



Magnetic Resonance Imaging-Based Radiomics of Axial and Sagittal Orientation in Pregnant Patients with Suspected Placenta Accreta Spectrum

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Rationale and Objectives: Placenta accreta spectrum (PAS) is associated with significant morbidity and mortality. Current radiomic analysis of PAS magnetic resonance (MR) images is often performed on a single imaging plane. However, depending on the chosen imaging plane, radiomic features extracted from the same patient may vary due to the differing orientations and anatomical contexts, potentially leading to inconsistent results. In this study, we applied region of interest (ROI)-based radiomic analysis on axial and sagittal MR images in pregnant patients at high risk for PAS. Our objective was to compare MR textural features extracted from these imaging planes and to correlate these findings with surgical outcomes, aiming to enhance the accuracy of PAS diagnosis and treatment planning.

Materials and Methods: This is a retrospective review of MR images of pregnancies with prenatally suspected PAS. Volumetric placental, uterus, and internal os of the cervix regions of interest (ROI) were manually segmented on axial and sagittal MR images for each patient. Radiomic features were extracted following the image biomarker standardization initiative guideline. Agreement in features extracted from axial and sagittal images were assessed using Spearman's rank correlation coefficient.

Results: Of the 101 pregnant patients that met the study inclusion criteria, 65 underwent cesarean hysterectomy for PAS. 77 percent of the radiomics features had strong Spearman rank correlations (>0.8) between axial and sagittal images, indicating that these imaging planes provide similar radiomics information. The diagnostic performance of features extracted from axial and sagittal planes was quantified under the receiver operating characteristics curve (AUC). We found that axial and sagittal planes have similar performance for the prediction of hysterectomy. Shape elongation, Placental Location within the Uterus (PLU), and heterogeneity features were significant predictors for hysterectomy regardless of the imaging plane.

Conclusion: Our study found that radiomics features extracted from axial and sagittal MR image plane in the same patient have excellent agreement and strong correlation. We identified several features present in both axial and sagittal images that were predictive in detecting PAS-suspected patient who required hysterectomy. These features may represent the underlying placental pathophysiology.

Key Words: Radiomics; Placenta accreta spectrum; Spearman rank correlation; Hysterectomy.

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INTRODUCTION

Placenta accreta spectrum (PAS) disorders are characterized by the partial or complete failure of the placenta to detach from the uterine wall at delivery (1). PAS results from defects in the endometrium-myometrial interface, typically at sites of prior uterine surgery, leading to inadequate decidualization and abnormal placental adherence. PAS is associated with significant risks, including massive hemorrhage, maternal morbidity, and mortality. There has been a rise in PAS incidence, due to an increase in cesarean deliveries, affecting up to 1 in 272 pregnancies (2). While in the past, hysterectomy has been the definitive surgical treatment for PAS, conservative management options that aim to avoid hysterectomy have been increasingly reported (3–5). Disease management depends on disease severity, the expertise, and resources of the healthcare team, and a multidisciplinary care team approach is essential to optimize outcomes (6, 7). Currently, in our practice, cesarean hysterectomy is performed by the obstetrical team with other surgical consultants at delivery if the placenta fails to deliver.

Magnetic resonance (MR) imaging serves as an adjunct to ultrasound (US) for assessing PAS severity and aiding in pre-operative surgical planning. PAS-MR markers have been outlined in a joint guideline from Society of Abdominal Radiology and European Society of Urogenital Radiology (8, 9). Additionally, MRI improves specificity over the ultrasound and number of cesarean deliveries based on parametric analysis (10). However, MR diagnosis of PAS remains highly dependent on the interpreter's experience, requiring a significant training for radiologists to achieve high inter-reader agreement and diagnostic accuracy (11, 12). Recently, there has been growing interest in applying quantitative radiomics to fetal MR image to evaluate imaging-based data that are not perceptible to the human eye. PAS MR markers such as placental heterogeneity, T2-dark bands, placental/uterine bulge, and asymmetric thickening/shape of the placenta can potentially be assessed by radiomics, machine learning (ML), and deep learning (DL) algorithms. These techniques may uncover information beyond visual markers that better reflect tissue pathology, thereby improving the accuracy of PAS diagnosis or pre-operative risk stratification.

While radiologists typically review MR images in all three plane (axial, sagittal, and coronal), most PAS radiomic, machine learning, and deep learning studies are often limited to a single imaging plane due to the time-consuming process of image segmentation. The placenta is a large organ, with a median placental volume of 513 cm³ at 27 weeks of gestation (13), and its morphology, particularly in high-grade PAS, can vary widely. Although some efforts have been made to automate placental segmentation (14–19), most PAS MR studies still rely on manual segmentation. Radiomic analysis of MR images suspected of PAS has been correlated with patient outcomes, such as risk of postpartum hemorrhage, hysterectomy, or the presence of PAS (20–25). However, the impact of image plane orientation on the diagnostic performance of radiomic models for PAS is not well understood. Radiomic features extracted from different planes, such as axial and sagittal MR images, of the same patient can

vary due to the orientation and anatomical context provided by each plane. In our study, we aimed to compare and correlate radiomic analyses from axial and sagittal MR images of a high-risk PAS population to predict the need for hysterectomy at the time of cesarean delivery. This analysis will enhance our understanding of placental spatial heterogeneity and help in selecting effective radiomic features based on imaging plane orientation. Additionally, it will provide essential information on whether plane orientation is critical and/or impacts the outcomes of radiomic analysis.

METHODS

Study Population

This study was an Institutional Review Board approved single-center retrospective chart review of MRI (9) data of pregnancies referred with prenatal suspicion of PAS based on abnormal US findings, and history of prior cesarean deliveries or uterine surgery between 2014 and 2019. MR images were acquired with a 1.5 T MR scanner (Avanto, Siemens Healthcare, Erlangen, Germany) with a body array coil over the pelvis, and pregnant patients positioned in the supine or left lateral decubitus position based on comfort. The patients were instructed to have a partially full bladder for optimal evaluation of the bladder-serosal interface. The electronic health record was reviewed for maternal demographic and clinical outcomes.

Manual Segmentation of the Uterus and Placenta

Study investigators were blinded to clinical history, US findings, and pregnancy outcome information. Anonymized MR images were archived to a Research PACS system (iPACS, in Vicro, Boston, MA) and then retrieved using a DICOM viewer (OsiriX, Pimeo SARRL, Bernex, Switzerland) running on Mac OSX for image evaluation. MR images analyzed in this study included a 7 mm T2-weighted (T2W) single shot fast spin echo sequence in the axial plane covering the entire gravid uterus, and a 5 mm T2W sequence in the sagittal plane for each patient. Table 1 details the MR parameters for the sequences analyzed in this study. Volumetric placental, uterus, and internal os (the opening of the endocervical canal into the uterine cavity) ROI were manually segmented by a single researcher under the supervision of a board-certified radiologist with 30 years of obstetrical and gynecologic MR experience (Fig 1). Image segmentation was performed using a Python-based in-house developed software on the Osirix DICOM viewer.

Radiomic Feature Extraction

All images were normalized and scaled by 100 with outliers 3 SD away truncated. A fixed bin width of 5 was used. In addition, all axial images were resampled to 1.5 × 1.5 × 7 mm and all sagittal images were resampled to 1.5 × 1.5 × 5 mm. All texture features were calculated by slice. All image modification

TABLE 1. MR Sequences Analyzed in the Study

Acquisition sequence	Plane	TR (ms)	TE (ms)	Slice thickness (mm)	Matrix size
T2W HASTE	Axial	1200	81	7	256 × 256
T2W HASTE	Sagittal	1100	103	5	256 × 256

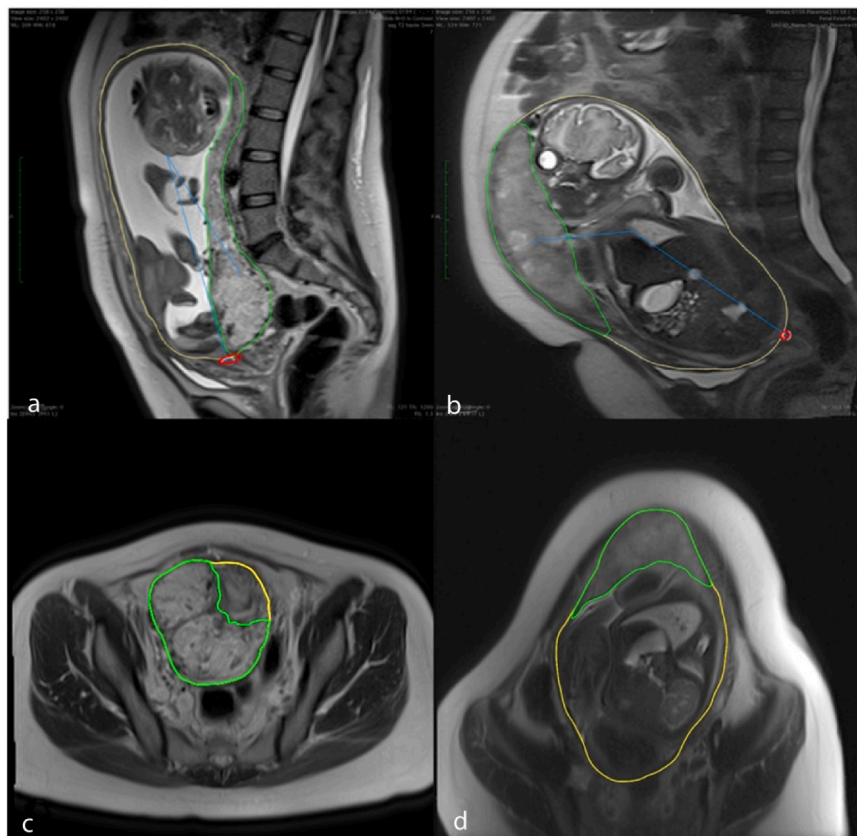


Figure 1. Sagittal T2W images demonstrating the regions of interest in a prenatally suspected PAS case with hysterectomy (**a**) and without hysterectomy (**b**). The uterus ROI is indicated in yellow, the placenta ROI in green, the internal os of the cervix ROI in red, and the PLU feature as a blue angle. Axial T2W images (**c**: hysterectomy and **d**: no hysterectomy) further illustrate the uterus ROI (yellow) and the placenta ROI (green). On axial images, the last slice with ROI indicated the location of the inferior cervix. PAS, placenta accreta spectrum; ROI, regions of interest; T2W, T2-weighted. (Color version of figure is available online.)

and feature extraction were done following the image biomarker standardization initiative (IBSI) guideline using the pyRadiomics package v3.0.1 (26). Radiomic features extracted included first order, shape, Gray Level Co-occurrence Matrix (GLCM), Gray Level Run Length Matrix (GLRLM), Gray Level Size Zone Matrix (GLSZM), Gray Level Dependence Matrix (GLDM), and Neighbouring Gray Tone Difference Matrix (NGTDM). Additionally, a custom feature, Placental Location within the Uterus (PLU) was also generated. PLU is defined as an angle that describes the relative location of the placenta to the internal os of the cervix (14). Because axial images are typically acquired at an oblique angle parallel to the tangent plan intersecting the uterus at the internal os, the calculation of PLU was slightly different for each plane. For images acquired in the sagittal plane, PLU was calculated as the angle between the vector extending from the epicenter of the uterus to the internal os, and the vector from the

epicenter of the uterus to the epicenter of the placenta. In the axial plane, PLU was calculated as the angle between the vector extending from the epicenter of the uterus perpendicular to the axial plane and the vector from the epicenter of the uterus to the epicenter of the placenta.

Maternal demographics were compared between those who required cesarean hysterectomy for PAS and those that did not, with Student's t-test and Fisher's exact test when appropriate. Correlation in features extracted from axial and sagittal images were assessed using Spearman's rank correlation coefficient. Strength of correlation was interpreted as: Strong: 0.8–1.0; Moderate 0.5–0.8; Fair: 0.3–0.5; Poor: values ≤ 0.3 . Lower correlation indicated that axial and sagittal image provides different information. To derive a multivariable regression model for sagittal and axial features, we use nested 10/10 fold cross validation with logistic

regression (in nested cross validation, the inner loop is responsible for hyperparameter tuning, i.e. variable selection, the outer loop is for testing, i.e. calculate testing area under the receiver operating characteristic curve [AUC]). Least absolute shrinkage and selection operator (LASSO) was used for variable selection. The diagnostic performance was averaged from 500 repeats. P values less than 0.05 were considered significant. All analyses were done in R 4.3.0 (R Core Team, Vienna, Austria).

RESULTS

Patient Population

Of the 101 pregnant patients meeting the study inclusion criteria, 65 underwent cesarean hysterectomy for PAS whereas 36 had a cesarean delivery with placental extraction. When comparing the hysterectomy with no hysterectomy group, there was a significant difference in the number of prior cesarean deliveries, and no significant differences in maternal age, gravidity, parity, gestational age (GA) at MRI, GA at delivery (Table 2).

Correlations Between Axial and Sagittal Images

77 percent of the radiomics features had strong correlations (> 0.8) between axial and sagittal images (Table S1).

Multivariable Regression

The diagnostic performance of features extracted from sagittal images (0.72 [95% CI 0.67–0.76]) and from axial images (0.79 [95% CI 0.75–0.84]) were not statistically different (P = 0.072, Fig 2).

Three radiomics features are as follows: PLU, Dependence non-uniformity normalized, and Shape elongation were selected in more than 90% iterations for both sagittal and axial images. Value for PLU was significantly different (P < 0.001) between those with hysterectomy (sagittal: 35.4° ± 24.4°, axial 35.8° ± 23.1°) and those without (sagittal: 61.8° ± 35.6°, axial 63.9° ± 35.1°). The Dependence non-uniformity normalized and Shape elongation radiomic features were also significantly different (P < 0.001) between those with hysterectomy and those without (Table 3). Figure 1 shows representative sagittal images of (A) a prenatally suspected PAS case with hysterectomy

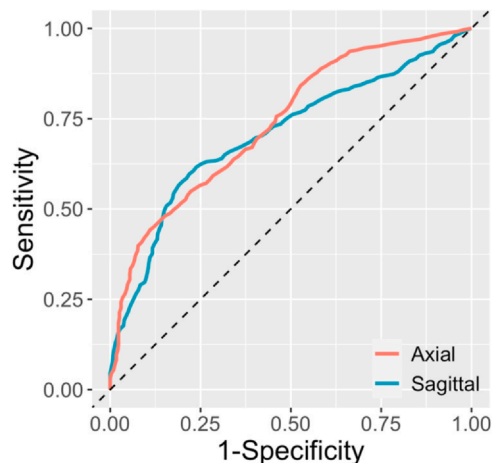


Figure 2. Receiver operating characteristics curves demonstrating the diagnostic performance of features extracted from axial and sagittal imaging planes. Axial and sagittal planes have similar performance.

with small PLU and Dependence non-uniformity normalized values; and (B) a prenatally suspected PAS case without hysterectomy with large PLU and Dependence non-uniformity normalized values. The final model for radiomics extracted from sagittal MR images for probability of hysterectomy was:

$$\text{Logit}(\text{Prob}(\text{hysterectomy})) = 4.222 - 0.0199 * \text{PLU} - 0.6597 * \text{original_Shape_elongation} + 9.6435 * \text{original_GLDM_DependenceNon-UniformityNormalized}$$

The final model for radiomics extracted from axial MR images for probability of hysterectomy was:

$$\text{Logit}(\text{Prob}(\text{hysterectomy})) = 4.283 - 0.034 * \text{PLU} - 0.564 * \text{original_Shape_elongation} + 11.608 * \text{original_GLDM_DependenceNon-UniformityNormalized}$$

DISCUSSION

Radiomics is an evolving field of research that facilitates the extraction and analysis of quantitative data from medical imaging. In our study, we analyzed the entire placental volume from both axial and sagittal planes. When comparing these imaging planes, radiomic features extracted from the same patient may vary due

TABLE 2. Clinical Characteristics of Study Population*

Characteristic	Hysterectomy N = 65	No hysterectomy N = 36	P value
Age at delivery	33.8 ± 5.4	32.2 ± 6.2	0.207
Gravidity	4 (3, 5)	3 (3, 4)	0.460
Parity	2 (1,3)	2 (1,3)	0.574
Gestational age at MRI	31.8 ± 3.4	31.9 ± 2.7	0.847
Gestational age at delivery	35.5 ± 1.7	36.1 ± 1.6	0.090
Number of prior cesarean deliveries	2 (1,2)	1 (1,2)	0.042

*Values are presented as mean ± standard deviation (SD) for normally distributed data and as medians with interquartile ranges (IQR) for non-normally distributed data.

TABLE 3. Values for the Three Features That Were Selected in More Than 90% of Iterations for Both Sagittal and Axial Images, Showing Significant Differences Between the Hysterectomy and no Hysterectomy Groups

Features	Axial		Sagittal		P value
	Hysterectomy	No hysterectomy	Hysterectomy	No hysterectomy	
PLU	35.8° ± 23.1°	63.9° ± 35.1°	35.4° ± 24.4°	61.8° ± 35.6°	P < 0.001
Dependence non-uniformity normalized	0.229 ± 0.05	0.2 ± 0.044	0.297 ± 0.075	0.246 ± 0.058	P < 0.001
Shape elongation	0.763 ± 0.138	0.832 ± 0.086	0.751 ± 0.127	0.828 ± 0.08	P < 0.001

to the differing orientation and anatomical context. The features extracted from axial images may emphasize patterns and variations across the horizontal plane, such as changes in tissue density, volume, and horizontal distribution of textures. Features from sagittal images may focus more on vertical and longitudinal variations, such as continuity of tissue types, vertical asymmetry, and the linearity of structure. Our MR study on high-risk PAS patients aimed to investigate whether the orientation of the imaging plane affects key radiomic findings. Spearman's rank correlation coefficients indicate that axial and sagittal imaging planes provide similar radiomic information from large placental volumes. Few studies have compared the radiomic analyses from different imaging planes in the same patient. For instance, Ren et al. reported excellent correlation between sagittal and coronal planes in predicting PAS (22). However, our study focused not just on the presence of PAS but on cases severe enough to necessitate hysterectomy.

We identified placental radiomic features that were significant predictors for PAS severe enough to result in hysterectomy, indicating that the features extracted from axial and sagittal images reflect similar underlying placental pathophysiology. We observe that cases that have a lower PLU are more likely to have placenta previa, an associated risk factor for PAS. High Dependence non-uniformity normalized value reflects a high level of heterogeneity, likely indicating presence of significant abnormal T2-dark bands and fibrin deposition in the placenta, which likely account for this heterogeneity (Fig 1). Shape elongation was also significantly different ($P < 0.001$) between those with hysterectomy and those without, with bulgy, less regularly shaped placentas in the hysterectomy group. By studying the visual differences between the hysterectomy and no hysterectomy cases for radiomic features that we identify to be significant, we plan to expand the understanding of the link between radiomic features and the visual cue of underlying pathophysiology. If the radiomic differences between groups can represent the classic T2 MR findings in clinical observations, radiomics may provide quantification which may be better than individual subjective interpretation on clinical exams. At this juncture, our findings may not be applicable in routine clinical practice but we plan to design algorithms for future applications.

Our study had several limitations. First, the sample size was relatively small, partly due to the rarity of the condition, which limits the generalizability of our findings beyond our cohort. Our population consisted primarily of pregnant patients with a history of cesarean delivery and suspected

placental invasion based on clinical history and ultrasound findings. The reliance on surgical impressions of invasion has been discussed in the literature, with most studies favoring the inclusion of surgical evaluations which may be superior to pathological evaluations. (27–30) Second, regions of interest were manually segmented in the study. This method is labor-intensive and may have high inter-reader variability. However, our results suggest that even with manual segmentation, radiomics extracted from either sagittal plane or axial plane can provide comparable information and contribute to developing an optimal prediction model.

CONCLUSION

Radiomics features extracted from axial and sagittal MR image plane in the same patient have excellent agreement and strong correlation. Shape elongation, PLU, and heterogeneity features were shown in both axial and sagittal images to be predictive in detecting PAS-suspected patient who required hysterectomy. This characterization is valuable in our understanding of placental spatial heterogeneity and the selection of effective radiomic features in the context of imaging plane.

DECLARATION OF COMPETING INTEREST

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Quyen N. Do reports financial support was provided by National Institutes of Health. Christina L. Herrera reports financial support was provided by National Institutes of Health. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the author did not use AI or AI-assisted technologies. The authors certify that the submitted article will not constitute "Redundant Publication."

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APPENDIX A. SUPPORTING INFORMATION

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.acra.2024.09.045](https://doi.org/10.1016/j.acra.2024.09.045).

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