

• 论 著 •

早孕期胎盘三维能量多普勒血流参数联合 辅助生殖史对子痫前期的预测价值

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【摘要】 目的 探讨早孕期辅助生殖技术受孕史联合胎盘三维能量多普勒参数对子痫前期的早期预测价值。**方法** 采用单中心回顾性研究方法,连续纳入2023年6月—2024年9月期间在河北省生殖健康医院接受检查的早孕期(11~13⁺周)单胎孕妇208例作为建模队列,根据妊娠结局分为子痫前期(preeclampsia, PE)组45例和正常妊娠对照组163例。另选取2025年1~3月期间符合相同标准的独立样本91例作为外部验证队列,其中包含PE 11例、正常妊娠80例。收集受孕方式及胎盘体积、血管化指数(vascularization index, VI)、血流指数(flow index, FI)、血管化—血流指数(vascularization-flow index, VFI)等胎盘三维能量多普勒参数,通过多因素Logistic回归分析筛选预测因子并构建预测模型,采用受试者工作特征(receiver operating characteristic curve, ROC)曲线及决策曲线(decision curve analysis, DCA)分析评价模型性能。**结果** 建模队列中早孕期(11~13⁺周)单胎孕妇208例,其中PE组45例,正常妊娠组163例。PE组辅助生殖技术受孕比例显著高于正常妊娠组,胎盘体积显著小于正常妊娠组,VI、FI、VFI均显著低于正常妊娠组,差异有统计学意义($P<0.05$)。多因素Logistic回归分析结果显示,辅助生殖技术受孕为子痫前期发生的独立危险因素($OR=2.690, P=0.010$),VI($OR=0.929, P=0.018$)和FI($OR=0.927, P=0.002$)为子痫前期发生的保护因素。基于辅助生殖技术受孕史、VI和FI构建的预测模型在训练集、测试集及外部验证集中的曲线下面积分别为0.732、0.753和0.781,模型校准度良好(Hosmer-Lemeshow检验 $P>0.05$),在低至中等风险阈值范围内具有较高的临床净获益。**结论** 辅助生殖技术受孕史及胎盘三维能量多普勒灌注参数与子痫前期的发生密切相关,三者联合构建的预测模型具有较好的早期风险识别能力和潜在临床应用价值。

【关键词】 子痫;超声检查;多普勒;生殖技术;辅助 doi:10.3969/j.issn.1007-3205.2026.01.013

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Predictive value of first-trimester placental 3D power Doppler angiography parameters combined with history of assisted reproduction for preeclampsia

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【Abstract】 Objective To investigate the early predictive value of a history of conception via assisted reproductive technology (ART), combined with first-trimester placental three-dimensional (3D) power Doppler parameters, for the development of preeclampsia (PE). **Methods** This single-center retrospective study consecutively enrolled 208 singleton pregnant women at early gestation (11—13⁺ weeks) who underwent examination at Hebei Reproductive Health Hospital between June 2023 and September 2024 as the modeling cohort. According to pregnancy outcomes, participants were categorized into the PE group ($n=45$) and the normal pregnancy control group ($n=163$). An independent cohort of 91 pregnant women meeting the same inclusion criteria and examined between January and March 2025 was selected as the external validation cohort, comprising 11 patients with PE and 80 women with normal pregnancies. Data on conception method and placental 3D power Doppler parameters, including placental volume, vascularization index (VI), flow index (FI), and vascularization-flow index (VFI), were collected. Multivariate logistic regression analysis was performed to identify predictive factors and to construct a prediction model. Receiver

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operating characteristic (ROC) curve analysis and decision curve analysis (DCA) were applied to evaluate the performance of the model. **Results** In the modeling cohort, 208 singleton pregnancies at 11–13⁺₆ weeks of gestation were analyzed, including 45 patients in the PE group and 163 women in the normal pregnancy group. The proportion of pregnancies conceived through ART was significantly higher in the PE group than in the normal pregnancy group, while placental volume was significantly smaller. Moreover, VI, FI, and VFI were all significantly lower in the PE group compared with the normal pregnancy group, with significant differences (all $P < 0.05$). Multivariate logistic regression analysis identified conception through ART as an independent risk factor for PE (OR=2.690, $P=0.010$), whereas VI (OR=0.929, $P=0.018$) and FI (OR=0.927, $P=0.002$) were identified as independent protective factors. The prediction model incorporating conception through ART, VI, and FI achieved the area under the curve (AUC) values of 0.732, 0.753, and 0.781 in the training set, internal test set, and external validation set, respectively. The model demonstrated good calibration performance (Hosmer-Lemeshow test, $P > 0.05$) and provided favorable clinical net benefit across low-to moderate-risk threshold probabilities. **Conclusion** A history of conception through ART and placental 3D power Doppler perfusion parameters are closely associated with the occurrence of PE. A predictive model jointly constructed using these factors exhibits good early risk discrimination ability and shows potential clinical application value for the early identification of PE.

[Key words] eclampsia; ultrasonography, Doppler; reproductive techniques, assisted

子痫前期 (preeclampsia, PE) 的发生率为 2%~8%^[1-2], 是妊娠常见的并发症之一^[3-4], 也是导致孕妇死亡和胎儿预后不良的一大主要原因^[5-6]。PE 的发病机制尚未完全明确, 目前普遍认为该病形成与胎盘灌注不足、血管内皮功能障碍及抗血管生成因子失衡密切相关^[7-8]。终止妊娠是目前 PE 唯一有效的根治方法^[9], 所以早期预测与干预对于改善母婴预后至关重要。单一的预测模型难以普遍适用^[10-11], 传统临床指标 (血压、体重指数等) 的预测效能有限, 受试者工作特征 (receiver operating characteristic, ROC) 曲线下面积 (area under the curve, AUC) < 0.7 ^[12]。现有的预测模型多基于单中心数据构建, 并且缺乏外部验证^[13-14], 限制了 PE 早期预测模型在临床上的转化与应用。近年来, 多模型整合策略逐渐成为 PE 预测的研究趋势^[14-15], 联合母体临床特征、血清标志物 (如可溶性血管内皮生长因子受体 1/胎盘生长因子比值) 及超声参数 (如子宫动脉搏动指数) 可以提升 PE 预测的效能 (AUC > 0.8)^[13-14]。因此, 本研究通过整合辅助生殖技术 (assisted reproductive technology, ART) 受孕方式和胎盘三维能量多普勒 (three-dimensional placental power Doppler, 3D-PD) 参数, 构建一个用于早期辨别 PE 风险的预测模型, 为 PE 早期筛查提供更精准可靠的工具。

1 资料与方法

1.1 一般资料 本研究是一项单中心回顾性病例对照研究, 采用内部模型构建与外部验证相结合

的设计。内部验证队列连续纳入了 2023 年 6 月—2024 年 9 月期间在河北省生殖健康医院产科就诊的于妊娠 11~13⁺₆ 周完成系统超声检查及胎盘三维能量多普勒成像, 并最终在本院分娩的单胎孕妇 208 例, 根据妊娠结局分为 PE 组 45 例和正常妊娠对照组 163 例。按 7:3 的比例随机分为训练集和测试集, 训练集用于模型建立, 测试集用于内部验证。另选取 2025 年 1—3 月符合相同标准的独立样本 91 例作为外部验证队列, 其中包含 PE 11 例、正常妊娠 80 例。本研究总计纳入分析 299 例孕妇。

纳入标准: ①于妊娠 11~13⁺₆ 周接受首次系统产前超声检查并完成胎盘三维能量多普勒成像的单胎孕妇; ②PE 组符合 PE 临床诊断标准, 对照组为正常妊娠; ③孕妇自愿参加研究并签署知情同意书; ④无精神障碍或严重认知障碍; ⑤近期末使用可能显著影响妊娠血流动力学或胎盘功能的激素或免疫调节药物。

排除标准: ①妊娠合并糖尿病、慢性高血压、肾病等基础疾病; ②合并胎盘早剥、羊水异常、胎儿畸形等妊娠并发症; ③有出血倾向或凝血功能异常; ④资料不全或依从性差; ⑤近 1 个月内接受过大剂量激素治疗。

1.2 方法

1.2.1 研究对象与研究设计 PE 组根据纳入标准, 从内部验证队列中筛选出所有最终确诊为 PE 的孕妇。其诊断依据为病案系统中记录的入院时临床资料, 包括常规产科检查、符合诊断标准的持续性高血压及蛋白尿等。

正常妊娠对照组从内部验证队列中选取健康

单胎孕妇作为对照。纳入标准为：无任何妊娠合并症（如妊娠期高血压疾病、糖尿病等）、胎儿生长发育正常，并排除有慢性高血压、肾病、心血管等疾病等基础病史者，以保证与PE组在基线健康状况上具有可比性。

1.2.2 临床资料 收集所有孕妇的一般临床资料，包括年龄、孕周、受孕方式（自然受孕或ART）、孕产史等，进行规范化整理。使用3D-PD超声采集孕妇的胎盘影像，获得血管化指数（vascularization index, VI）、血流指数（flow index, FI）及血管化—血流指数（vascularization-flow index, VFI）参数，将所有数据录入数据库后进行严格质控管理。

1.2.3 超声检查设备与人员 采用GE Voluson E10彩色多普勒超声诊断仪进行所有检查。设备配备RAB6-D凸阵探头（频率1~6 MHz）用于常规二维及频谱多普勒测量，以及C1-6-D腹部容积探头（频率3.5~6 MHz）用于三维能量多普勒数据采集。所有检查及后续图像分析均由2位具有5年以上产科超声工作经验的主治医师独立完成。在正式研究开始前，2位医师就扫描规范及测量方法进行了统一培训与校准。

1.2.4 检查前准备与体位 孕妇在检查前适当充盈膀胱，取仰卧位，必要时可稍向左侧倾斜以预防仰卧位低血压综合征。首先进行常规早孕期超声检查，确认胎儿存活、测量头臀长（crown-rump length, CRL）及颈项透明层（nuchal translucency, NT）厚度，常规测量CRL和NT以确认孕周及胎儿状态，不作为本研究分析变量。

本研究的核心图像数据获取遵循以下标准化流程。

胎盘定位与取样框设置：在二维超声模式下清晰显示胎盘最大长轴切面。将取样框（volume of interest, VOI）调整至完全覆盖整个胎盘实质，并避开胎盘后方母体子宫肌层的大血管信号。扫描角度统一设置为80°，以确保获取足够的胎盘容积数据。

图像采集：切换至三维能量多普勒模式。在确保孕妇屏住呼吸、探头保持稳定的状态下，启动自动容积扫描。待扫描完成后，将原始三维数据存储于仪器硬盘。

离线分析与参数计算：使用设备内置的VOCAL软件进行离线分析。由操作医师手动勾画胎盘边界，软件自动生成胎盘的三维能量多普勒直方图，并计算以下量化参数：VI，代表感兴趣

容积内彩色体素所占的百分比，反映血管密度。FI，代表彩色体素内的平均多普勒信号强度，反映血流速度。VFI，为VI与FI的乘积，是综合评估指标。

质量控制与重复测量：为减少误差，对同一胎盘连续进行3次独立的容积采集与离线分析，最终取3次测量结果的平均值作为该病例的最终数据。2位医师分析结果的一致性通过计算组内相关系数进行评估，一致性相关系数（intraclass correlation coefficient, ICC）>0.85，表明测量具有良好的一致性。

子宫动脉血流动力学参数测量：使用RAB6-D凸阵探头，于宫颈内口水平横切找到宫颈峡部，向两侧滑动探头显示子宫动脉。采用脉冲多普勒获取血流频谱，确保取样门宽度为2 mm，声束与血流夹角<30°。获取至少3个稳定、形态一致的波形后，由仪器自动计算并记录收缩期/舒张期流速比、搏动指数及阻力指数。

1.3 统计学方法 应用R4.2.2软件进行统计分析。计量资料以 $(\bar{x} \pm s)$ 表示，两组间比较采用独立样本 t 检验；计数资料以（例数，%）表示，组间比较采用 χ^2 检验或Fisher确切概率法。采用多因素Logistic回归模型分析PE发生的独立影响因素，计算比值比（odds ratio, OR）和95%CI。建立Logistic回归模型前，对ART、VI及FI三项自变量进行共线性诊断，采用相关系数矩阵、方差膨胀因子（variance inflation factor, VIF）及条件数（condition index, CI）进行检验，结果未见明显共线性。采用逐步回归法建立预测模型，绘制ROC曲线计算AUC值评估模型的区分能力，其中AUC值0.5~0.7表示区分度一般，0.7~0.9表示区分度较好，>0.9表示区分度较高。采用校准曲线及Hosmer-Lemeshow拟合优度检验（Hosmer-Lemeshow goodness-of-fit test, H-L检验）评估模型的拟合优度，并计算Brier评分；H-L检验 $P>0.05$ 表明模型拟合良好，Brier评分越接近0表示预测误差越小。采用决策曲线分析（decision curve analysis, DCA）曲线评估模型在不同阈值概率下的临床净获益。 $P<0.05$ 为差异有统计学意义。

2 结 果

2.1 2组孕妇早孕期一般临床资料、胎盘三维能量多普勒及子宫动脉血流参数比较 本研究共纳入孕妇208例，其中PE组45例，正常妊娠组163例。PE组ART受孕比例显著高于正常妊娠组，差异有

统计学意义 ($P<0.05$); 2组年龄、不良孕产史、既往PE病史及产次差异均无统计学意义 ($P>0.05$)。见表1。PE组胎盘体积显著小于正常妊娠组, VI、FI、VFI均显著低于正常妊娠组, 差异

有统计学意义 ($P<0.05$); 2组脐带插入部异常比例、S/D、PI、RI差异均无统计学意义 ($P>0.05$)。见表2。

表1 2组临床资料比较

Table 1 Comparison of clinical data between the two groups

组别	例数	年龄 ($\bar{x}\pm s$, 岁)	受孕方式(例数, %)		不良孕产史 (例数, %)	既往PE病史 (例数, %)	产次(例数, %)	
			自然受孕	ART			初产妇	经产妇
正常妊娠组	163	31.10 $\pm$ 4.70	83(50.92)	80(49.08)	51(31.29)	1(0.61)	104(63.80)	59(36.20)
PE组	45	31.60 $\pm$ 3.40	13(28.89)	32(71.11)	15(33.33)	2(4.44)	35(77.78)	10(22.22)
t/χ^2 值		0.780		6.887	0.068	—		3.106
P 值		0.437		0.009	0.794	0.119*		0.078

*为Fisher确切概率法

表2 2组胎盘三维能量多普勒参数比较

Table 2 Comparison of placental three-dimensional power Doppler parameters between the two groups

组别	例数	脐带插入部异常(例数, %)	胎盘体积 ($\bar{x}\pm s$, cm ³)	VI ($\bar{x}\pm s$)	FI ($\bar{x}\pm s$)	VFI ($\bar{x}\pm s$)	S/D ($\bar{x}\pm s$)	PI ($\bar{x}\pm s$)	RI ($\bar{x}\pm s$)
正常妊娠组	163	8(4.91)	60.00 $\pm$ 21.00	10.00 $\pm$ 7.00	36.00 $\pm$ 8.00	3.50 $\pm$ 2.46	1.73 $\pm$ 0.34	0.57 $\pm$ 0.22	0.40 $\pm$ 0.11
PE组	45	0(0.00)	52.00 $\pm$ 21.00	8.00 $\pm$ 6.00	32.00 $\pm$ 8.00	2.47 $\pm$ 1.98	1.80 $\pm$ 0.44	0.59 $\pm$ 0.25	0.42 $\pm$ 0.12
t 值		—	2.333	2.406	3.590	2.688	1.040	0.474	0.770
P 值		0.351*	0.021	0.017	<0.001	0.008	0.300	0.636	0.442

*为Fisher确切概率法

2.2 PE预测模型的构建与内部验证 考虑到VFI为基于VI和FI计算得到的综合指标, 与VI、FI之间存在高度共线性风险, 故在多因素Logistic回归建模时未将VFI同时纳入模型。以是否发生PE为因变量, 以受孕方式、VI和FI为自变量, 进行多因素Logistic回归分析, 结果显示, ART受孕为PE的独立危险因素 (OR=2.690, $P=0.010$), VI (OR=0.929, $P=0.018$) 和FI (OR=0.927, $P=0.002$) 为独立保护性因素。见表3、表4。ART妊娠者发生PE的风险较自然受孕者高2.69倍, 而胎盘血管化程度及血流灌注每增加一个单位, 其发生PE的风险分别降低约7%。共线性诊断显示, ART、VI与FI之间相关系数均较低 ($r<0.1$), VIF值约为1, 条件数<10, 提示自变量间不存在明显多重共线性。

在内部验证中, 模型于训练集和测试集的

表3 自变量赋值表

Table 3 Assignment of independent variables

变量	赋值说明
受孕方式	自然受孕=0, ART=1
VI	连续变量
FI	连续变量
是否发生PE	正常妊娠=0, PE=1

ROC的AUC分别为0.732 (95%CI: 0.65~0.81) 和0.753 (95%CI: 0.63~0.84), 显示出良好的区分能力。列线图以ART、VI和FI三项指标构建, 能直观预测个体PE风险。校准曲线显示模型预测值与实际发生率高度一致 (训练集H-L检验 $P=0.531$; 测试集 $P=0.685$), Brier评分分别为0.151和0.1521, 提示拟合良好。DCA分析表明, 当阈值概率在0.05~0.28范围内, 模型净获益高于“全干预”及“无干预”策略, 显示较好的临床实用性, 见图1~4。

表4 多因素Logistic回归分析结果

Table 4 Results of multivariate Logistic regression analysis

指标	回归系数	标准误	Wald χ^2 值	P 值	OR值	95%CI
ART	0.990	0.383	6.692	0.010	2.690	1.271~5.694
VI	-0.074	0.031	5.562	0.018	0.929	0.873~0.988
FI	-0.076	0.024	9.769	0.002	0.927	0.883~0.972
常量	1.311	0.873	2.254	0.133	3.709	—

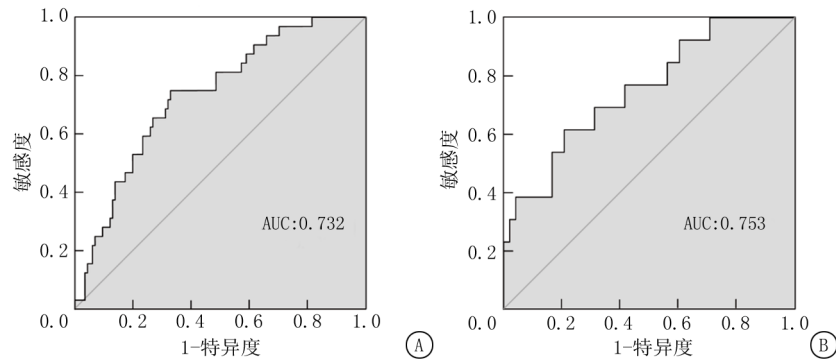


图1 预测模型在训练集与测试集中的受试者工作特征曲线

A. 训练集; B. 测试集

Figure 1 Receiver operating characteristic curves of the prediction model in the training and testing sets

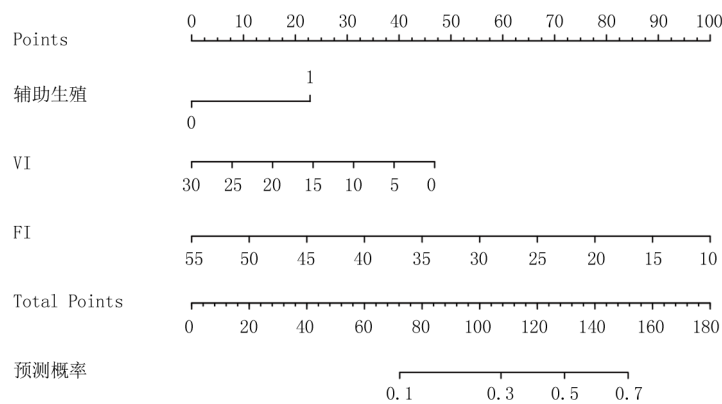


图2 预测PE发生风险的列线图

Figure 2 Nomogram for predicting the risk of preeclampsia

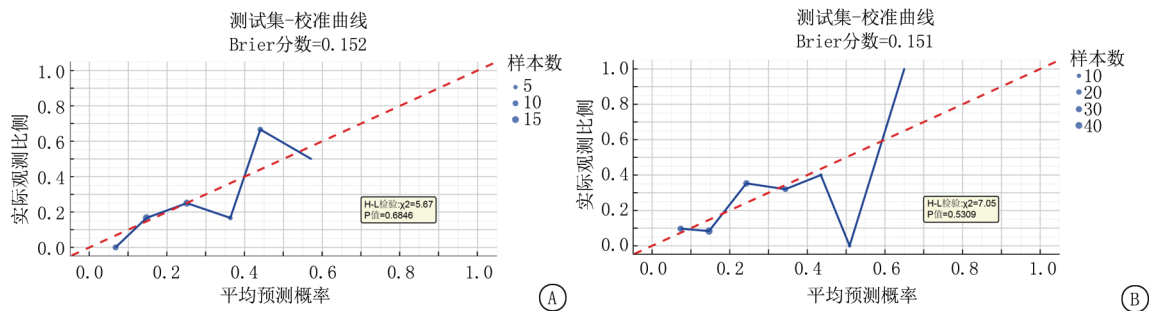


图3 预测模型在训练集与测试集中的校准曲线

A. 训练集; B. 测试集

Figure 3 Calibration curves of the prediction model in the training and testing sets

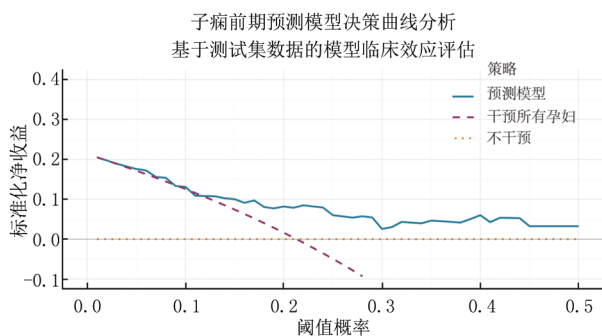


图4 预测模型的决策曲线分析

Figure 4 Decision curve analysis of the prediction model

2.3 预测模型的外部验证 外部验证纳入孕妇91例, 其中包含PE群体11例和正常妊娠群体80例。模型AUC值=0.781, 表明在独立样本中, 该模型仍具备良好的辨别能力; 在H-L检验中, $P=0.139$, 表明校准曲线与理想线拟合良好; DCA结果显示, 在阈值概率0.05~0.20范围内, 模型的净获益最优, 该模型具备较好的稳定性, 具有一定的临床推广价值, 见图5~7。

2.4 典型胎盘三维能量多普勒图像特征 为直观展示胎盘灌注的组间差异, 本研究选取了具有代

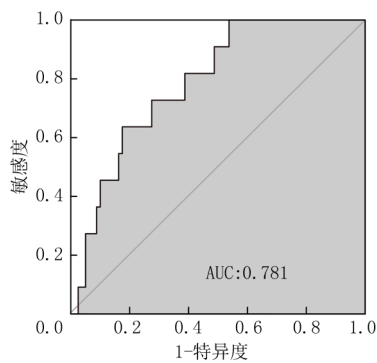


图5 预测模型在外部验证集中的受试者工作特征曲线

Figure 5 Receiver operating characteristic curve of the prediction model in the external validation set

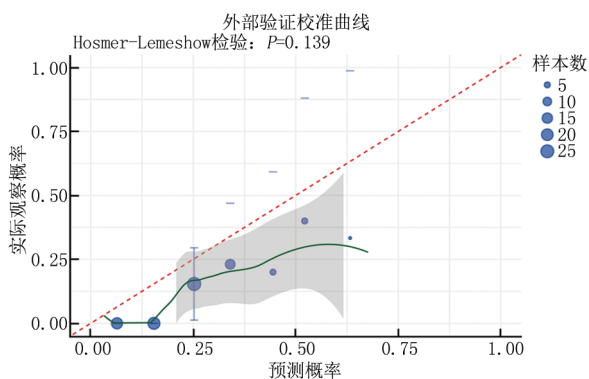


图6 预测模型在外部验证集中的校准曲线

Figure 6 Calibration curve of the prediction model in the external validation set

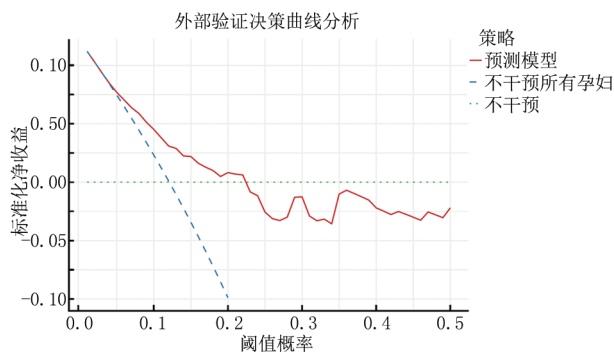


图7 预测模型在外部验证集中的决策曲线分析

Figure 7 Decision curve analysis of the prediction model in the external validation set

表性的病例进行图像对比分析(图8)。

在正常妊娠组中,胎盘三维能量多普勒图像显示胎盘实质内血流信号分布广泛且均匀,彩色体素(代表血流信号)填充密集,血管网络结构清晰(图8A)。通过VOCAL软件对该胎盘进行三维重建与定量分析,自动计算得到:胎盘体积为 60.54 cm^3 ,VI为9.28,FI为42.71,VFI为3.96。

在PE组中,胎盘三维能量多普勒图像显示胎盘实质内血流信号显著稀疏,彩色体素分布范围减小、信号强度减弱,呈现低灌注状态(图8B)。

经VOCAL软件定量分析,其胎盘体积为 45.76 cm^3 ,VI降至3.56,FI降至29.07,VFI仅为1.04。

3 讨论

本研究旨在探讨早孕期(11~13⁺6周)3D-PD血流参数联合ART史对PE的早期预测价值。结果表明,ART受孕是PE发生的独立危险因素,而胎盘VI与FI是PE发生的保护因素。模型在训练集、测试集及外部验证集中的AUC分别为0.732、0.753和0.781,显示了良好的区分度与稳定性。校准曲线结果表明,模型预测值与实际发生率拟合良好,由DCA曲线分析得知该模型阈值概率在0.05~0.20范围内时具有较高的临床净获益。

PE是一种异质性疾病^[16-17],与胎盘和母体之间多重环节的相互作用有关^[18-19],它的核心机制包含胎盘螺旋动脉重构异常^[20-22]、胎盘灌注不足^[23-24]、血管生成因子失衡^[25]和母体免疫调节紊乱^[26]。多项研究^[27-28]显示,接受体外受精/显微受精后妊娠的孕妇发生PE风险的概率显著高于自然受孕人群,OR值大多数位于2.0~2.5之间,本研究进一步证实了ART是PE的独立危险因素(OR=2.690)。然而,ART如何导致胎盘功能障碍并最终引发PE,尤其在早孕期的直接影像学证据尚不充分。本研究的重要发现在于,首次在早孕期(11~13⁺6周)通过三维能量多普勒成像,直接观测到ART孕妇胎盘VI与FI显著降低。这一发现为“ART影响胎盘早期灌注”的病理生理假说提供了关键的即时影像学证据。ART可能通过多种机制导致早孕期胎盘灌注降低^[21, 29]:首先,ART过程中的激素超生理刺激和胚胎体外操作可能诱发表观遗传改变^[30-31],干扰滋养细胞侵袭与分化,导致螺旋动脉重构不全;其次,ART周期中内源性黄体支持不足及激素水平异常可能影响母体血管适应性及内皮功能;此外,涉及配子捐赠的ART可能引发母胎界面免疫失调^[32-34],增强炎症反应,抑制血管生成。本研究中观察到的VI、FI降低,正是上述病理过程导致“胎盘早期灌注不足”的直接体现,从而将临床危险因素(ART)与功能性影像学标志物(3D-PD参数)有机联系起来^[35-38]。

三维能量多普勒灌注参数能够敏感反映胎盘微循环的血管密度与血流状态,相比较传统子宫动脉血流指标,更能直接揭示胎盘功能早期异

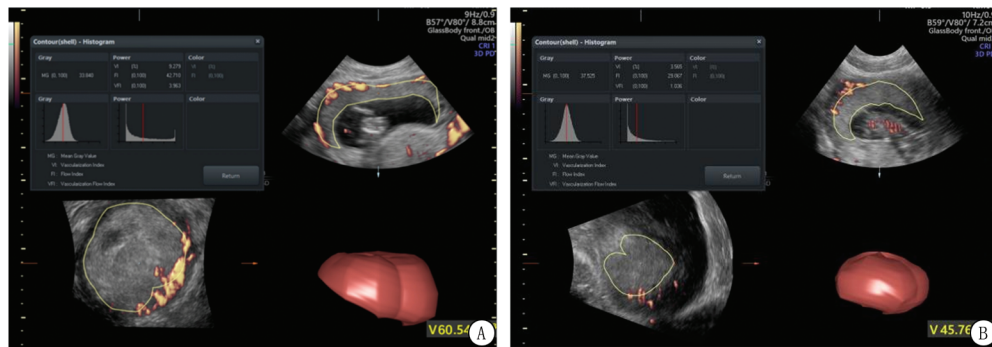


图8 正常妊娠与PE孕妇早孕期胎盘三维能量多普勒图像及定量分析比较

A. 正常妊娠组;B. PE组

Figure 8 Comparison of early - pregnancy placental three - dimensional power Doppler images and quantitative analysis between normal pregnancy and preeclampsia

常^[39-40]。近年来,随着人工智能技术的发展,其在临床评估中的应用价值进一步得到拓展^[41-42]。本研究中PE组的VI、FI及VFI水平均显著低于正常妊娠组,这与多项在不同孕期开展的研究结论相一致^[43-44],证实了胎盘灌注不足是PE发生发展中的持续现象。而本研究的推进之处在于,将这一观测成功前移至更早的孕期(11~13⁺6周),提示这些参数可能具有更早期的预警价值。例如,在PE预测中联合使用3D-PD与弹性成像,PE组的VI和FI明显低于对照组;妊娠高血压疾病组的3D-PD参数显著降低^[43]。尽管不同研究在测量时窗与阈值上存在差异,但3D-PD血管化相关指标在识别胎盘功能异常方面展现出稳定价值。因此,将“ART临床史”与“早孕期胎盘灌注影像学标志物”这两个维度的证据相结合,为在早孕期识别由ART相关胎盘功能障碍引发的PE高风险群体,提供了一个可量化、直观的评估工具。本研究构建的预测模型在内部验证和外部验证中都具有良好的区分度与校准性,外部验证中AUC值=0.781, H-L检验中 $P=0.139$,表明模型的预测功能稳定。DCA结果显示,模型的净获益在低至中等风险阈值(0.05~0.20)范围内,显著优于“全干预”和“无干预”策略,表明该模型在PE临床早期筛查阶段具有一定的决策价值。

但本研究仍存在一定局限性。首先,本研究为单中心回顾性设计,样本量相对有限,结果可能存在选择偏倚。其次,本研究变量构成较为单一,未纳入母体血清生化指标(如可溶性fms样酪氨酸激酶1、胎盘生长因子等)。特别需要说明的是,作为一项聚焦于挖掘常规早孕期超声影像学参数(3D-PD)预测价值的回顾性研究,孕妇在早孕期(11~13⁺6周)的系统性血压及身高体

重(用于计算体重指数)数据在历史病历中并未作为统一的研究变量被完整记录,因此未能将早孕期血压、体重指数等传统预测指标纳入基线比较与模型构建。然而,这一局限性也从另一角度凸显了本研究的核心发现:在未包含上述传统强预测因子的情况下,仅基于“辅助生殖史”与“胎盘3D-PD灌注参数”所构建的模型,依然表现出良好的预测效能(AUC为0.732~0.781)。这提示,胎盘血流灌注参数可能提供了独立于传统临床指标之外的重要预测信息,这为开发不依赖于孕妇基础体征、更直接反映胎盘功能状态的新型早期筛查工具提供了依据。当然,这也意味着需要在未来开展的前瞻性研究中,通过系统收集多维度数据(包括生命体征、血清标志物等)进行验证与完善。最后,胎盘三维能量多普勒检查对操作者技术和设备有一定依赖,其标准化是推广应用中需解决的问题。

综上所述,PE发生与ART受孕和胎盘血管化参数降低有关,基于ART、VI及FI构建的预测模型具有良好的区分度和校准度。该模型可有效筛查PE早期风险,为高危妊娠的早期识别与个体化干预提供重要参考。

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