·专题研究:肿瘤·

PET/MRI在乳腺癌诊疗方面的应用

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[摘 要] 乳腺癌是女性最常见的恶性肿瘤之一,其发病率和死亡率逐年升高,对乳腺癌患者开展早期精确诊断与治疗是改善患者预后的关键。一体化正电子发射断层扫描/磁共振成像(positron emission tomography/magnetic resonance imaging,PET/MRI)作为一种新兴的多模态分子影像技术,融合了PET的分子代谢成像和MRI的高分辨率软组织成像优势,能够以更高清晰度识别肿瘤及其与周边组织的关系,在乳腺癌的诊疗过程中有着重要的临床意义。文章旨在对PET/MRI在乳腺癌诊断、分期、分子分型及疗效监测等方面的应用及进展进行综述。

[关键词] 乳腺癌;正电子发射断层扫描;磁共振成像

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Application of PET/MRI in the diagnosis and treatment of breast cancer

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[**Abstract**] Breast cancer is one of the most common malignant tumors in women, with its incidence and mortality rates increasing annually. Early and accurate diagnosis and treatment of breast cancer patients are crucial for improving prognosis. Integrated positron emission tomography/magnetic resonance imaging (PET/MRI) as an emerging multimodal molecular imaging technology, combines the molecular metabolic imaging capabilities of PET with the high-resolution soft tissue imaging advantages of MRI. This allows for clearer identification of tumors and their relationships with surrounding tissues, holding significant clinical importance in the diagnosis and treatment of breast cancer. This article primarily reviews the applications and advancements of PET/MRI in the diagnosis, staging, molecular typing, and treatment monitoring of breast cancer.

[**Key words**] breast cancer; positron emission tomography; magnetic resonance imaging

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乳腺癌是女性发病率最高、最常见的恶性肿瘤之一,世界卫生组织国际癌症研究机构(International Agency for Research on Cancer,IARC)发布的最新全球癌症统计显示,2022年全球女性新发癌症病例数970万人,其中乳腺癌新发病例数230万人,为全球女性第一大癌种,占女性恶性肿瘤患者比例为23.8%[1]。在传统乳腺癌诊断领域,乳腺X线摄影(mammography,MMG)是常用的筛查手段,其对乳腺钙化灶敏感性较高,但对软组织的分辨率相对较低,易导致漏诊。乳腺超声(ultrasonography,US)检查操作便捷且无辐射,能较好呈现乳腺肿块的多项特征,不过在微小钙化灶的显示及诊断客观性上有所欠缺[2]。磁共振成像(magnetic resonance imaging,MRI)在乳腺病变检出敏感性上表现卓越,但在精确探测乳腺癌特异性分子标志物及全面评估肿瘤生物学行为方面不足。随着医学影像技术不断发展,多模态成像技术逐渐在临床诊疗中展现出独特的优势,正电子发射断层扫描/磁共振成像(positron

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emission tomography/magnetic resonance imaging，PET/MRI）是一种先进的融合成像技术，PET通过探测放射性示踪剂衰变产生的γ光子反映组织代谢活性，MRI利用氢质子在外加磁场中的弛豫特性，提供高分辨率的解剖结构信息。两种成像模式相互结合从而实现在一次检查中同时获取病灶功能代谢与解剖结构信息。相较于传统的乳腺钼靶成像、乳腺超声，或是单一磁共振成像，PET/MRI单次检查便能够实现多序列、多参数成像，获得全身解剖结构、功能状态及分子代谢等丰富信息，对乳腺癌患者进行全面评估，已逐渐成为乳腺癌临床研究与诊疗实践中的重要工具[3]。本文主要就氟代脱氧葡萄糖（^{18}F-fludeoxyglucose，^{18}F-FDG）PET/MRI在乳腺癌诊疗方面的应用综述如下。

1 ^{18}F-FDG PET/MRI在乳腺癌诊断方面的应用

相比于乳腺MMG和超声检查，MRI在乳腺癌诊断中展现出更高的准确性，然而，MRI也伴随着较高的假阳性率[4]。随着PET的不断发展，PET显像能够在疾病早期分子水平变化阶段发现病灶，从而为乳腺癌的诊断提供更为有力的依据。Sasaki等[5]比较了MRI、PET以及^{18}F-FDG PET/MRI融合显像对乳腺癌原发病变的检出效能，结果显示，有13%的病变在单纯乳腺MRI上无法被检测到，7%的病变在单一PET图像上无法被检测到，而在乳腺^{18}F-FDG PET/MRI融合图像中，所有病变均能被视觉检测到，这表明^{18}F-FDG PET/MRI融合显像比单一的MRI或者PET显像对乳腺癌的检测更为敏感。此外，PET成像凭借其独特的成像参数，在区分乳腺疾病的良恶性方面发挥着重要作用。Leithner等[6]发现，在^{18}F-FDG PET/MRI图像中，最大标准化摄取值（maximum standard uptake value，SUVmax）可作为区分乳腺癌良恶性的参考指标，乳腺恶性肿瘤的平均SUVmax为5.2，而良性肿瘤的平均SUVmax为2.6（$P < 0.001$）。Romeo等[7]在一项纳入102例患者的前瞻性研究中对比了MRI和^{18}F-FDG PET/MRI对乳腺癌诊断的准确性，建立了一个集成模型，该模型结合了从动态增强MRI（dynamic contrast enhanced MRI，DCE-MRI）、PET图和表观扩散系数（apparent diffusion coefficient，ADC）图中提取的定量参数和放射组学特征，在受试者工作特征（receiver operating characteristic，ROC）曲线分析中展现出最佳性能，其曲线下面积（area under curve，AUC）为0.983，而单独的动态对比增强MRI的AUC值为0.937，进一步证明了^{18}F-FDG PET/MRI作为一种非侵入性诊断工具，在区分乳腺良性和恶性病变方面具有较高的准确性，为乳腺癌的诊断提供了有力的支持。

2 ^{18}F-FDG PET/MRI在乳腺癌分期方面的应用

对于乳腺癌患者，准确的临床分期信息对于制定治疗方案和预测疾病预后至关重要。根据美国癌症联合会（American Joint Committee on Cancer，AJCC）发布的第八版癌症临床分期系统，乳腺癌分期包括原发肿瘤的大小（T）、区域淋巴结状态（N）和远处转移（M）[8]。^{18}F-FDG PET/MRI提供的解剖和功能代谢信息在乳腺癌患者的准确分期及再分期方面表现出较高的诊断性能[9]。

2.1 T分期

乳腺癌T分期的评估包括肿瘤的大小和浸润程度，术前进行正确的评估可以更好明确患者治疗方案，如手术方式的选择，以及是否需要行手术前后的辅助化疗或激素治疗[10]。Singnurkar等[11]指出，^{18}F-FDG PET/MRI融合显像对于乳腺癌T分期的诊断正确率高于单独的PET和MRI。Grueneisen等[12]在一项纳入50例患者的前瞻性研究中对比了MRI、^{18}F-FDG PET/CT和^{18}F-FDG PET/MRI的影像学结果，并以病理结果作为金标准进行参考，结果表明，与^{18}F-FDG PET/CT（34/50，68%）相比，^{18}F-FDG PET/MRI和单独MRI显示了相同的结果（41/50，82%），均能对更多乳腺肿瘤的T分期进行正确评估（$P < 0.05$）。Botsikas等[13]研究也显示，单独MRI和^{18}F-FDG PET/MRI之间的T分期差异并无统计学意义，另外还发现^{18}F-FDG PET/MRI准确识别出了2例常规影像学检查遗漏的乳头受累病变。综上，^{18}F-FDG PET/MRI对于乳腺癌T分期诊断具有较高的敏感性，与MRI不相上下，但对于一些微小病变尤其是原发于乳头乳晕处的隐匿性乳腺癌更具诊断价值。

2.2 N分期

淋巴结转移是乳腺癌最常见的转移方式，癌细胞可经淋巴道转移至腋窝淋巴结、内乳淋巴结及锁骨上、下淋巴结[14]。目前，评估乳腺癌N分期的金标准仍是淋巴结活检，但腋窝结构破坏往往会导致上肢淋巴水肿或组织水肿、血肿以及活动障碍，因此，无创影像学的检查对于乳腺癌淋巴结状态的评估至关重要。Morawitz等[15]指出，^{18}F-FDG PET/MRI在确定新诊断乳腺癌患者淋巴结的状态方面优于普通MRI和CT成像，诊断准确率分别为82.2%、69.9%和63.0%。Bruckmann等[16]分析了80例患者的淋

巴结表现状态，与CT相比，^{18}F-FDG PET/MRI对于乳腺癌N分期的诊断准确率更高，该研究中有80%的患者通过CT正确区分了淋巴结的良恶性状态，且对73.75%的患者进行了准确的N分期，相比之下，^{18}F-FDG PET/MRI对于淋巴结良恶性判断的准确率为88.75%，对于N分期的诊断准确率为87.5%。对于此研究中39例淋巴结阳性的患者，^{18}F-FDG PET/MRI的检出率（32/39）优于CT（24/39），相应的灵敏度差异为20.6%，且遗漏的7例患者均为N1期。然而，与^{18}F-FDG PET/CT相比，^{18}F-FDG PET/MRI对于乳腺癌N分期的诊断是否具有优势尚存在争议。Han等[17]对18项研究2 057例患者进行荟萃分析，结果表明，在乳腺癌腋窝淋巴结转移中，^{18}F-FDG PET/CT诊断灵敏度为52%，相应的AUC值为0.73，而^{18}F-FDG PET/MRI对于腋窝淋巴结转移的诊断灵敏度为84%，AUC值为0.86。但Mooij等[18]研究比较了两种成像对于腋窝淋巴结分期的诊断性能，^{18}F-FDG PET/MRI具有更高的敏感性而^{18}F-FDG PET/CT具有更高的特异性，两者之间差异无统计学意义。综上，与传统影像学检查相比，^{18}F-FDG PET/MRI更能对乳腺癌患者的N分期进行准确分期，尤其是对于多枚淋巴结转移的患者，但与^{18}F-FDG PET/CT相比，^{18}F-FDG PET/MRI似乎并没有表现出显著的诊断优势。

2.3 M分期

乳腺癌常见的远处转移部位包括骨骼、肺部、肝脏及脑部。早期发现转移灶对患者的治疗和预后有着重要意义。Bruckmann等[16]对比了全身CT和^{18}F-FDG PET/MRI对于乳腺癌患者远处转移的诊断，80例患者中有74例通过CT正确定义了M期，灵敏度和特异度分别为57.1%和95.9%，相比之下，^{18}F-FDG PET/MRI检测到了所有远处转移，没有任何假阳性发现。目前，^{18}F-FDG PET/MRI对乳腺癌患者远处转移的研究大多聚焦于骨转移，Xia等[19]对16项研究1 261例患者进行荟萃分析指出，对于乳腺癌骨转移，^{18}F-FDG PET/MRI表现出比^{18}F-FDG PET/CT更高的敏感性和相似的特异性。Melsaether等[20]对30例患者242个远处转移进行分析发现，^{18}F-FDG PET/MRI显示骨转移和肝转移水平的敏感性高于^{18}F-FDG PET/CT（$P < 0.05$），而对肺转移灶的检出情况与^{18}F-FDG PET/CT相似。

越来越多的研究表明，^{18}F-FDG PET/MRI成像系统在乳腺癌分期方面发挥着重要作用。Han等[21]指出，使用^{18}F-FDG PET/CT或^{18}F-FDG PET/MRI进行乳腺癌初始分期，使25%的患者分期发生改变，并调整了18%的患者治疗管理方法。在Catalano等[22]的研究中，^{18}F-FDG PET/MRI对于乳腺癌患者TNM分期诊断的准确率为98%，且^{18}F-FDG PET/MRI与真实分期的一致性显著高于^{18}F-FDG PET/CT（$P < 0.05$）和MRI。总体而言，与传统影像技术相比，^{18}F-FDG PET/MRI对于乳腺癌的分期更具诊断潜能，未来^{18}F-FDG PET/MRI广泛使用将能够更准确地评估乳腺癌患者的恶性程度及全身情况，指导治疗决策。

2.4 再分期

乳腺癌再分期是指在初次治疗后对患者的疾病状态进行重新评估的过程，再分期的目的是为了确定疾病的进展、复发或转移情况，以便指导后续的治疗决策[23]。阳依宏等[24]回顾分析了29例乳腺癌术前及术后患者的图像数据，结果表明，^{18}F-FDG PET/MRI术前临床分期与病理金标准的诊断一致性较高（Kappa值=0.892）。^{18}F-FDG PET/MRI检测复发的灵敏度为100.0%，特异度为92.3%，准确率为94.4%。Grueneisen等[25]也表示，与MRI相比，^{18}F-FDG PET/MRI对复发性乳腺癌病变的检测具有很高的诊断价值，但两者之间并无显著差异（$P > 0.05$）。Sawicki等[26]用不同的影像学方法对17例复发乳腺癌患者的134个病灶分别进行评估，^{18}F-FDG PET/MRI、^{18}F-FDG PET/CT、MRI和CT对病灶识别准确率分别为98.5%（132/134）、94.8%（127/134）、88.1%（118/134）和57.5%（77/134），结果表明，与^{18}F-FDG PET/CT、MRI和CT相比，^{18}F-FDG PET/MRI在复发性乳腺癌患者全身分期中显示出最高的诊断性能。

3 ^{18}F-FDG PET/MRI在预测乳腺癌分子分型方面的应用

乳腺癌是一种高度异质性肿瘤，其分子生物学特性在病情发展、预后评估和治疗策略选择中起着至关重要的作用。近年来，随着分子生物学技术的不断进步，对乳腺癌的分子分型和标志物的研究取得了显著进展，为乳腺癌的个体化治疗提供了重要的理论依据。乳腺癌不同的亚型使其对不同治疗模式和预后反应有所不同[27]。乳腺癌的分子标志物主要包括雌激素受体（estrogen receptors，ER）、孕激素受体（progesterone receptors，PR）、人表皮生长因子受体-2（human epidermal growth factor receptor-2，HER-2）以及肿瘤细胞增殖指数（Ki-67）。根据分子标志物的不同将乳腺癌分为4种亚型：Luminal A

型、Luminal B型、HER-2过表达型以及三阴性(triple-negative breast cancer,TNBC)。Umutlu等[28]研究表明,基于多参数^{18}F-FDG PET/MRI的放射组学模型能够有效预测乳腺癌的分子分型,其中PET参数能够区分Luminal型和其他亚型(AUC=0.95,准确率为88.5%),而MRI参数可以进一步鉴别Luminal A型和Luminal B型(AUC=0.98,准确率为97.3%)。Catalano等[29]通过^{18}F-FDG PET/MRI成像参数在21例患者中成功预测了13例正确的表型,其中HER-2阴性患者肿瘤的ADCmean(P=0.009)和SUVmax(P=0.046)显著高于HER-2阳性肿瘤,Ki-67低表达患者的ADCmean值显著低于Ki-67高表达者(P=0.011)。Remeo等[30]基于PET图像参数和ADC开发了一种用于鉴别TNBC和其他亚型的影像组学模型,其诊断准确性为82.8%,敏感度为79.7%,特异度为86.0%,另外还发现在PET图像参数中,TNBC的SUVmax显著高于其他分子亚型(9.5 *vs.* 4.9)。Jannusch等[31]发现,ER/PR的表达与SUVmax有显著的负相关(r=−0.27,P < 0.01;r=−0.19,P < 0.05),Ki-67的表达与SUVmax和SUVmean呈显著正相关(r=0.42,P < 0.01;r=0.19,P < 0.05)。综上,虽然影像学技术不能取代病理活检,但利用^{18}F-FDG PET/MRI多参数成像可以预测乳腺癌分子分型,尤其是SUVmax对于区分不同的受体表达状态有着一定的意义。

4 ^{18}F-FDG PET/MRI在乳腺癌新辅助治疗方面的应用

对于炎性乳腺癌或出现无法切除或局部进展性疾病患者,美国临床肿瘤学会推荐新辅助治疗(neoadjuvant chemotherapy,NAC)为首选治疗方案,在手术之前对患者进行全身系统性治疗,将肿瘤体积缩小,降低肿瘤分期[32]。NAC后达到病理完全缓解(pathological complete response,pCR)的患者具有极高的长期生存率,然而,有60%~85%的患者对治疗没有反应,在早期预测到无应答者,及时调整治疗方案可能会改善生存结果。对乳腺新辅助治疗的早期评估是^{18}F-FDG PET/MRI很重要的研究方向,^{18}F-FDG PET/MRI参数可以在乳腺癌治疗过程中早期预测NAC反应,且混合标志物比单参数能更准确地预测治疗反应。Sekine等[33]对比了74例患者NAC治疗前后的^{18}F-FDG PET/MRI图像,根据病理结果,^{18}F-FDG PET/MRI预测pCR和非pCR患者总体敏感度和特异度分别为72.2%和78.6%,且在治疗前乳腺原发病灶呈肿块样生长的患者pCR率显著高于非肿块样生长的患者(P=0.018)。在Mooij等[34]的实验中,42例接受NAC的乳腺癌患者分别在治疗前中后三个时期行^{18}F-FDG PET/MRI检查,研究表明,结合原发性肿瘤SUVmax和SER的下降百分比可以提高^{18}F-FDG PET/MRI的诊断价值,然而其不能预测治疗后淋巴结阳性患者的腋窝淋巴结反应。Koyasu等[35]将乳腺专用PET(dedicated breast PET,dbPET)加入研究,在dbPET上,非pCR肿瘤的SUVmax显著高于pCR肿瘤,dbPET检测非pCR肿瘤的灵敏度(57.9%)也显著高于普通PET(21.1 %,P=0.016)。目前研究证据表明,对于接受新辅助治疗的乳腺癌患者,^{18}F-FDG PET/MRI能够早期预测其原发肿瘤反应,未来dbPET的不断发展将更有效地检测乳腺癌治疗效果[36]。

5 ^{18}F-FDG PET/MRI在乳腺癌预后和生存期方面的应用

^{18}F-FDG PET/MRI是预测乳腺癌预后及生存期的重要指标,Kitajima等[37]对214例乳腺癌患者^{18}F-FDG PET/MRI参数及临床特征进行分析,高SUVmax和低ADC值与患者高TNM分期、高核级、高Ki-67表达等显著相关,且ADCmean与预后因素的相关性优于ADCmin。Gelezhe等[38]通过分析MRI及^{18}F-FDG PET/CT定量参数得出,ADC值、正增强积分(positive enhancement integral,PEI)及SUVmax值与乳腺癌诺丁汉预后指数(Nottingham prognostic index,NPI)之间存在显著相关性,通过综合这些定量成像参数构建的预后模型能够可靠地预测NPI风险组。Huang等[39]从113例乳腺癌患者的PET和MRI图像中提取了84个放射学特征,其在预测无复发生存期(recurrence-free survival,RFS)方面表现出较高的准确性,1年和2年的RFS平均AUC值分别为0.75和0.68,MRI衍生的灰度共生矩阵(gray level co-occurrence matrix,GLCM)逆差矩归一化和PET衍生的GLCM簇突出是RFS预测模型中的关键特征,提示这两个特征在乳腺癌预后评估中具有重要作用。PET和MRI参数能够有效反映瘤生物学特征的表达和肿瘤侵袭性,综合^{18}F-FDG PET/MRI参数能够有效预测乳腺癌患者预后及生存期。

6 ^{18}F-FDG PET/MRI在评估乳腺癌肿瘤标志物方面的应用

肿瘤标志物是指在肿瘤发生、增殖过程中,由

肿瘤细胞合成、释放或机体对肿瘤细胞反应而产生的一类物质。肿瘤微环境被证明与癌细胞的代谢活动以及局部免疫反应有关，肿瘤浸润淋巴细胞（tumor-infiltrating lymphocyte，TIL）由T淋巴细胞组成，能够反映腺癌抗肿瘤细胞活性。Murakami等[40]发现，^{18}F-FDG PET/MRI参数能够预测TIL的表达水平，与TIL低表达患者相比，TIL高表达患者的SUVmax更高（P=0.013）。目前，关于^{18}F-FDG PET/MRI表现与肿瘤标志物表达之间的相关研究还比较欠缺，但已有研究表明，^{18}F-FDG PET/CT能够反映肿瘤标志物的表达水平，比如糖类抗原15-3（carbohydrate antigen 15-3，CA15-3）。Dong等[41]指出，在可疑乳腺癌复发的患者中，^{18}F-FDG PET/CT阳性患者血清CA15-3水平高于阴性患者。Mwania等[42]对154例治疗后的乳腺癌患者研究发现，84.4%的CA15-3水平升高的患者在^{18}F-FDG PET/CT上表现出复发，但SUVmax与CA15-3水平之间没有显著关系（P=0.385）。未来^{18}F-FDG PET/MRI技术的不断发展，将能够更有效地体现乳腺癌患者血清学肿瘤标志物的水平。

7 其他PET显像剂在乳腺癌中的应用

在乳腺癌分子影像学研究中，目前常用的显像技术主要基于两大成像原理：生物过程成像和受体成像[43]。

生物过程成像是通过示踪肿瘤细胞的异常代谢活动来实现功能显像，^{18}F-FDG即基于肿瘤细胞特有的异常葡萄糖代谢机制成像。^{11}C-蛋氨酸（^{11}C-Methionine，^{11}C-MET）是最常见的氨基酸PET显像剂，已被应用于测定腺癌患者甲硫氨酸的积累，通过流式细胞术测量发现，^{11}C-MET摄取与细胞有丝分裂比例相关，这表明^{11}C-MET的高摄取可能与乳腺癌的高增殖率相关[44]。Sato等[45]通过一项乳腺癌腋窝淋巴结转移的个案研究，对比分析了^{18}F-FDG和^{11}C-MET PET成像特征，结果表明，^{11}C-MET对于淋巴结病灶的摄取优于^{18}F-FDG，基于这一发现，该患者通过低甲硫氨酸饮食和口服重组甲硫氨酸酶联合化疗实现了pCR，这也表明^{11}C-MET PET成像在精准评估乳腺癌生物学行为以及个体化指导治疗手段方面的独特价值。氟代米索硝唑（^{18}F-Fluoromisonidazole，^{18}F-FMISO）是一种硝基咪唑类化合物，能够特异性靶向肿瘤乏氧环境，其摄取程度直接反映肿瘤的缺氧程度，与缺氧诱导因子-1α（Hypoxia-Inducible Factor-1α，HIF-1α）表达呈正相关[46]，在乳腺癌多模态成像中具有独特的临床应用潜力。Cheng等[47]对16例ER阳性乳腺癌患者的33个病灶进行分析发现，基线^{18}F-FMISO的摄取值与用来曲唑内分泌治疗3个月后的疾病进展情况呈正相关，以4 h肿瘤背景比（tumor-to-background ratio，TBR）≥1.2为截断值，可以预测88%的疾病进展（15/17）。

受体成像通过放射性核素标记的配体或抗体，特异性靶向肿瘤细胞表面过表达的受体，从而无创评估乳腺癌生物学特性。氟代雌二醇（^{18}F-Fluoroestradiol，^{18}F-FES）能够反映R在体内的表达和分布[48]，Kurland等[49]对来自11项研究的327个乳腺病变进行荟萃分析发现，^{18}F-FES PET检测ER阳性的敏感性为78%，特异性为98%。PR受雌激素相关基因调节，其表达高度依赖于ER，氟代呋喃基去甲孕酮（^{18}F-Fluorofuranylnorprogesterone，^{18}F-FFNP）是唯一已在人体中进行临床评估的基于PR的探针[50]。Dehdashti等[51]探讨了43例ER阳性乳腺癌患者接受内分泌治疗前后的^{18}F-FFNP PET图像，结果表明，对治疗有反应的28例患者^{18}F-FFNP的摄取明显增高，SUV变化≥7%，同时这部分患者的生存期显著长于对内分泌治疗无反应的患者，这表明^{18}F-FFNP能够有效预测ER阳性乳腺癌患者的疗效。曲妥珠单抗（Trastuzumab）是HER-2阳性乳腺癌患者的标准治疗方法，^{89}Zr-Trastuzumab PET显像可以实现对HER-2阳性病灶的可视化[52]。Ulaner等[53]发现，^{89}Zr-Trastuzumab PET/CT显像能够检测到HER-2阴性乳腺癌患者体内未被发现的HER-2阳性转移灶，从而为HER-2靶向治疗识别出更多潜在的受益患者。尽管这些新型显像剂尚未在临床实践中取代^{18}F-FDG，但它们在乳腺癌的诊疗过程中展现出了巨大的应用潜力，未来靶向示踪剂的不断发展将有助于更精准地评估乳腺癌生物学特性，为患者的个体化诊疗提供更有力的支持。

8 总 结

综上，一体化PET/MRI作为一种新兴的多模态分子成像技术，能够对乳腺癌患者进行全面的病变分析，能够准确对乳腺癌进行诊断、分期、分子分型以及疗效预测。然而，目前PET/MR在临床上还没有被广泛开展应用，未来对于新型示踪剂的研究以及影像组学和人工智能的不断发展，PET/MRI在乳腺癌个体化诊疗中的重要性将愈发显著。

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卞雨蒙参与论文设计、论文撰写；丁紫藤和唐立钧参与文章修改和润色；李天女负责选题、论文修改、经费支持。

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