



Quantitative assessment of active bleeding on contrast-enhanced computed tomography in primary postpartum hemorrhage

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PURPOSE

This study aimed to evaluate whether computed tomography (CT)-derived extravasation rate from dynamic contrast-enhanced CT is associated with invasive hemostatic intervention and clinical severity in primary postpartum hemorrhage.

METHODS

This retrospective single-center study included 36 patients with active intrauterine arterial bleeding on contrast-enhanced CT among 135 patients who underwent CT for primary postpartum hemorrhage between January 2020 and December 2025. The extravasation rate was calculated as the increase in extravasation volume from arterial to delayed phase divided by the interphase interval. Associations with hysterectomy and transcatheter arterial embolization (TAE), and correlations with clinical variables, were assessed.

RESULTS

The median extravasation rate was 3.7 mL/min. In the overall cohort, the extravasation rate was higher in patients who underwent hysterectomy than in those who did not, although the difference was not statistically significant (21.71 vs. 3.37 mL/min, $P = 0.083$). After exclusion of laparotomy cases, the extravasation rate tended to be higher in patients who underwent TAE than in those managed conservatively (4.07 vs. 0.90 mL/min, $P = 0.075$). Exploratory receiver operating characteristic curve analyses yielded areas under the curve of 0.705 and 0.764 for hysterectomy and TAE, respectively, although the corresponding confidence intervals were wide. The extravasation rate showed weak negative correlations with hemoglobin level ($\rho = -0.356$, $P = 0.033$) and hematocrit ($\rho = -0.343$, $P = 0.040$), whereas the correlations with systolic and diastolic blood pressure did not reach statistical significance.

CONCLUSION

CT-derived extravasation rate showed exploratory associations with hemorrhagic severity and invasive hemostatic intervention. These preliminary findings require validation in larger studies using standardized CT acquisition and measurement protocols.

CLINICAL SIGNIFICANCE

Quantitative assessment of contrast extravasation on dynamic CT provides a continuous imaging measure beyond the binary presence or absence of active bleeding.

KEYWORDS

Postpartum hemorrhage, contrast-enhanced CT, contrast extravasation, bleeding rate, transcatheter arterial embolization

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Severe postpartum hemorrhage remains one of the leading causes of maternal mortality, and timely, appropriate hemostatic intervention is essential to prevent maternal morbidity and death. In contemporary obstetric practice, the burden of severe postpartum hemorrhage is occurring against a background of demographic and obstetric changes, including advanced maternal age, increasing use of assisted reproductive technology, and a substantial cesarean delivery burden, all of which have been associated with greater hemorrhagic risk.¹

Contrast-enhanced computed tomography (CT) has emerged as a valuable imaging modality for identifying active arterial bleeding in severe postpartum hemorrhage. In particular, arterial contrast extravasation within the uterine cavity on dynamic CT has recently been recognized as a clinically important imaging finding associated with treatment-resistant hemorrhage. In a multicenter Japanese case-control study, patients with this CT finding had a markedly higher likelihood of requiring embolization than those without extravasation (86.2% vs. 28.7%), together with greater blood loss and transfusion requirements.² These findings suggest that the presence of active bleeding on contrast-enhanced CT may serve as an important marker when considering escalation to transcatheter arterial embolization (TAE).

TAE is a well-established and potentially life-saving treatment for severe postpartum hemorrhage, providing rapid hemorrhage control while preserving the uterus and future fertility and thereby avoiding hysterectomy in many patients.³ Nevertheless, although TAE is generally considered an effective and uterus-preserving procedure, it is not entirely without risk. Previous studies have reported associations between uterine

artery embolization for postpartum hemorrhage and adverse outcomes in subsequent pregnancies, including recurrent postpartum hemorrhage, placental disorders, and preterm birth.⁴⁻⁶ Therefore, accurately identifying patients who are most likely to benefit from TAE is important to ensure timely intervention while avoiding unnecessary invasive procedures.

Currently, decision-making based on contrast-enhanced CT is largely dichotomous, relying on the presence or absence of active extravasation. However, this binary framework may be insufficient for individualized treatment selection. In clinical practice, some patients with CT-demonstrable active bleeding ultimately fail conservative management and require delayed TAE, whereas others show apparent hemodynamic improvement by the time the procedure is initiated. This discrepancy suggests that the amount of active bleeding, rather than its mere presence, may be a more clinically meaningful determinant of the need for invasive hemostatic intervention.

The purpose of this study is to evaluate whether the CT-derived extravasation rate is associated with invasive hemostatic interventions and clinical severity in patients with primary postpartum hemorrhage.

Methods

Study design and patient population

This retrospective single-center study was conducted at Yokohama City University Medical Center and was approved by the

Institutional Review Board of Yokohama City University on December 17, 2025 (approval number: F251200004). The requirement for written informed consent was waived, and the study was conducted in accordance with the Declaration of Helsinki.

At the institution, interventional radiologists provided 24-hour, 7-day-a-week coverage for both contrast-enhanced CT interpretation and TAE, upon request by obstetricians. Consecutive patients who underwent contrast-enhanced CT for primary postpartum hemorrhage between January 2020 and December 2025 were reviewed. Among 135 patients who underwent contrast-enhanced CT during the study period, 36 patients with intrauterine arterial active bleeding were included in the final analysis (Figure 1). Active bleeding was defined as contrast extravasation into the uterine cavity on arterial-phase CT with subsequent spread on delayed-phase imaging, regardless of the amount of extravasation.² The presence of active bleeding was assessed by a board-certified radiologist. Cases without definite arterial-phase intrauterine contrast extravasation or without subsequent spread of contrast material on CT images were excluded.

The median age of the 36 patients was 37.0 years [interquartile range (IQR): 32.5–39.0 years], and 17 patients (47.2%) were primiparous. Most patients (88.9%) were referred from other hospitals. The patient characteristics of the hysterectomy group (n = 8), TAE group (n = 22), and conservative management group (n = 5) are shown in Table 1. One additional patient underwent uterine

Main points

- Computed tomography (CT)-derived extravasation rate provides a quantitative assessment of active intrauterine bleeding on dynamic contrast-enhanced CT in patients with primary postpartum hemorrhage.
- Higher CT-derived extravasation rates tended to be observed in patients undergoing more invasive hemostatic interventions, including hysterectomy and transcatheter arterial embolization.
- CT-derived extravasation rate showed weak negative correlations with hemoglobin level and hematocrit, providing preliminary evidence of an association with hemorrhagic severity.

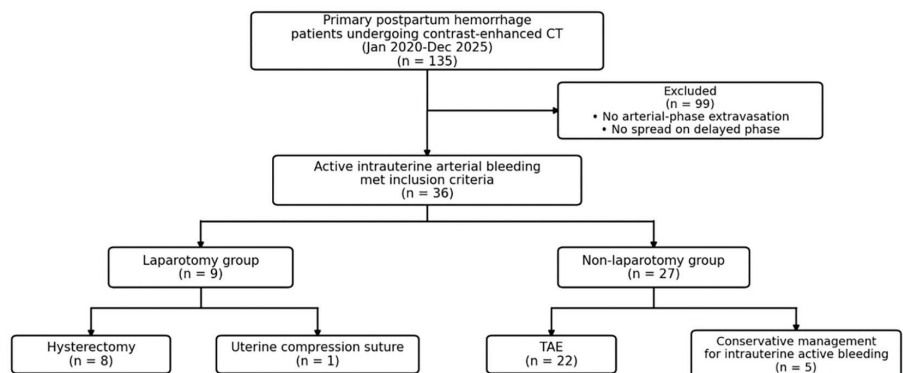


Figure 1. Flow diagram of patient selection. A total of 135 patients with primary postpartum hemorrhage who underwent contrast-enhanced computed tomography between January 2020 and December 2025 were reviewed. Patients without arterial-phase contrast extravasation or without subsequent spread on delayed-phase imaging were excluded. Finally, 36 patients with active intrauterine arterial bleeding were included in the analysis. The study cohort was subsequently divided into a laparotomy group (n = 9) and a non-laparotomy group (n = 27). The laparotomy group consisted of patients who underwent hysterectomy (n = 8) or uterine compression suture (n = 1), whereas the non-laparotomy group consisted of patients treated with TAE (n = 22) or conservative management (n = 5). TAE, transcatheter arterial embolization; CT, computed tomography.

Table 1. Baseline characteristics of patients managed conservatively, patients who underwent TAE, and patients who underwent hysterectomy

Variables	Conservative management (n = 5)	TAE (n = 22)	Hysterectomy (n = 8)	P value
Maternal age (years)	36.0 (31.0–38.5)	37.0 (33.5–40.0)	36.5 (36.0–38.8)	0.707
Primipara, n (%)	2 (40.0%)	11 (50.0%)	3 (37.5%)	0.889
Referral from other hospital, n (%)	4 (80.0%)	19 (86.4%)	8 (100.0%)	0.501
CT-derived extravasation rate (mL/min)	0.90 (0.30–4.39)	4.07 (1.48–8.57)	21.71 (1.45–39.0)	0.054
Time from delivery to CT scan (min)	277.0 (148.5–453.5)	242.5 (168.5–427.0)	254.0 (215.0–368.3)	0.943
Transfused blood products				
RBC (units)	10.0 (4.0–14.0)	12.0 (6.0–17.0)	24.0 (17.0–37.5)	0.004*
FFP (units)	6.0 (0.0–19.0)	12.0 (6.0–14.0)	25.0 (20.5–36.0)	0.009*
Platelets (units)	0.0 (0.0–20.0)	0.0 (0.0–20.0)	20.0 (20.0–20.0)	0.022*
Fibrinogen concentrates (g)	3.0 (0.0–4.5)	3.0 (2.25–3.0)	4.5 (3.0–6.0)	0.261
Vital signs				
Heart rate (bpm)	95.0 (61.0–117.5)	102.5 (92.0–110.3)	141.5 (105.0–149.5)	0.037*
Systolic BP (mmHg)	145.0 (120.0–155.5)	108.0 (90.3–126.5)	104.0 (87.8–154.3)	0.083
Diastolic BP (mmHg)	96.0 (56.0–136.5)	63.5 (47.5–70.3)	57.5 (38.5–106.3)	0.227
Laboratory data				
WBC count	14.06 (10.69–24.13)	13.72 (11.56–16.17)	11.91 (8.01–18.20)	0.485
Hemoglobin (g/dL)	8.80 (6.40–9.90)	7.15 (6.10–8.28)	4.75 (3.35–6.53)	0.006*
Hematocrit (%)	26.50 (19.70–30.10)	21.55 (18.05–23.48)	14.35 (10.88–19.23)	0.003*
Platelet count	125.0 (73.0–225.5)	126.5 (80.8–175.3)	91.0 (59.3–124.3)	0.321
APTT (sec)	30.40 (29.50–53.05)	38.05 (29.05–45.95)	50.35 (45.90–101.10)	0.007*
PT (INR)	1.04 (0.97–1.48)	1.09 (0.95–1.31)	1.37 (1.32–1.58)	0.044*
Fibrinogen (mg/dL)	235.5 (118.0–321.5)	170.5 (133.0–205.3)	97.5 (78.0–141.0)	0.071
Creatinine (mg/dL)	0.45 (0.40–0.79)	0.59 (0.41–0.68)	0.66 (0.50–0.98)	0.416

* $P < 0.05$ indicates statistical significance. Continuous variables were compared using the Kruskal–Wallis test, and categorical variables were compared using the Fisher–Freeman–Halton exact test. One patient who underwent open uterine compression suturing without hysterectomy was excluded from this descriptive three-group summary because the treatment did not correspond to conservative management, TAE, or hysterectomy. CT, computed tomography; Q1, 25th percentile; Q3, 75th percentile; TAE, transcatheter arterial embolization; RBC, red blood cell; FFP, fresh frozen plasma; BP, blood pressure; WBC, white blood cell; APTT, activated partial thromboplastin time; PT (INR), prothrombin time (international normalized ratio).

compression suture via laparotomy without hysterectomy; this patient was 30 years old and primiparous. Regarding management at the time of CT, intrauterine balloon tamponade had been performed in 6 patients (16.7%). Resuscitative endovascular balloon occlusion of the aorta catheters had been placed in 3 patients (8.3%); however, no patients had balloon inflation at the time of CT.

Computed tomography data acquisition

Dynamic contrast-enhanced CT was performed using a multidetector-row CT scanner (Aquilion Prime; Canon Medical Systems, Otawara, Japan). The imaging protocol included a tube voltage of 120 kVp, with tube current automatically modulated using an automatic exposure control system. Images were reconstructed with a slice thickness of 2 mm using a standard soft tissue kernel (FC03). Bolus monitoring was performed using Real Prep (Canon Medical Systems), with a region of interest placed in the abdominal

aorta at the level of the celiac artery. Aortic enhancement was visually monitored, and arterial-phase acquisition was manually initiated by a radiologic technologist when aortic attenuation reached approximately 250–300 Hounsfield unit (HU); attainment of this attenuation level did not automatically trigger image acquisition. The contrast dose was adjusted according to body weight to provide a total iodine dose of 450 mgI/kg. Non-ionic iodinated contrast media with iodine concentrations ranging from 300 to 370 mgI/mL were used. Contrast material was generally administered over approximately 30 seconds, with the injection rate calculated from the contrast volume and planned injection duration. A saline flush was not routinely used. Dynamic contrast-enhanced CT consisted of an arterial phase and a delayed phase. Delayed-phase acquisition was manually initiated with reference to the scanner timer. The median interval between the arterial- and delayed-phase acquisitions was 87.5

seconds (IQR: 71.8–95.3 seconds). The actual time interval between the two acquisitions was used to calculate the CT-derived extravasation rate for each patient.

Quantitative assessment of contrast extravasation

Quantitative image analysis was performed using commercially available software (VINCENT; Fujifilm, Tokyo, Japan) (Figure 2). All quantitative measurements were performed by a single board-certified radiologist with 10 years of experience in diagnostic radiology, who was blinded to the final treatment outcomes at the time of image analysis. For each patient, the radiologist manually defined a volume of interest (VOI) to include the entire area of contrast extravasation while excluding adjacent normal structures, such as the uterine wall, as much as possible. Within the VOI, regions with attenuation values of ≥ 80 HU were extracted as contrast material. No validated attenua-

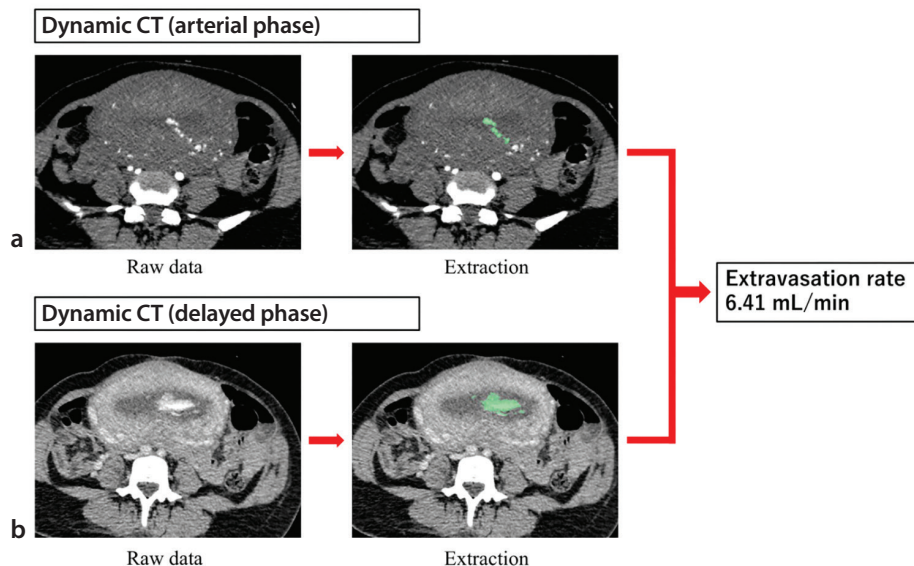


Figure 2. Quantitative assessment of active bleeding using dynamic contrast-enhanced computed tomography. Extravasation of contrast material within the uterine cavity was segmented (green area) on the arterial phase (a) and delayed phase (b). The quantified extravasation volumes were 1.20 mL on the arterial phase and 11.88 mL on the delayed phase. Given a time interval of 100 seconds between the two phases, the extravasation rate was calculated as 6.41 mL/min. This patient did not require transcatheter arterial embolization or hysterectomy. CT, computed tomography.

tion threshold has been established for intrauterine contrast extravasation in postpartum hemorrhage. The 80-HU threshold was selected a priori as a relatively inclusive operational threshold to reduce the risk of excluding diluted, lower-attenuation portions of contrast extravasation. The automatically extracted regions were visually reviewed on each image, and portions corresponding to the contrast-enhanced uterine wall, pelvic vessels, and other non-extravasated high-attenuation structures were manually excluded. This approach was based on the practical consideration that manual removal of falsely included regions were more feasible than manual addition of omitted portions of extravasation. Manual correction was applied when necessary to exclude non-hemorrhagic structures. Quantitative assessment was performed on both arterial-phase and delayed-phase images. The extravasation rate (mL/min) was calculated as the difference in extravasation volume between the delayed and arterial phases divided by the time interval between the two acquisitions, according to the following formula:

Extravasation rate (mL/min) = (extravasation volume on delayed-phase CT – extravasation volume on arterial-phase CT)/time interval between acquisitions (min)

Clinical variables and outcomes

Vital signs and laboratory data obtained upon arrival at the institution were used for

transferred patients, whereas the most recent values obtained immediately before CT were used for patients who developed postpartum hemorrhage at the institution.

The index test was the CT-derived extravasation rate calculated from dynamic contrast-enhanced CT. The reference outcomes were hysterectomy and TAE, determined from the medical records. Hysterectomy and TAE were used as clinically relevant reference outcomes for invasive hemostatic intervention.

Clinical data were retrospectively extracted from the medical records. The collected variables included patient demographics, laboratory data, transfusion requirements, treatment course, and clinical outcomes. Laboratory variables included hemoglobin level and coagulation-related parameters, such as fibrinogen level, platelet count, prothrombin time (international normalized ratio) [PT (INR)], and activated partial thromboplastin time (APTT). Transfusion data included red blood cell (RBC), fresh frozen plasma (FFP), and platelet transfusions, as well as administration of fibrinogen products.

The clinical outcomes of interest were hysterectomy, TAE, and other invasive hemostatic interventions. Associations between CT-derived extravasation rate and these clinical outcomes were evaluated. In addition, the relationship between extravasation rate and clinical severity indicators, including laboratory abnormalities and transfusion volume,

was assessed. The patient who underwent uterine compression suture via laparotomy without hysterectomy was classified as not having undergone hysterectomy in the hysterectomy analysis, but was excluded from the TAE analysis because the procedure required laparotomy and did not represent a non-surgical management pathway.

Statistical analysis

Continuous variables are presented as median (IQR) and categorical variables are presented as counts and percentages. A hierarchical analytical framework was used to evaluate the clinical relevance of CT-derived extravasation rate. In Step 1, the association between extravasation rate and hysterectomy was assessed in the overall cohort, given that hysterectomy represents the most definitive invasive hemostatic intervention. In Step 2, patients who underwent laparotomy, including hysterectomy or uterine compression suture via laparotomy, were excluded, and the association between extravasation rate and TAE was evaluated among the remaining patients. Comparisons between groups were performed using the Mann-Whitney U test for continuous variables. In addition to the prespecified hierarchical analyses, an exploratory comparison was performed among the conservative management, TAE, and hysterectomy groups. Continuous variables were compared using the Kruskal-Wallis test, and categorical variables were compared using the Fisher-Freeman-Halton exact test. The patient who underwent uterine compression suturing without hysterectomy was excluded from this three-group analysis because the treatment did not correspond to any of the three predefined categories. The relationships between extravasation rate and continuous clinical variables, including laboratory values and transfusion volume, were assessed using Spearman rank correlation analysis. Exploratory receiver operating characteristic (ROC) curve analyses were performed to assess the ability of the CT-derived extravasation rate to discriminate between patients who did and did not undergo hysterectomy and, in the non-laparotomy group, between patients who underwent TAE and those managed conservatively. The exploratory cut-off value was selected by maximizing the Youden index (sensitivity + specificity – 1). Area under the ROC curves (AUCs) and their 95% confidence intervals (CIs) were estimated using the non-parametric method implemented in the SPSS software package (version 31; IBM Corp., Armonk, NY, USA). Exact binomial 95%

CI for sensitivity and specificity were calculated using the Clopper–Pearson method. Positive and negative predictive values were also calculated. All statistical analyses were performed using SPSS. All statistical tests were two-sided, and a P value of < 0.05 was considered statistically significant.

Results

The delayed-phase segmented extravasation volume was greater than the arterial-phase volume in all 36 patients. The median CT-derived extravasation rate was 3.7 mL/min (IQR: 1.3–14.7 mL/min), and the median time from delivery to CT scan was 249.0 min (IQR: 175.0–379.8 min). The median CT-derived extravasation rates were 0.90 mL/min (IQR: 0.30–4.39 mL/min) in the conservative management group, 4.07 mL/min (IQR: 1.48–8.57 mL/min) in the TAE group, and 21.71 mL/min (IQR: 1.45–39.0 mL/min) in the hysterectomy group (Table 1 and Figure 3). Although the median values were numerically higher across the conservative management, TAE, and hysterectomy groups, the exploratory overall three-group comparison did not reach statistical significance ($P = 0.054$). Because the overall comparison was not statistically significant, post-hoc pairwise comparisons were not performed.

The extravasation rate in the patient who underwent uterine compression suture was

1.4 mL/min. In 1 of the 22 patients treated with TAE, conservative management was initially attempted; however, because hemostasis could not be achieved, TAE was ultimately performed 12 hours after CT (CT-derived extravasation rate: 8.9 mL/min). Among patients who underwent laparotomy or TAE, no additional hemostatic interventions were required after the initial procedure. There were no in-hospital deaths among the study population.

Association between computed tomography-derived extravasation rate and hysterectomy

In the overall cohort, the CT-derived extravasation rate was higher in patients who underwent hysterectomy than in those who did not (21.71 vs. 3.37 mL/min, $P = 0.083$). In the binary comparison between patients with and without hysterectomy, patients who underwent hysterectomy required significantly greater transfusion support, including RBCs (24.0 vs. 12.0 units, $P = 0.001$), FFP (25.0 vs. 12.0 units, $P = 0.003$), and platelets (20.0 vs. 0.0 units, $P = 0.017$). They also had a higher heart rate (141.5 vs. 102.5 bpm, $P = 0.012$), lower hemoglobin level (4.8 vs. 7.3 g/dL, $P = 0.002$), lower hematocrit (14.4% vs. 21.9%, $P = 0.001$), prolonged APTT (50.4 vs. 37.2 sec, $P = 0.001$), higher PT (INR) (1.37 vs. 1.09, $P = 0.013$), and lower fibrinogen level (97.5 vs. 170.5 mg/dL, $P = 0.015$).

Association between computed tomography-derived extravasation rate and transcatheter arterial embolization vs. conservative management in the non-laparotomy group

In the non-laparotomy group, the CT-derived extravasation rate tended to be higher in patients who underwent TAE than in those managed conservatively (4.07 vs. 0.90 mL/min, $P = 0.075$). Among the evaluated clinical variables, systolic blood pressure was significantly lower in the TAE group (108 vs. 145 mmHg, $P = 0.016$).

Correlation of clinical findings and computed tomography extravasation rate

The CT-derived extravasation rate showed weak negative correlations with hemoglobin level ($\rho = -0.356$, $P = 0.033$) and hematocrit ($\rho = -0.343$, $P = 0.040$). Inverse correlations were also observed with systolic blood pressure ($\rho = -0.302$, $P = 0.073$) and diastolic blood pressure ($\rho = -0.293$, $P = 0.083$), although these did not reach statistical significance (Table 2). No statistically significant correlations were observed between the CT-derived extravasation rate and transfusion requirements, including RBC transfusion ($\rho = 0.191$, $P = 0.264$), FFP transfusion ($\rho = 0.072$, $P = 0.676$), or platelet transfusion ($\rho = -0.098$, $P = 0.568$).

Exploratory receiver operating characteristic curve analyses according to hysterectomy and transcatheter arterial embolization status

Exploratory ROC curve analysis showed that the CT-derived extravasation rate had an AUC of 0.705 (95% CI: 0.464–0.947) for discriminating between patients who did and did not undergo hysterectomy (Figure 4). The cut-off value selected by maximizing the Youden index was 12.8 mL/min, yielding a sensitivity of 62.5% (5/8; 95% CI: 24.5%–91.5%) and a specificity of 85.7% (24/28; 95% CI: 67.3%–96.0%). The positive and negative predictive values were 55.6% (5/9) and 88.9% (24/27), respectively. In the non-laparotomy group, exploratory ROC curve analysis showed that the CT-derived extravasation rate had an AUC of 0.764 (95% CI: 0.536–0.992) for discriminating between patients who underwent TAE and those managed conservatively (Figure 5). The cut-off value selected by maximizing the Youden index was 2.5 mL/min, yielding a sensitivity of 68.2% (15/22; 95% CI: 45.1%–86.1%) and a specificity of 80.0% (4/5; 95% CI: 28.4%–99.5%). The positive and negative predictive values were 93.8% (15/16) and

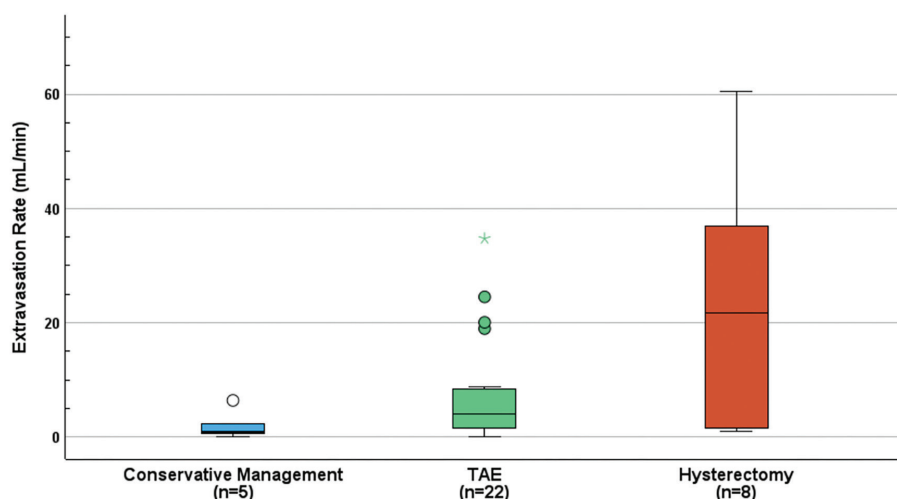


Figure 3. Distribution of computed tomography (CT)-derived extravasation rate according to final hemostatic treatment category. Box-and-whisker plot showing the distribution of CT-derived extravasation rate among patients managed conservatively, those who underwent transcatheter arterial embolization (TAE), and those who underwent hysterectomy. Boxes indicate the interquartile range (IQR), horizontal lines indicate medians, and whiskers indicate the range excluding outliers. Circles indicate values > 1.5 times the IQR from the box, and asterisks indicate values > 3 times the IQR from the box. One patient who underwent open uterine compression suturing without hysterectomy was excluded from this three-group plot because the treatment did not correspond to conservative management, TAE, or hysterectomy.

Table 2. Spearman's rank correlation coefficients between CT-derived extravasation rate and clinical findings

Variables	Correlation coefficient (ρ)	P value
Vital signs		
Systolic blood pressure (mmHg)	−0.302	0.073
Diastolic blood pressure (mmHg)	−0.293	0.083
Heart rate (bpm)	0.134	0.437
Laboratory findings		
WBC count ($\times 10^3/\mu\text{L}$)	0.061	0.723
Hemoglobin (g/dL)	−0.356*	0.033
Hematocrit (%)	−0.343*	0.040
Platelet count ($\times 10^3/\mu\text{L}$)	0.001	0.993
APTT (sec)	−0.001	0.996
PT (INR)	−0.102	0.555
Fibrinogen (mg/dL)	−0.043	0.803
Creatinine (mg/dL)	0.144	0.402
Transfused blood products		
RBC (units)	0.191	0.264
FFP (units)	0.072	0.676
Platelets (units)	−0.098	0.568
Fibrinogen concentrates (g)	0.167	0.330
Others		
Age (years)	−0.033	0.847
Time from delivery to CT scan (min)	−0.034	0.845

* $P < 0.05$ indicates statistical significance (Spearman's rank correlation test, two-tailed). CT, computed tomography; ρ , Spearman's rank correlation coefficient; WBC, white blood cell; APTT, activated partial thromboplastin time; PT (INR), prothrombin time (international normalized ratio); RBC, red blood cell; FFP, fresh frozen plasma.

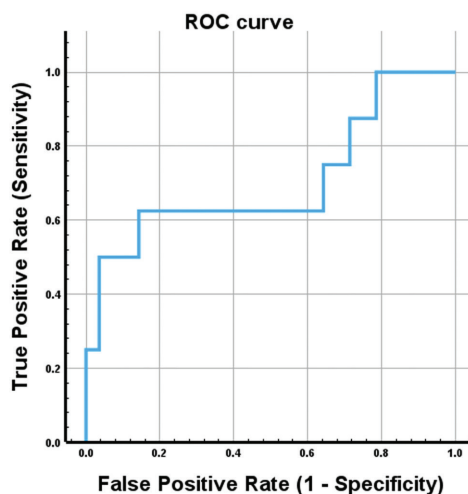


Figure 4. Receiver operating characteristic (ROC) curve according to hysterectomy status. This shows the ROC curve of the computed tomography-derived extravasation rate for discriminating between patients who did and did not undergo hysterectomy. The area under the ROC curve was 0.705. The cut-off value selected by maximizing the Youden index was 12.8 mL/min, yielding a sensitivity of 62.5% and a specificity of 85.7%.

36.4% (4/11), respectively. At the exploratory cut-off value of 7.0 mL/min, the sensitivity was 36.4% (8/22; 95% CI: 17.2%–59.3%) and the specificity was 100.0% (5/5; 95% CI: 47.8%–100.0%).

Discussion

The principal contribution of this study was the quantitative characterization of active intrauterine contrast extravasation on

dynamic CT. Although the observation that greater contrast extravasation tended to be associated with more invasive hemostatic treatment is clinically intuitive, the quantitative values showed a broad distribution among patients with active bleeding. This finding indicates that the binary presence or absence of active extravasation encompasses a wide range of CT-detectable bleeding activity. Therefore, the significance of the present study lies primarily in describing active extravasation as a continuous quantitative imaging parameter rather than in demonstrating the expected ordering of treatment categories.

Assessment of active bleeding on contrast-enhanced CT has traditionally relied on the presence or absence of contrast extravasation. However, in recent years, several studies across different clinical fields have reported the quantitative evaluation of extravasation volume and its association with disease severity and treatment requirements.^{7–10} For example, in gastrointestinal bleeding, the volume of contrast extravasation detected on CT has been shown to correlate with the need for hemostatic intervention and massive transfusion.⁹ In addition, a study evaluating multiphasic CT in gastrointestinal bleeding demonstrated that extravasation volumes measured in both arterial and venous phases—by semiautomatic extraction with manual correction—were significantly larger in patients with angiographically confirmed active bleeding, particularly in the venous phase.⁷ Notably, this approach is methodologically similar to that used in our study, and the reported interobserver agreement was high, with a mean analysis time of approximately 6 min.⁷ The present study extends this quantitative approach to primary postpartum hemorrhage, in which contrast extravasation occurs within the uterine cavity and may be affected by different anatomical and physiological factors. To our knowledge, this is the first study to apply this quantitative approach to active intrauterine bleeding in primary postpartum hemorrhage.

Importantly, the CT-derived extravasation rate should not be interpreted as a direct physiological measurement of the rate of blood loss. It represents the temporal increase in CT-detectable contrast extravasation volume between the arterial and delayed phases, normalized to the time interval between the two acquisitions. The measured value may be influenced by contrast dilution and redistribution within the uterine cavity, hemodynamic and circulatory conditions, image acquisition timing, iodine concentra-

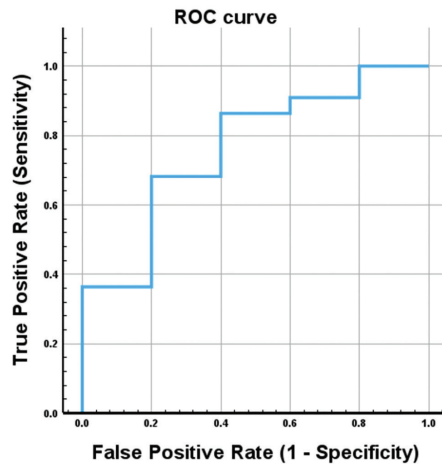


Figure 5. Receiver operating characteristic (ROC) curve according to transcatheter arterial embolization (TAE) status in the non-laparotomy group. This shows the ROC curve of the computed tomography-derived extravasation rate for discriminating between patients who underwent TAE and those managed conservatively, after exclusion of patients who underwent laparotomy. The area under the ROC curve was 0.764. The cut-off value selected by maximizing the Youden index was 2.5 mL/min, yielding a sensitivity of 68.2% and a specificity of 80.0%. A higher cut-off value of 7.0 mL/min yielded a specificity of 100.0%, although sensitivity decreased to 36.4%.

tion, contrast dose and injection rate, and the attenuation threshold and manual correction used for segmentation. Therefore, the CT-derived extravasation rate should be regarded as a quantitative imaging metric characterizing the temporal progression of contrast extravasation rather than as a validated measure of the actual rate of blood loss.

The median CT-derived extravasation rate was numerically higher in patients who underwent hysterectomy than in those who did not (21.71 vs. 3.37 mL/min), although the binary comparison did not reach statistical significance ($P = 0.083$). In the exploratory three-group analysis, median values were also numerically higher across the conservative management, TAE, and hysterectomy groups, but the overall difference was not statistically significant ($P = 0.054$). Substantial overlap was observed among the treatment groups. Moreover, the selection of TAE or hysterectomy is influenced not only by the extent of contrast extravasation but also by hemodynamic status, laboratory findings, obstetric etiology, previous treatment, and response to conservative management. Accordingly, the present findings should not be interpreted as establishing a treatment algorithm or demonstrating that the CT-derived extravasation rate independently determines the need for invasive intervention. Rather, they provide preliminary evidence supporting further investigation of quantitative extravasation assessment as a potential adjunct to conventional clinical evaluation.

The weak negative correlations of the CT-derived extravasation rate with hemoglobin and hematocrit were secondary findings. Inverse correlations were also observed with systolic and diastolic blood pressure, although these did not reach statistical significance in two-sided testing. These findings provide preliminary supportive evidence that the CT-derived metric may reflect hemorrhagic severity, but they do not demonstrate incremental value over conventional clinical assessment. Furthermore, these clinical variables were not necessarily measured simultaneously with CT and may have been affected by resuscitation, transfusion, or the interval between hospital arrival and CT acquisition. Therefore, these correlations should be interpreted cautiously and were not the primary focus of the present study.

Yamaguchi et al.² have emphasized the need for a novel stratification framework for severe postpartum hemorrhage with intrauterine contrast extravasation on contrast-enhanced CT, which cannot be adequately characterized by the conventional “4Ts” (tone, trauma, tissue, and thrombin) classification. The present study advances this concept from a qualitative assessment of the presence or absence of active bleeding to a quantitative evaluation of the temporal increase in contrast extravasation. Although TAE is an effective uterus-preserving treatment, accurate identification of patients who are likely to benefit from invasive intervention remains important to ensure timely hemostasis while avoiding unnecessary procedures. Nevertheless, the present study does

not establish that the CT-derived extravasation rate should be directly incorporated into treatment decision-making.

The ROC curve analyses and the observed differences among treatment categories should be considered exploratory. Although the point estimates of the AUCs suggested moderate discriminatory ability for hysterectomy and TAE, their wide 95% CIs indicate substantial statistical uncertainty. The small sample size, limited number of outcome events, unequal distribution of patients among treatment groups, and derivation and evaluation of the cut-off values within the same cohort further limit the reliability and generalizability of these results. In the non-laparotomy group, all patients with a CT-derived extravasation rate of > 7.0 mL/min underwent TAE, and one patient with a value above this level who was initially managed conservatively subsequently required TAE. Although this observation may be useful for generating hypotheses for future studies, it was based on a very small number of patients and on a value selected and evaluated within the same cohort. Therefore, 7.0 mL/min should not be regarded as a validated treatment threshold or used independently to determine the need for prompt embolization. All ROC curve-derived cut-off values should be considered hypothesis-generating estimates that require prospective external validation in larger cohorts.

This study has several limitations. First, it was a single-center retrospective study with a small sample size. In particular, the number of patients undergoing hysterectomy was limited to eight, and only five patients did not undergo any invasive hemostatic intervention, reducing the statistical power for group comparisons. The imbalance in the number of patients among the treatment groups may also have affected the statistical analyses. Second, most patients were referred from other hospitals, resulting in a relatively long interval from delivery to CT acquisition. Variations in imaging timing, pre-treatment, fluid resuscitation, and transfusion may have influenced the estimated extravasation rate. Third, the CT acquisition and contrast administration protocols were not fully standardized. Although the contrast dose was adjusted to provide a total iodine dose of 450 mg/kg and contrast material was generally administered over approximately 30 seconds, the iodine concentration and corresponding injection rate varied among patients. In addition, delayed-phase acquisition was manually initiated with reference to the scanner timer, resulting in variability in the actual ac-

quisition timing. These variations may have affected contrast attenuation, segmentation based on the 80-HU threshold, and the calculated CT-derived extravasation rate. Future prospective studies should use standardized iodine concentration and injection parameters together with a fixed delayed-phase acquisition time. Fourth, all quantitative measurements were performed by a single radiologist, and interobserver and intraobserver reproducibility was not assessed. Because the present analysis included manual VOI placement and manual correction of threshold-based segmentation, observer-dependent measurement variability may have affected the results. Future prospective studies should formally assess measurement reproducibility using multiple independent observers and standardized segmentation procedures. Finally, treatment selection was determined by multiple clinical and obstetric factors and was not based solely on the extent of contrast extravasation. Consequently, the observed associations do not establish that the CT-derived extravasation rate independently predicts the need for TAE or hysterectomy.

In conclusion, quantitative measurement of the temporal increase in intrauterine contrast extravasation on dynamic contrast-enhanced CT was feasible and showed a broad distribution among patients with primary postpartum hemorrhage. Higher values tended to be observed in patients undergoing more invasive hemostatic interventions, although a substantial overlap was present among treatment categories. These exploratory findings do not establish a treatment

algorithm or clinically applicable cut-off values but support further investigation of quantitative CT assessment in larger, prospective studies using standardized acquisition and measurement protocols. Future studies should also determine whether this quantitative imaging metric provides incremental value beyond established clinical and laboratory parameters.

Footnotes

Conflict of interest disclosure

The authors declared no conflicts of interest.

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