and 8.0% in the TXA and placebo groups, respectively, which indicated that prophylactic administration of TXA did not significantly reduce the risk of PPH in uncomplicated obstetric patients [7]. This double-blind RCT of low-risk vaginal delivery patients revealed that compared with administration of placebo, prophylactic administration of TXA did not significantly decrease the overall incidence of PPH (P = 0.14) [29].

Interestingly, although patients in the control group exhibited substantially greater total postpartum EBL, peripartum fluctuations in Hb levels, changes in haematocrit level, and allogeneic RBC transfusion volume were not significantly greater in the control group than in the TXA group. These comparable haematologic and transfusion outcomes can be largely explained by the higher utilization rate of intraoperative cell salvage among patients with greater blood loss in the control group (5.6% [12/215] vs. 16.7% [36/215]). There was also a marked disparity in the utilization rate of intraoperative cell salvage between the abnormally adherent placenta subgroup and the abnormally invasive placenta subgroup. Washed autologous salvaged blood compensates for massive intraoperative haemorrhage in high-risk patients with an abnormally invasive placenta, preventing excessive demand for donor blood; this intervention maintains a stable native circulating volume and correspondingly decreases reliance on allogeneic transfusion. Similarly, cohort analyses have revealed that autologous salvaged blood reinfusion reduces maternal allogeneic transfusion demand by approximately half, with no severe catastrophic complications, including amniotic fluid embolism, documented throughout follow-up [30]. To date, obstetric cell salvage has been formally endorsed by numerous national anaesthesia societies and international multidisciplinary guidelines, with priority recommendations for individuals who are predicted to experience substantial intraoperative haemorrhage and elevated transfusion exposure [31]. A recent long-term retrospective observational study spanning 9 years at a single tertiary teaching hospital further confirmed the consistent tangible clinical benefits of perioperative cell salvage for peripartum patients with haemorrhagic risk [32].

Retrospective population-based registry data have indicated that up to 52% of patients with histologically confirmed PAS undergo emergent peripartum hysterectomy because of refractory massive obstetric haemorrhage [33]. In our present study, TXA treatment resulted in a decline in peripartum hysterectomy rates, but there was no significant difference observed between groups. These findings are consistent with those reported in previous studies. Whereas the WOMAN trial revealed that TXA administration did not prevent hysterectomy (risk ratio [RR] 1.02, 95% CI, 0.88 to 1.07), it substantially reduced the number of laparotomies performed for bleeding control [16]. Similarly, meta-analyses of the effects of prophylactic administration of TXA among women at high risk of PPH undergoing caesarean delivery, including patients with PAS, have reported lower blood loss and transfusion requirements; nevertheless, no significant reduction in the peripartum hysterectomy rate was observed despite favourable haemorrhage-related outcomes [34]. Similarly, a large multicentre RCT in patients with placenta previa demonstrated that TXA administration mitigated the risk of major PPH, with no detectable between-group difference in hysterectomy incidence [11]. For deeply invasive PAS, peripartum hysterectomy may be planned antenatally following multidisciplinary-team assessment, and the need for peripartum hysterectomy is not determined exclusively by intraoperative blood loss. This clinical scenario may mask the true treatment effect of TXA on the rate of hysterectomy.

Few previous studies have evaluated the association between TXA administration and postpartum length of stay among patients with PAS stratified by the depth of the abnormally invasive placenta. Tests for interaction revealed a significant interaction between the depth of the abnormally invasive placenta and TXA exposure (*P* for interaction = 0.041), indicating that the impact of TXA on postpartum hospitalization varied substantially according to the degree of placental infiltration. Within the subgroup of patients with an abnormally adherent placenta, no significant intergroup difference was detected in the postpartum length of stay between the TXA and control groups (4.9±2.0 vs. 5.0±1.6, *P* = 0.746), indicating that routine TXA administration failed to yield benefits in shortening the duration of postpartum hospitalization for patients

with shallow placental adherence. In contrast, among the subgroup of patients with a deeply infiltrating abnormally invasive placenta, TXA exposure significantly reduced the duration until delivery (6.0±2.1 vs. 6.9±2.6, *P* = 0.004). Collectively, these subgroup stratification findings confirm that the depth of the abnormally invasive placenta acts as a prominent effect modifier for the association between TXA use and postpartum hospitalization duration. TXA administration effectively controls the postpartum hospitalization duration exclusively in patients with deep placental invasion, which further explains the inconsistent overall association between TXA administration and postpartum length of stay observed in the whole PAS cohort. No significant intergroup disparity in total length of hospital stay was detected in our overall cohort, which is consistent with the latest trial conducted by Zhang Lizi et al. Their study of women with placenta previa who underwent caesarean delivery confirmed that prophylactic administration of TXA effectively reduced the rate of sPPH but did not significantly influence total hospitalization duration, with a mean hospital stay of 7 days in both the TXA and placebo arms [11]. Similarly, the large RCT reported by Pacheco LD et al. demonstrated that routine prophylactic administration of TXA for uncomplicated caesarean delivery failed to shorten the postoperative hospital stay, with a median length of stay of 3 days; this outcome is consistent with the findings observed within the subgroup of patients with a superficial abnormally adherent placenta in our present analysis [7].

Study limitations

Several limitations of this study should be acknowledged. First, this retrospective single-institution observational study has inherent methodological limitations. A limited sample size and a geographically confined patient pool increase the risk of unmeasured confounding bias that cannot be fully adjusted for via statistical models; accordingly, large-scale multicentre investigations are warranted to corroborate these single-centre findings and to increase generalizability. Second, PAS staging relies on subjective clinical judgement, which results in measurable interobserver discrepancies in disease grading among different clinicians. Third, no long-term maternal or neonatal follow-up data were obtained because of the retrospective design, precluding the evaluation of long-term endpoints, including neonatal neurodevelopment and maternal coagulation profiles.

Conclusions

In summary, this retrospective PSM study suggests that intrapartum TXA administration reduces postpartum EBL and the need for blood conservation measures among women with placenta accreta spectrum. Although TXA administration reduced bleeding in both the abnormally adherent placenta subgroup and the abnormally invasive placenta subgroup, its benefit in terms of shortening the duration of postpartum hospital stay was restricted to patients with abnormally invasive placenta, with a significant interaction observed between PAS severity and TXA treatment. These findings indicate that PAS severity acts as an effect modifier for the clinical benefits conferred by TXA. For high-risk patients with abnormally invasive placenta, intrapartum TXA may serve as an effective therapeutic measure to mitigate adverse haemorrhage-related maternal outcomes. Further large-scale multicentre investigations are warranted to validate these observations.

List of abbreviations

aOR: Adjusted Odds Ratio

APTT: Activated Partial Thromboplastin Time

BMI: Body Mass Index

CI: Confidence Interval

EBL: Estimated Blood Loss

FFP: Fresh Frozen Plasma

FIGO: International Federation of Gynaecology and Obstetrics

GDM: Gestational Diabetes Mellitus

Hb: Haemoglobin

Hct: Haematocrit

HDCP: Hypertensive Disorder Complicating Pregnancy

HDP: Hypertensive Disorders of Pregnancy

HIS: Hospital Information System

ICU: Intensive Care Unit

INR: International Normalized Ratio

IQRs: Interquartile Ranges

IVF-ET: In Vitro Fertilization with Embryo Transfer

LIS: Laboratory Information System

MD: Mean Difference

OR: Odds Ratio

PPH: Postpartum Haemorrhage

PSM: Propensity-Score Matching

RBC: Red Blood Cell

RCTs: Randomized Controlled Trials

SDs: Standard Deviations

SMDs: Standardized Mean Differences

sPPH: Severe Postpartum Haemorrhage

STROBE: Strengthening the Reporting of Observational Studies in Epidemiology

TT: Thrombin Time

TXA: Tranexamic Acid

WHO: World Health Organization

Declarations

Data availability

The complete datasets analysed herein are not publicly accessible owing to patient privacy protection and institutional administrative restrictions; access can be provided by the corresponding author to qualified researchers following reasonable formal requests.

Ethics approval and consent to participate

This retrospective study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Institutional Review Board and Medical Ethics Committee of Shanghai General Hospital (Ethics approval number: 2026/381). The committee waived the requirement for written informed consent from the participants due to the retrospective nature of the study, which involved the analysis of de-identified data from electronic medical records.

Consent for publication

Not applicable. This manuscript does not contain any individual person's data in any form (including any individual details, images, or videos).

Availability of data and materials

The datasets used and/or analysed during the current study are not publicly available due to patient privacy and hospital regulations but are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

SOURCES OF FUNDING:

This work was supported by WeiGao Science Foundation of Chinese Society of Blood Transfusion (CSBT-WG-2024-08). Clinical Research Innovation Plan of Shanghai General Hospital (CCTR-2025C47, CCTR-2026C87). Social Development (Medical and Health) Program of Science and Technology Development Fund of Qingpu District, Shanghai (Grant No. QKY2025-80)

Authors' contributions

H.D. designed and conceived this project; S.C. and N.P. performed experiments and generated data; L.W. and K.Z. analysed and interpreted data; X.W. and J.Z. made suggestions for this project; H.D. wrote the draft; J.Z. and S.W. revised and finalised the manuscript; All authors contributed to and approved the manuscript. Huimin Deng and Kai Zhang contributed equally to this work.

Acknowledgements

Not applicable.

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Figures

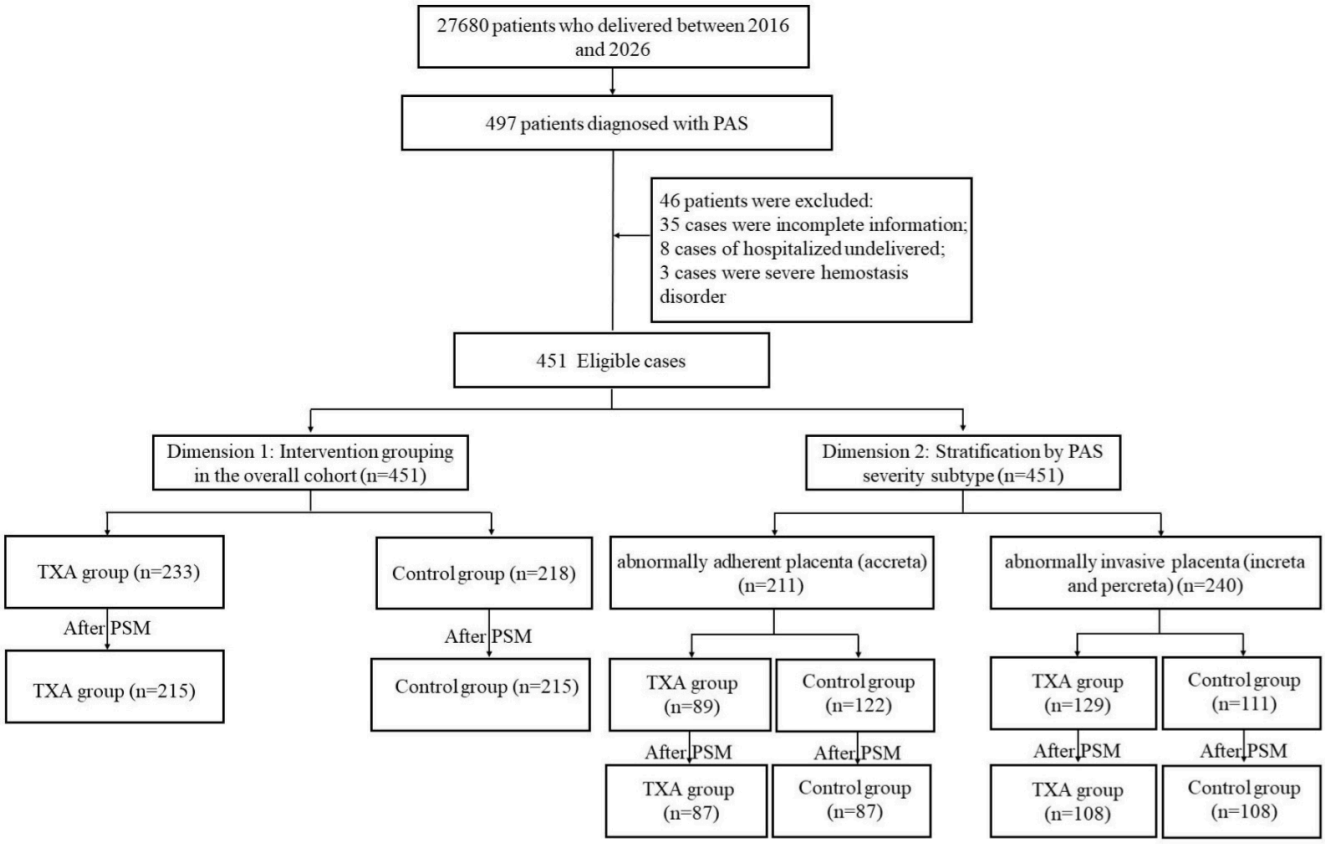


Figure 1

Research flow chart. PAS: placenta accreta spectrum; TXA: tranexamic acid; PSM: propensity score matching.