·论著·

基于HR-VWI特征构建青年急性缺血性脑卒中患者颅内动脉狭窄的风险因素模型

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摘要 目的 基于高分辨率磁共振血管壁成像(HR-VWI)特征构建青年急性缺血性脑卒中(AIS)患者颅内动脉狭窄的风险因素模型。**方法** 回顾性分析2021年1月至2023年1月于衡水市人民医院就诊的290例青年AIS患者,按照7∶3的比例随机将其分为建模集(203例)和验证集(87例),根据患者是否发生颅内动脉狭窄将建模集患者分为狭窄组和无狭窄组。采用多因素logistic回归分析建模集患者临床数据及HR-VWI特征,筛选出青年AIS患者发生颅内动脉狭窄的影响因素;使用R软件构建风险因素模型,并对模型进行验证。**结果** 290例青年AIS患者中共有88例发生颅内动脉狭窄,发生率为30.34%。狭窄组低密度脂蛋白胆固醇(LDL-C)、斑块负荷、吸烟史、高血压、偏心性斑块比例均高于无狭窄组($P<0.05$),最小管腔面积、重构指数均低于无狭窄组($P<0.05$);多因素logistic回归分析结果显示,吸烟史、高血压、LDL-C、斑块负荷、斑块形态、重构指数均为青年AIS患者发生颅内动脉狭窄的影响因素($P<0.05$);基于上述危险因素,使用R软件构建列线图模型,受试者操作特征曲线结果显示,列线图模型在建模集、验证集中预测患者发生颅内动脉狭窄的曲线下面积分别为0.872(95%*CI*:0.815~0.902)、0.850(95%*CI*:0.789~0.891);建模集和验证集的Hosmer-Lemeshow检验结果显示,2组校准曲线与标准曲线均表现出良好的一致性($\chi^2=0.589$,$P=0.571$;$\chi^2=0.602$,$P=0.558$)。**结论** 本研究基于HR-VWI特征构建的青年AIS患者颅内动脉狭窄的风险因素模型具有良好的预测效能,为临床防治提供了新的思路和方法。

关键词 高分辨率磁共振血管壁成像;急性缺血性脑卒中;颅内动脉狭窄;列线图模型
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Constructing a risk factor model for intracranial artery stenosis in young patients with acute ischemic stroke based on HR-VWI features

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Abstract Objective To establish a risk factor model for intracranial artery stenosis in young patients with acute ischemic stroke(AIS) based on high-resolution magnetic resonance vascular wall imaging(HR-VWI). **Methods** Young patients with AIS($n=290$) treated at Hengshui People's Hospital between January 2021 and January 2023 were retrospectively analyzed and randomly divided into a modeling set(203 cases) and a validation set($n=87$) at a ratio of 7∶3. Patients in the modeling set were divided into the stenosis and non-stenosis groups according to whether they had intracranial artery stenosis. Multivariate logistic regression was used to analyze the clinical data and HR-VWI characteristics of the patients in the modeling set to screen for factors influencing intracranial artery stenosis in young patients with AIS. R software was used to construct and verify the risk factor model. **Results** Among the 290 patients,88 had intracranial artery stenosis(30.34%). The proportions of low-density lipoprotein cholesterol(LDL-C),plaque load,smoking history,hypertension,and eccentric plaques were higher in the stenosis group than in the non-stenosis group($P<0.05$),and the minimum lumen area and remodeling index were lower in the stenosis group than in the non-stenosis group($P<0.05$). Multivariate logistic regression analysis showed that smoking history,hypertension,LDL-C level,plaque load,plaque morphology,and remodeling index were all factors influencing intracranial artery stenosis in young patients with AIS($P<0.05$). Based on the above risk factors,R was used to build a nomogram early warning model. The ROC results showed that the AUC of the nomogram model for predicting intracranial artery stenosis in the modelling and vali-

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dation sets were 0.872 (95%*CI*: 0.815–0. 902) and 0.850 (95%*CI*: 0.789–0.891), respectively. The Hosmer-Lemeshow test results of the modeling and validation sets were χ^2=0.589, *P* = 0.571 and χ^2=0.602, *P* = 0.558, respectively. The calibration curves of the two groups were consistent with the standard curves. **Conclusion** The risk factor model for intracranial artery stenosis in young patients built in this study based on HR-VWI features exhibits good predictive efficacy, providing a new method for clinical prevention and treatment.

Keywords high-resolution magnetic resonance vascular wall imaging; acute ischemic stroke; intracranial artery stenosis; nomogram model

近年来，随着生活方式的改变和社会压力的增加，青年卒中患者的数量逐渐增多，其中急性缺血性脑卒中（acute ischemic stroke，AIS）约占脑卒中的70%，致残率和死亡率均较高[1]。青年AIS患者往往伴有症状性颅内动脉狭窄，这一病理特征不仅增加了卒中的复发风险，还极大地影响了患者的预后和生活质量[2]。因此，建立有效的风险因素模型，识别颅内动脉狭窄高风险患者，在临床上有重要意义。由于传统血管检查方法的侵入性和高费用，鲜有研究关注AIS患者的影像学特征和颅脑血管狭窄。高分辨率磁共振血管壁成像（high-resolution magnetic resonance vascular wall imaging，HR-VWI）作为一种新兴的无创性影像检查技术，可清晰显示颅内动脉管壁的细微结构，包括斑块的位置、形态、成分及稳定性，为颅内动脉疾病的诊断提供了强有力的支持[3]。LEHMAN等[4]研究发现，HR-VWI在颅内狭窄的表征中补充了传统管腔血管造影技术，提高了临床诊断的特异性，在某些情况下可作为颅内动脉病变的参考指标。鉴于此，本研究基于HR-VWI特征建立青年AIS患者发生颅内动脉狭窄的风险因素模型，对青年AIS患者的临床资料和HR-VWI特征进行分析，筛选出与颅内动脉狭窄相关的风险因素，为青年AIS的早期诊断和治疗提供依据。

1　材料与方法

1.1　一般资料

选取衡水市人民医院2021年1月至2023年1月收治的290例青年AIS患者进行回顾性分析，按照7∶3的比例随机分为建模集（203例）和验证集（87例）。纳入标准：符合相关诊断标准，经临床确诊为AIS[5]；年龄>18且<45岁；发病14 d内行HR-VWI检查；临床资料完整。排除标准：伴有颅内肿瘤或其他脑部器质性病变者；影像资料不清晰者；精神障碍者；患有脑炎、蛛网膜下腔出血者；患有明确的心源性栓塞、肝肾功能不全者。本研究获得衡水市人民医院伦理审批委员会批准（编号2021-1-008）。

1.2　研究方法

1.2.1　临床资料收集：收集患者年龄、性别、体重指数（body mass index，BMI）、合并基础疾病、吸烟史、饮酒史、总胆固醇（total cholesterol，TC）、甘油三酯（triglycerides，TG）、高密度脂蛋白胆固醇（high-density lipoprotein cholesterol，HDL-C）、低密度脂蛋白胆固醇（low-density lipoprotein cholesterol，LDL-C）等指标。

1.2.2　HR-VWI检查：使用德国西门子3.0TMRI扫描仪，患者仰卧位，头部置于头部线圈中心保持不动。采用三维T1 加权成像（T1-weighted imaging，T1WI）、T2 加权成像（T2-weighted imaging，T2WI）和质子密度加权成像（proton density weighted imaging，PDWI）序列进行 HR-VWI 检查。各向同性分辨率为0.5~0.8 mm；层厚为1~2 mm；T1WI 的重复时间设置为 500~800 ms，回波时间为 10~20 ms；T2WI 的重复时间设置为 2 000~4 000 ms，回波时间为 80~120 ms；矩阵为256×256。进行定位扫描后，按照预设的扫描参数进行 HR-VWI 检查。扫描范围包括整个颅内血管，如颈内动脉、大脑中动脉、椎动脉和基底动脉等。

由2位具有10年以上神经影像诊断经验的副主任医师及以上职称的影像科医生分别对HR-VWI图像进行评估，观察斑块负荷、斑块形态、最小管腔面积、血管壁重构指数等参数。若评估过程中出现异议由影像科主任进行复核，复核结果认定为最终结果。

1.3　颅内动脉狭窄的判定[6]

患者均行数字减影血管造影（digital subtraction angiography，DSA）检查，根据患者是否伴有颅内动脉狭窄分为狭窄组和无狭窄组。

1.4　统计学分析

采用SPSS 26.0进行统计分析。计量资料符合正态分布，以$\bar{x} \pm s$表示，2组间比较采用独立样本*t*检

验；计数资料以率（%）表示，采用χ^2检验比较。青年AIS患者发生颅内动脉狭窄的危险因素通过多因素logistic回归分析，使用R软件构建相关风险因素模型，并通过绘制受试者操作特征（receiver operating characteristic，ROC）曲线和校准曲线对模型预测效能进行验证。$P<0.05$为差异有统计学意义。

2　结果

2.1　建模集与验证集临床资料比较

290例青年AIS患者中共有88例发生颅内动脉狭窄，发生率为30.34%，其中建模集203例患者中有65例发生颅内动脉狭窄，验证集87例患者中有23例发生颅内动脉狭窄。建模集和验证集患者临床资料比较均无统计学差异（$P>0.05$），具有可比性，见表1。

2.2　狭窄组和无狭窄组临床资料比较

狭窄组与无狭窄组患者年龄、性别构成、BMI、饮酒史、糖尿病占比、TC、TG、HDL-C水平均无明显差异（$P>0.05$），狭窄组LDL-C、斑块负荷、吸烟史、高血压、偏心性斑块占比均高于无狭窄组（$P<0.05$），最小管腔面积、重构指数均低于无狭窄组（$P<0.05$），见表2。

表1　建模集与验证集临床资料比较

Tab.1　Comparison of clinical data between the modeling and validation sets

Item	Modeling set (n = 203)	Validation set (n = 87)	t/χ^2	P
Age (year)	34.58 ± 5.31	33.42 ± 5.20	1.715	0.087
Sex [n (%)]			0.174	0.676
Male	122 (60.10)	50 (57.47)		
Female	81 (39.90)	37 (42.53)		
BMI (kg/m^2)	23.25 ± 1.66	23.32 ± 1.58	0334	0.739
Smoking history [n (%)]			0.673	0.412
Yes	99 (48.77)	47 (54.02)		
No	104 (51.23)	40 (45.98)		
Drinking history [n (%)]			0.954	0.329
Yes	90 (44.33)	44 (50.57)		
No	113 (55.67)	43 (49.43)		
Hypertension [n (%)]	61 (30.05)	30 (34.48)	0.556	0.456
Diabetes [n (%)]	22 (10.84)	10 (11.49)	0.027	0.870
TC (mmol/L)	4.24 ± 0.88	4.35 ± 0.92	0.962	0.337
TG (mmol/L)	1.42 ± 0.34	1.37 ± 0.36	1.127	0.261
HDL-C (mmol/L)	1.95 ± 0.46	1.89 ± 0.44	1.031	0.303
LDL-C (mmol/L)	2.82 ± 0.71	2.73 ± 0.69	0.998	0.319
Minimum cavity area (mm^2)	4.22 ± 0.89	4.15 ± 0.91	0.610	0.543
Reconstruction index	1.00 ± 0.23	0.96 ± 0.20	1.409	0.160
Plaque burden (%)	4.89 ± 1.16	4.75 ± 0.97	0.987	0.324
Plaque morphology [n (%)]			0.988	0.320
Eccentric	85 (41.87)	31 (35.63)		
Centripetal	118 (58.13)	56 (64.37)		

2.3　青年AIS患者颅内动脉狭窄的多因素分析

以患者是否发生颅内动脉狭窄为因变量，将表2中差异有统计学意义的指标作为自变量，剔除混杂因素和交互作用后，采用向前法进行多因素回归分析，结果显示，吸烟史、高血压、LDL-C、斑块负荷、斑块形态、重构指数均为青年AIS患者发生颅内动脉狭窄的影响因素（$P<0.05$），见表3。

2.4　风险因素模型构建及验证

基于多因素结果得出的影响因素，构建列线图模型，各指标对颅内动脉狭窄的影响以具体分值体现，所有指标得分之和即为总分，根据总分对应的风险值可推测出患者颅内动脉狭窄的发生概率，见

图1。

ROC结果显示，列线图模型在建模集、验证集中预测患者发生颅内动脉狭窄的曲线下面积分别为0.872（95%*CI*：0.815~0.902）、0.850（95%*CI*：0.789~0.891），见图2。建模集和验证集的Hosmer-Lemeshow检验结果显示，2组校准曲线与标准曲线均表现出良好的一致性（分别为χ^2=0.589，P = 0.571；χ^2=0.602，P = 0.558），见图3。

表2　狭窄组和无狭窄组临床资料比较

Tab.2　Comparison of clinical data between stenosis and non-stenosis groups

Item	Stenosis group (n = 65)	Non-stenosis group (n = 138)	t/χ^2	P
Age (year)	35.49 ± 5.14	34.15 ± 5.37	1.681	0.094
Sex [n (%)]			3.325	0.068
Male	45 (69.23)	77 (55.80)		
Female	20 (30.77)	61 (44.20)		
BMI (kg/m^2)	23.40 ± 1.79	23.18 ± 1.64	0.866	0.388
Smoking history [n (%)]			4.828	0.028
Yes	39 (60.00)	60 (43.48)		
No	26 (40.00)	78 (56.52)		
Drinking history [n (%)]			2.463	0.117
Yes	34 (52.31)	56 (40.58)		
No	31 (47.69)	82 (59.42)		
Hypertension [n (%)]	27 (41.54)	34 (24.64)	6.005	0.014
Diabetes [n (%)]	9 (13.85)	13 (9.42)	0.896	0.344
TC (mmol/L)	4.36 ± 0.93	4.18 ± 0.87	1.345	0.180
TG (mmol/L)	1.47 ± 0.35	1.39 ± 0.31	1.645	0.102
HDL-C (mmol/L)	1.91 ± 0.45	1.97 ± 0.48	0.847	0.398
LDL-C (mmol/L)	3.17 ± 0.76	2.65 ± 0.66	4.985	<0.001
Minimum cavity area (mm^2)	3.36 ± 0.80	4.63 ± 1.05	8.638	<0.001
Reconstruction index	0.90 ± 0.21	1.04 ± 0.25	3.910	<0.001
Plaque burden (%)	7.24 ± 1.96	3.78 ± 0.90	17.395	<0.001
Plaque morphology [n (%)]			12.910	<0.001
Eccentric	39 (60.00)	46 (33.33)		
Centripetal	26 (40.00)	92 (66.67)		

表3　青年AIS患者颅内动脉狭窄的多因素分析

Tab.3　Multivariate analysis of intracranial artery stenosis in young patients with AIS

Variable	β	SE	Wald χ^2	OR	95%CI	P
Smoking history	0.731	0.296	6.099	2.077	1.365–3.235	0.014
Hypertension	0.496	0.208	5.686	1.642	1.261–2.273	<0.001
LDL-C	0.853	0.351	5.906	2.347	1.596–3.524	<0.001
Plaque burden	1.115	0.426	6.851	3.050	2.479–4.185	<0.001
Eccentric plaque	0.962	0.321	8.981	2.617	2.104–3.747	<0.001
Reconstruction index	–0.802	0.318	6.361	0.448	0.175–0.628	0.003
Constant	–0.493	0.312	2.497	–	–	–

3　讨论

颅内动脉狭窄的发生可引起患者脑部供血不足，导致不同程度的神经功能缺损症状，影响患者预后。XU等[7]研究发现有将近40%的青年患者伴有大脑中动脉狭窄，且此类患者临床结局往往相对

较差，伴颅内动脉狭窄的AIS患者疾病情况更复杂，不利于患者预后。HR-VWI为临床无创、高分辨率的成像技术，通过优化扫描参数和图像后处理技术，能够实现对颅内动脉管壁结构的精细成像，为颅内动脉的评估提供重要依据[8]。

本研究多因素分析结果显示，吸烟史、高血压、LDL-C、斑块负荷、斑块形态、重构指数均为青年AIS患者发生颅内动脉狭窄的影响因素。吸烟可引起血管收缩，增加血管阻力，长期作用可导致血管壁增厚和硬化。此外，吸烟还会损伤血管内皮细胞，促进血小板聚集和血栓形成，这些因素共同作用，增加了青年AIS患者发生颅内动脉狭窄的风险[9]。

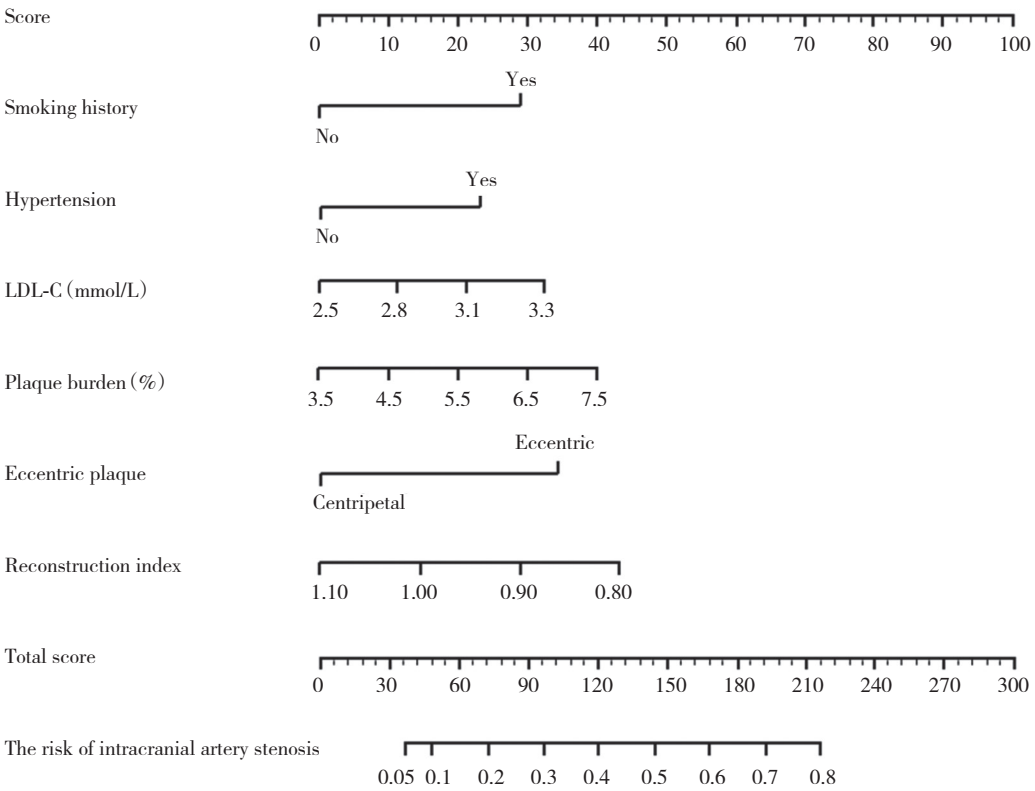
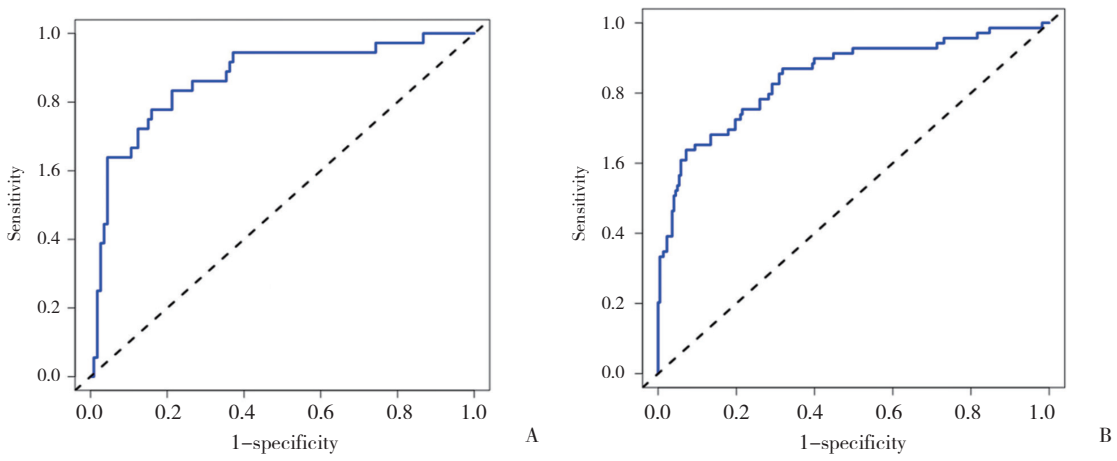


图1　青年AIS患者颅内动脉狭窄的风险因素模型

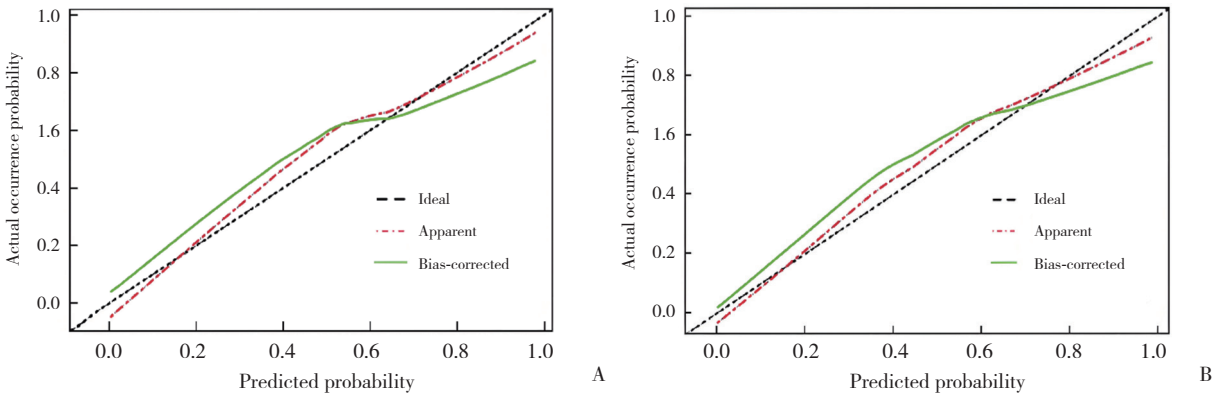
Fig.1　Risk factor model of intracranial artery stenosis in young patients with AIS



A，modeling set；B，validation set.

图2　模型预测患者发生颅内动脉狭窄的ROC曲线

Fig.2　ROC curve of the model used to predict intracranial artery stenosis



A, modeling set; B, validation set.

图3　模型预测患者发生颅内动脉狭窄的校准曲线

Fig.3　Calibration curves of the model for predicting intracranial artery stenosis in patients

高血压可促进动脉粥样硬化的发生和发展，加速血管狭窄的进程。LDL-C是导致动脉粥样硬化的主要危险因素之一，高水平的LDL-C会在血管壁内沉积，被巨噬细胞吞噬后形成泡沫细胞，逐渐形成动脉粥样硬化斑块[10]。既往研究[11]发现，患者若合并高LDL-C血症，发生颅内动脉狭窄的风险将大大增加，与本研究结果一致。斑块负荷是指颅内动脉粥样硬化斑块的体积与血管体积之比，斑块负荷越大，说明血管内的粥样硬化病变越严重，血管狭窄的风险也越高[12]。血流在血管内流动时，会对血管壁产生不同的剪切力，在血管分支处、弯曲处等部位血流剪切力较大，容易导致血管内皮损伤，偏心性斑块多在这些部位形成，导致血管腔狭窄，影响脑部血液供应[13]。此外，偏心性斑块结构不稳定，存在破裂风险，其破裂后易引发出血并形成血栓。这一病理过程可能持续加剧血管腔狭窄程度，最终导致血管完全闭塞。

列线图模型已普遍应用于临床医学研究，通过定量评估、整合不同变量风险评分预测事件发生风险[14]。本研究基于多种因素分析结果建立风险模型，该模型在验证过程中表现出良好的拟合度和预测效能，ROC曲线分析结果显示曲线下面积达到0.7以上，表明该模型具有较高的临床应用价值[15]。

综上所述，本研究通过HR-VWI特征分析，成功构建了青年AIS患者颅内动脉狭窄的风险因素模型，为临床医生提供了更有效的诊断工具。同时，本研究也存在一定的局限性，由于样本量相对较小，可能无法完全代表青年AIS患者的总体人群；此外，HR-VWI对设备和技术要求较高，并非所有医疗机构都具备开展该检查的条件，限制了其在临床中的广泛应用。未来的研究可通过进一步扩大样本量、改进成像技术进行模型的验证和推广。

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