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Hybrid Imaging Technologies (PET/MRI) In Diagnostic Radiology: A Comprehensive Review

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Abstract

Background: The integration of positron emission tomography and magnetic resonance imaging (PET/MRI) has transformed diagnostic radiology, particularly in the study of dementia and mild cognitive impairment (MCI). With the rising incidence of Alzheimer's disease (AD) among the elderly, early and accurate diagnosis is crucial for effective intervention.

Methods: This comprehensive review evaluates studies published from 2000 to 2023, focusing on the application of PET/MRI in diagnosing dementia subtypes. A PubMed search was conducted using keywords related to PET/MRI and dementia, filtering for studies with a minimum sample size of ten and relevant imaging techniques.

Results: The review highlights advancements in hybrid imaging technologies, demonstrating enhanced diagnostic accuracy for various dementias. Studies indicate that PET/MRI can identify early amyloid-beta accumulation and subtle MRI changes in preclinical stages of dementia. Additionally, machine learning and artificial intelligence have improved image analysis, optimizing the detection of neurodegenerative changes. Notably, the combination of 18F-FDG and amyloid tracers has shown promise in clinical applications, providing better insights into disease progression.

Conclusion: PET/MRI is a pivotal tool in the early diagnosis and management of dementia, enabling a comprehensive assessment of brain function and structure. Future research should focus on developing new tracers and addressing the limitations of current methodologies, particularly for non-Alzheimer's dementia. The integration of advanced imaging techniques with AI holds potential for enhancing diagnostic capabilities and patient outcomes.

Keywords: PET/MRI, Alzheimer's Disease, Mild Cognitive Impairment, Hybrid Imaging, Diagnostic Radiology.

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1. Introduction

In recent years, the use of combined positron emission tomography and magnetic resonance imaging (PET/MRI) hybrid imaging has revolutionized our comprehension and visualization of dementia and moderate cognitive impairment (MCI). Its function is projected to broaden owing to a predicted rise in the number of elderly patients (aged 65 years and older). The incidence of Alzheimer's disease (AD) in this group is around 4% and escalates significantly with age [1]. This worldwide health concern is further exacerbated by the underdiagnosis of dementia according to existing professional recommendations. Research indicates a disparity between diagnosis rates and the anticipated rise in dementia prevalence in both developed and developing countries [2,3]. Ferri et al. concluded that the age-specific incidence of Alzheimer's disease (AD) dementia is anticipated to be consistent globally; nevertheless, variations arise from challenges in assessing social impairment or reduced survival rates [2]. Their team posits that emerging countries with a comparatively low baseline are anticipated to have rapid growth. For instance, it was anticipated that whereas in 2010 Latin American nations had around half the number of individuals with dementia compared to North America, this figure is projected to reach nearly 9 million by 2040.

A multitude of studies underscore the need for early management and prevention by standard therapies, like acetylcholinesterase inhibitors or monoclonal antibodies targeting amyloid-beta (Aβ), which may be enhanced by concurrent PET/MRI imaging [4,5]. Amyloid deposition seems to stabilize early during the presymptomatic or prodromal stages of Alzheimer's disease, based on longitudinal data from patients receiving serial amyloid and MR imaging assessments [6]. Individuals diagnosed with Alzheimer's disease often do not exhibit a significant rise in amyloid over time, as assessed by PET tracers, underscoring the importance of hybrid imaging that may identify small alterations on MRI during the preclinical stages of dementia [7]. The recent development of innovative anti-amyloid beta monoclonal antibodies signifies a paradigm change in the therapy of Alzheimer's disease, heralding a new era of focused medicines. Lecanemab, the first monoclonal antibody sanctioned by the United States Food and Drug Administration, has shown a substantial delay in clinical deterioration and enhancement of functional status in individuals with Alzheimer's dementia. The effectiveness of lecanemab has been shown only in early-stage illness. Consequently, the early diagnosis of amyloid-beta accumulation in the progression of the disease is critically significant. Progress in PET/MR technology may facilitate the identification of individuals exhibiting first imaging indicators of Alzheimer's dementia who might benefit from lecanemab and analogous anti-amyloid beta therapeutics. Given the urgent need to comprehend and delineate dementia for this expanding population, PET/MRI is more pivotal in early diagnosis.

Prior work on hybrid PET/MR imaging in dementia mostly pertains to eras before 2020, concentrating on numerous features like alterations in image collection parameters, post-processing techniques, and areas of interest such as the hippocampus, and tracers [8-10]. This narrative review aims to analyze recent studies published from 2018 to 2023 about the applicability of PET/MRI in characterizing different subtypes of dementia, as imaging technology rapidly advances. This article will highlight important discoveries in major brain areas for future applications, as well as the general distribution of scanner field strengths, brands, and tracers in the most recent research.

2. Methods

A PubMed search was conducted using the MeSH keywords ("PET-MR" OR "PET-MRI") AND ("Dementia" OR "MCI" OR "Mild cognitive impairment" OR "Alzheimer" OR "AD") in 2023, with the date range limited to 2014-2023. Standard abbreviations were used to identify relevant studies concerning the application of hybrid imaging to dementia subtypes or mild cognitive impairment (MCI). The criteria for initial eligibility of studies were publication in English, a minimum sample size of ten human individuals, relevance to MCI or dementia, and the use of hybrid PET/MRI imaging. This difference is crucial, since some studies may have included PET/MRI as a keyword while imaging patients with each modality individually at various time intervals. Abstracts were omitted if the study's purpose was to compare the performance of various PET tracers or if they originated from a conference session.

3. Artificial Intelligence

This evaluation included extensive debates on artificial intelligence (AI) and machine learning (ML) across all publication genres [11-13]. Zhou et al. and Minoshima et al. delineated the prevalent machine learning methodologies used in radiology, including feed-forward neural networks (FFNN) and convolutional neural networks (CNN) [11,12]. This study demonstrated that the majority of AI research in hybrid imaging is either a convolutional neural network (CNN) or a generative adversarial network (GAN) inside the classification model. Convolutional Neural Networks (CNNs) effectively extract spatial elements from pictures and may learn pertinent hierarchies; but they are inadequate for processing temporal information, making them unsuitable for assessing the course of Alzheimer's Disease across time using volumetric data. Generative Adversarial Networks (GANs) may provide synthetic data that mimics authentic dementia samples; yet, training them can be arduous and may result in implausible visuals. Logan et al. provide a comparable elucidation of various networks and describe the utilization of ensemble models that amalgamate the outputs of distinct models for a conclusive prediction [13].

Recurring themes in the review papers are constant, particularly with brain areas pertinent to dementia; nevertheless, the current surge in interest in artificial intelligence has led to an increase in research examining how machine learning enhances PET/MRI acquisitions compared to earlier times. Currently, CNNs have superior performance and promise in neuroimaging analysis, making them the preferred model above other networks in this study. This model can autonomously extract and learn picture characteristics while effectively analyzing large datasets of PET/MRI images. The limitations of CNNs are not exclusive to this model but impact the whole area of AI, including sensitivity to imaging techniques, which may be alleviated by training on diverse scanners or field strengths, and the risk of overfitting when data is scarce. This session will further elaborate on the technological enhancements and clinical categorization of dementia subtypes facilitated by breakthroughs in machine learning.

4. Technological Enhancements

Technical studies comprised 19.4% (18/93) of the chosen publications. A predominant emphasis was placed on precise attenuation correction (AC) [14-19]. Historically, a density map for correction needed to be generated from MRI to accurately assess PET tracer activity, but this was difficult owing to the absence of bone signal [20]. A variety of strategies were examined to rectify attenuation in a large cohort. The most effective approaches, such as RESOLUTE, a prominent segmentation-based AC technique, show sensitivity to certain MRI sequences, rendering them potentially affected by advancements in models or system upgrades [21]. Ladefegod et al. used convolutional neural networks (CNNs) to transform non-attenuation corrected PET pictures into attenuation and scatter-corrected images, demonstrating enhanced robustness across various scanners owing to the inherent characteristics of neural networks [22]. Subsequent investigations used deep learning to associate a longitudinal relaxation rate, optimally assessed using a T1-weighted examination, with Hounsfield units in osseous and soft tissues of the brain to execute AC [16]. In 2020, Sgard et al. conducted research using zero echo-time (ZTE) MRI to produce the attenuation map, resulting in reduced bias and interindividual variability in comparison to a single-atlas attenuation correction approach [14]. Furthermore, a quality evaluation study conducted by Øen et al. confirmed that MRI-based attenuation correction (MRAC) closely approximated CT-based attenuation correction (CTAC). The scores for FDG absorption indicated that the cerebellar area exhibited the least mean absolute difference according to this article [15].

Diverse techniques have been assessed to rectify motion. This encompasses mechanical techniques, such as head restraints, and image-based techniques, such as frame-based motion correction (FBMC), which aligns PET scans to a reference position for proper registration [23]. This review includes two technical publications that examined and quantitatively assessed the effect of motion correction on imaging in dementia patients [24,25]. Research conducted by Tiss et al. showed that frame-by-frame motion detection decreased the standard deviation in tau accumulation quantification by 16% to 49% in regions including the precuneus and amygdala [24]. In research including 30 dementia sufferers, Chen et al. observed that motion correction significantly influenced areas with greater amplitude motion, particularly the medial orbitofrontal cortex [25].

Several studies in this review examined methods for the thorough assessment of tracer intensity scores in hybrid imaging [26,27]. Research conducted by Coath et al. examined the use of Centiloid conversion to standardize assessments of amyloid-beta plaque buildup assessed by 18F-Florbetapir across several study cohorts, including Insight 46 and the Alzheimer's Disease Neuroimaging Initiative (ADNI) [26]. The standardized uptake value ratio (SUVR) is often used for data extraction from PET imaging. This measure relies on several factors, such as the tracer used, target and reference areas, and picture acquisition settings. The 0 Centiloids (CL) reference point signifies the mean amyloid concentration in young, healthy individuals, while 100 Centiloids denote the average concentration in a typical Alzheimer's Disease (AD) patient, expressed by the generalized linear equation: Centiloids = a × (SUVR) + b. The coefficients are established by a calibration procedure using samples at the anchor points. A separate study by Ford et al. [27] used a heuristic scoring approach to quantify brain areas that fell below a predetermined z-score threshold via statistical parametric mapping (SPM). This approach standardizes and analyzes brain pictures on a voxel-by-voxel level and utilizes statistical tests like ANOVA or Student's t-test to identify significant differences. The scoring approach demonstrated comparable efficacy to the random forest technique trained on all z-scores for distinguishing frontotemporal lobar degeneration (FTLD) from Alzheimer's disease (AD). This heuristic approach is more accessible than a machine learning tool for laboratories that lack computing resources.

Notably, there is an initiative to produce zero-dose healthy baselines of FDG PET/MRI images and get hybrid imaging at ultra-low doses using GANs and CNNs to aid in the formulation of patient safety procedures [28-31]. Numerous doctors analyze the FDG-PET component of hybrid pictures with healthy controls of comparable demographics. Diminished tracer uptake is non-specific and may indicate inherent anatomical variations or result from previous neurological damage, such as chronic microvascular ischemia changes. Prior studies have used variational autoencoders (VAEs), a category of neural networks that compress input picture data and then rebuild it to its original state. The variational component enables the encoder to allocate the input within a latent space, facilitating variability and enhancing control over the VAE's picture-generation process. In research conducted by Hinge et al., these artificially created pictures were compared with healthy controls, demonstrating invariance in mean relative percent difference and mean absolute value relative difference [29]. A separate series of research aimed at maintaining diagnostic quality while reducing scan durations with a high-sensitivity time-of-flight (TOF) PET device. Behr et al. demonstrated that the picture quality of TOF PET/MRI was equivalent to or superior to that of PET/CT, even with abbreviated scan durations, and confirmed that the 4-minute acquisition intervals earned the highest ratings. While the brain and parotid glands exhibited no significant changes in SUVmax, other normal tissues such as the humerus, aorta, lung, spleen, and liver had substantial discrepancies. This indicates constraints in the use of this technique beyond neuroimaging. In a separate investigation, photos of ultra-low dosage tau accumulation were augmented using a GAN [32]. The scientists used 5% of the original full dosage and discovered that the ultra-low-dose photos exhibited an underestimate in SUVRs in areas with traditionally elevated uptake; however, the bias was reduced in the improved images, particularly within the amyloid-positive healthy cohort. This is particularly advantageous for tracers specific to amyloid-beta plaques, such as 18F-Florbetaben, due to their relatively short half-life, which enhances the safety profile of these imaging procedures [33]. These results must be considered when planning future high-powered experiments to minimize subject radiation exposure.

In summary, 18F-FDG is the predominant tracer used in clinical practice and is the most often cited in the studies reviewed. It is now non-specific for Alzheimer's disease pathology, since hypometabolism may manifest in numerous forms of dementia and neurological disorders. Nonetheless, the use of the tracer in assessing both Alzheimer's Disease and non-Alzheimer's neurodegenerative disorders is crucial, since it is extensively utilized in clinical practice and supported by a substantial body of research for comparative analysis. Furthermore, the majority of tracers targeting amyloid and tau plaques, including 18F-Flutemetamol, 18F-MK-6240, and 18F-PI-2620, are mostly used in research environments owing to the evolution of procedures. 11C-PiB is well-validated and esteemed for its selectivity towards amyloid-beta plaques; nonetheless, its short half-life of roughly 20 minutes necessitates an on-site cyclotron, hence limiting its use in research facilities. Conversely, 18F-Florbetapir is a compound that selectively binds to amyloid plaques and is authorized for clinical use in several countries, including the United States, to assess plaque density, making this tracer valuable for Alzheimer's disease assessment. Nonetheless, it is not sanctioned for the confirmation of an Alzheimer's disease diagnosis. Our results indicate that a combination of 18F-FDG and 18F-Florbetapir should be used in clinical practice for the characterisation of Alzheimer's disease, whereas a combination of 18F-FDG and 11C-PiB should be applied in research institutions, when accessible. For non-Alzheimer's disease causes of dementia, 18F-FDG may be suitable as an initial imaging modality in PET/MRI. A meta-analysis showed that the accuracy of hybrid imaging markers varies according to the measurement method of the tracer and the specific kind of tracer used [34]. Frisoni et al. indicated that 18F-FDG exhibited greater variability than amyloid biomarkers due to the absence of a robust consensus on imaging protocols and urged clinicians to evaluate studies utilizing standard diagnostic criteria from the International Working Group and well-validated data analysis tools such as FreeSurfer [32]. Thus, PET/MRI is most effective when a reference normative population, such as healthy controls, is available for baseline comparison within the same research.

5. Functional Connectivity

Functional connectivity studies focused on the relationships between the activity of various brain areas and often using functional MRI (fMRI), continue to be a pivotal emphasis in PET/MRI research. Networks often examined in dementia include the default mode network (DMN), salience network (SN), central executive network (CEN), sensorimotor networks, along with linguistic and visual networks. The DMN is engaged during wakeful rest, including daydreaming and memory recall, but the CEN is responsible for advanced cognitive functions, such as problem-solving and decision-making. The SN is essential for sifting pertinent internal and external inputs and orchestrating responses to these stimuli. A team headed by Zhang et al. demonstrated reduced glucose metabolism in the DMN, CEN, and SN of individuals with AD relative to healthy controls [35]. Studies indicated that the temporal characteristics of the DMN were modified in PET/MRI scans of patients at various stages of AD, indicating that afflicted individuals engaged with this network for a reduced duration. Particular abnormalities in the DMN including diminished long-range functional connectivity between the medial prefrontal cortex (MPFC) and a reduction in blood-oxygenation level-dependent (BOLD) functional connectivity within the precuneus of the DMN [32]. In the SN, individuals with posterior cortical atrophy and semantic dementia had decreased activity from the left superior frontal gyrus to the right anterior insula [21].

Fractional anisotropy measurements revealed substantial increases in the entorhinal, perirhinal, and cornu ammonis (CA) 1 areas in individuals with dementia or mild cognitive impairment (MCI). The limbic cortico-striato-thalmo-cortical (CTSC) circuit has been thoroughly examined in relation to the behavioral form of frontotemporal dementia during both presymptomatic and symptomatic phases [30,34]. This investigation revealed decreased frontostriatal connection and increased striatothalamic and thalamofrontal connectivity in asymptomatic carriers of a tau protein mutation relative to non-carriers. Common drawbacks in functional connectivity studies include their mostly cross-sectional design at a singular time point (imaging time), which fails to illustrate illness progression or the development of network connection alterations.

6. Related Diseases

Various etiologies of cognitive impairment exist for which PET imaging may be crucial in diagnosis and therapy, including Parkinson's disease (PD), normal pressure hydrocephalus (NPH), multiple sclerosis (MS), and Down syndrome. This research indicates that an investigation of Parkinson's disease with moderate cognitive impairment (PD-MCI) revealed that 8 out of 25 individuals (32%) had amyloid-beta positive. The research revealed substantial accumulation in areas such as the right caudal and rostral middle frontal cortex, precuneus, and left pars triangularis among amyloid-beta-positive individuals [31]. Research on multiple sclerosis indicated that reduced myelin content, as seen by diminished 11C-PiB uptake, correlated with worse cognitive state [15].

Ultimately, Down's syndrome is distinctive in that a significant proportion of individuals with this condition ultimately have cognitive impairment. Machine learning research using support vector machine (SVM) regression models to demonstrate a substantial decrease in white matter connectivity in PiB-positive individuals with Down's syndrome relative to PiB-negative patients [14]. Due to the continuous advancement in imaging procedure literature, there is a lack of robust agreement about tracers for investigating dementia etiologies outside Alzheimer's disease. A comparable methodology to that outlined in Section 4.2.3 may be used, whereby 18F-FDG serves as the primary imaging agent owing to its widespread usage, but 18F-Florbetapir may be included in clinical practice if amyloid pathology is suspected among the dementia subtypes.

7. Imaging devices

Future suggestions must critically assess the predominant field strengths, model brands, and tracers used in PET/MRI. FDG was the most often used tracer in the examined publications. 3 T was the predominant field strength, aligning with the models already available for commercial sale in the combined PET/MRI imaging systems market. GE and Siemens are the only manufacturers of integrated imaging systems, aligning with the almost equal distribution among the leading scanner brands identified in this analysis.

This review includes single research that highlighted the benefits of using ultra-high field MRI in conjunction with PET for examining the hippocampus, in contrast to the 1.5 T and 3 T strengths [22]. 7 T has been progressively used to discern small distinctions that separate pathological and physiological brain states in the context of Cushing's illness, epilepsy, dementia, and analogous clinical conditions [36-38]. The AD group had markedly reduced metabolic activity in the middle CA1, posterior CA1, and CA2/3 areas of the left hippocampus, as well as in the middle and posterior CA2/3 regions of the right hippocampus. This work also delineated reduced activity between CA4 and the dentate gyrus (DG) in the hippocampus. The limitations include that 7 T has mostly been confined to the scientific environment. Nonetheless, 7 T MRI is anticipated to become broadly accessible in clinical environments shortly, potentially facilitating the identification of modest hippocampus anomalies in the pre-symptomatic phases of Alzheimer's disease.

8. Comparison with MRI or PET

Progress in PET/MRI hybrid imaging, including the creation of novel tracers and methodologies, has been rapid and has undergone more thorough comparisons to PET or MRI in isolation. Initially, research on PET/MRI focused on the brain, integrating PET imaging of neurotransmitter activity with MRI assessment of white matter injury [39-41]. A feasibility investigation conducted by Schlemmer et al. in 2008 demonstrated that picture quality was equivalent to that of the individual scanners, and the temporal and spatial registration enabled precise alignment of tracer uptake and MR signal characteristics [40]. Subsequent research demonstrated that using characteristics from both modalities resulted in enhanced performance relative to each modality alone [36,42,43].

Dukart et al. [41] demonstrated that a support vector machine (SVM) classification could effectively differentiate between Alzheimer's disease (AD) and frontotemporal lobar degeneration (FTLD) by utilizing gray-matter data from MRI and fluorodeoxyglucose (FDG) uptake from PET, achieving an accuracy of 94%, surpassing the performance of the model trained solely on MRI data. Previous investigations have shown that MRI alone lacks specificity in diagnosing Alzheimer's disease, especially in its early stages [44,45]. A 2007 research by Matsunari et al. indicated that voxel-based morphometry (VBM), an MRI-based technique, had a specificity of 87% for early-onset Alzheimer's disease, in contrast to 96% for FDG-PET [43]. Moreover, interest in PET/MRI expanded with the rising use of novel tracers beyond FDG, like 11C-Pittsburgh compound-B (PiB). PiB was first launched in 2004 and selectively binds to amyloid-beta plaques in the brain, enabling direct assessment of plaque load in the brain [46]. These enhancements may enhance the specificity of multimodal picture capture in dementia subtyping, facilitating assessment within a single session for several individuals who may otherwise struggle with multiple sessions.

PET/MRI has become more cost-effective for assessing cognitive impairment owing to its enhanced effectiveness [46]. Manuel et al. estimate that each five-year postponement in the onset of dementia results in direct savings of almost USD 8 billion annually, or to about USD 135,000 per individual [47]. Presently, owing to the sluggish integration of hybrid systems, cycle durations for the latest generation of cars may exceed 10 years. Consequently, an increasing number of firms are striving to develop specialized brain PET inserts that may enhance standalone MRI systems, which is more cost-effective than a whole hybrid system. The cost of a packaged hybrid system is roughly USD 6 million, but a PET insert, which can be integrated into a USD 3 million 3 T MRI system, is around USD 1.3 million, making PET/MRI a more appealing modality [33]. The growing acceptance of the technology will persist in driving clinical research and reviews to more effectively guide the trajectory of multimodal imaging.

9. Current Challenges and Future Perspectives of Hybrid Imaging

Hybrid imaging will be essential in diagnosing Alzheimer's disease and other neurocognitive diseases. The prompt identification of amyloid-beta accumulation is critically significant in the advancing age of targeted monoclonal antibodies and other treatments. Nonetheless, there is a scarcity of evidence about hybrid imaging for the diagnosis and therapy of frontotemporal dementia (FTD), Lewy body dementia (LBD), and other significant contributors to cognitive decline. In our thorough analysis, just eight research included individuals with a probable diagnosis of FTD, and only three encompassed patients exhibiting clinical symptoms of LBD [48].

The advancement of innovative radiotracers and nuclear imaging methodologies for frontotemporal dementia (FTD) is garnering heightened attention; although being relatively rare, FTD is often marked by an early start and fast progression. Hybrid imaging may facilitate early identification and the timely commencement of neurobehavioral therapies for this uncommon but severe illness. Moreover, although I-123 ioflupane SPECT imaging and FDG PET/CT are often used to validate a suspected diagnosis of LBD, their sensitivity and specificity are somewhat constrained. Hybrid imaging offers a means to enhance the assessment of individuals exhibiting clinical signs and symptoms of LBD. The identification of alternative etiologies of neurocognitive impairment, such as NPH and CBD, may be enhanced using hybrid imaging; however, further research is required to validate dependable imaging biomarkers for these disorders.

10. Conclusions

This review article encapsulates PET/MRI research conducted from 2016 to 2023, highlighting the benefits and limitations of simultaneous imaging over this timeframe. This report outlines suggestions for future applications and anticipated advancements in hybrid imaging via the incorporation of novel tracers and artificial intelligence. The future of hybrid imaging involves integrating additional AI methodologies to enhance the technical components of PET/MRI, such as attenuation and motion correction, validating a greater number of multi-modal biomarkers for dementia assessment, and clarifying additional regions of interest and functional connectivity networks. Present issues in the domain include the elevated expenses of integrated PET/MRI systems relative to standalone scanners, the complexities of image registration and analysis of dual data layers, and the heightened radiation exposure to patients. Current results indicate that hybrid imaging will be pivotal in the diagnosis, treatment, and monitoring of dementia. Further research is required to construct hybrid imaging methodologies for assessing non-Alzheimer's dementia and to develop methods that promote the prompt beginning of pharmacological and neurobehavioral therapies.

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تقنيات التصوير الهجينة (PET/MRI) في الأشعة التشخيصية: مراجعة شاملة

الملخص

الخلفية :أحدث دمج تقنية التصوير المقطعي بالإصدار البوزيتروني والرنين المغناطيسي (PET/MRI) تحولاً في الأشعة التشخيصية، خاصة في دراسة الخرف والضعف الإدراكي البسيط .(MCI) مع ارتفاع معدلات الإصابة بمرض الزهايمر (AD) بين كبار السن، يُعد التشخيص المبكر والدقيق أمرًا بالغ الأهمية للتدخل الفعال.

الطرق :تُقيّم هذه المراجعة الشاملة الدراسات المنشورة من عام 2000 إلى 2023، مع التركيز على تطبيق تقنية PET/MRI في تشخيص أنواع الخرف. تم إجراء بحث في PubMed باستخدام الكلمات المفتاحية المتعلقة بـ PET/MRI والخرف، مع تصفية الدراسات التي تحتوي على حجم عينة لا يقل عن عشرة واستخدام تقنيات تصوير ذات صلة.

النتائج :تُبرز المراجعة التطورات في تقنيات التصوير الهجينة، مما أظهر تحسينات في دقة التشخيص لأنواع مختلفة من الخرف. تشير الدراسات إلى أن تقنية PET/MRI يمكنها تحديد تراكم الأميلويد-بيتا في المراحل المبكرة والتغيرات الدقيقة في التصوير بالرنين المغناطيسي في المراحل ما قبل السريرية للخرف. بالإضافة إلى ذلك، حسّنت تقنيات التعلم الآلي والذكاء الاصطناعي تحليل الصور، مما ساعد في اكتشاف التغيرات التنكسية

العصبية بشكل أكثر دقة. وعلى وجه الخصوص، أظهر دمج متتبعات F-FDG 18ومتتبعات الأميلويد نتائج واعدة في التطبيقات السريرية، حيث يوفر رؤى أفضل حول تطور المرض.

الاستنتاج :تُعد تقنية PET/MRI أداة محورية في التشخيص المبكر وإدارة الخرف، حيث توفر تقييماً شاملاً لوظائف الدماغ وهيكله. ينبغي أن تركز الأبحاث المستقبلية على تطوير متتبعات جديدة ومعالجة قيود المنهجيات الحالية، خاصة في الخرف غير المرتبط بمرض الزهايمر. كما أن دمج تقنيات التصوير المتقدمة مع الذكاء الاصطناعي يحمل إمكانات كبيرة لتحسين قدرات التشخيص ونتائج المرضى.

الكلمات المفتاحيةPET/MRI :، مرض الزهايمر، الضعف الإدراكي البسيط، التصوير الهجين، الأشعة التشخيصية.