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RESEARCH

Role of 18F-FDG PET/CT in assessing systemic involvement in ANCA-associated vasculitis

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Abstract

The utilization of ^{18}F-fluorodeoxyglucose positron emission tomography/computed tomography (^{18}F-FDG PET/CT) has become a pivotal tool in diagnosing anti-neutrophil cytoplasmic antibodies (ANCA)-associated vasculitis, especially when the disease presents with neurological symptoms as the initial indicator. This advanced imaging technique was applied in a 68-year-old female patient who presented with recurrent limb weakness and intermittent blindness, symptoms that warranted thorough investigation due to their complexity and severity. The ^{18}F-FDG PET/CT revealed significant radiotracer uptake in the kidneys, spleen, skeletal muscles, and right axillary lymph nodes, indicative of systemic involvement—a hallmark of ANCA-associated vasculitis (AAV) that can lead to multi-organ damage if not promptly managed. Complementary electromyography (EMG) identified multiple instances of peripheral nerve damage, adding further evidence to the diagnosis. This case underscores the intricate interplay between clinical symptoms, imaging findings, and laboratory results, all crucial in accurately diagnosing AAV. The findings highlight that ^{18}F-FDG PET/CT not only facilitates early detection of neurogenic skeletal muscle damage and occult lesions, but also aids in precise disease classification, essential for guiding treatment strategies. The ability of this imaging modality to provide early warnings of major organ involvement offers clinicians a valuable opportunity to intervene before irreversible damage occurs, ultimately improving the accuracy of diagnosis and contributing to more effective management and outcomes for patients with this complex autoimmune disorder.

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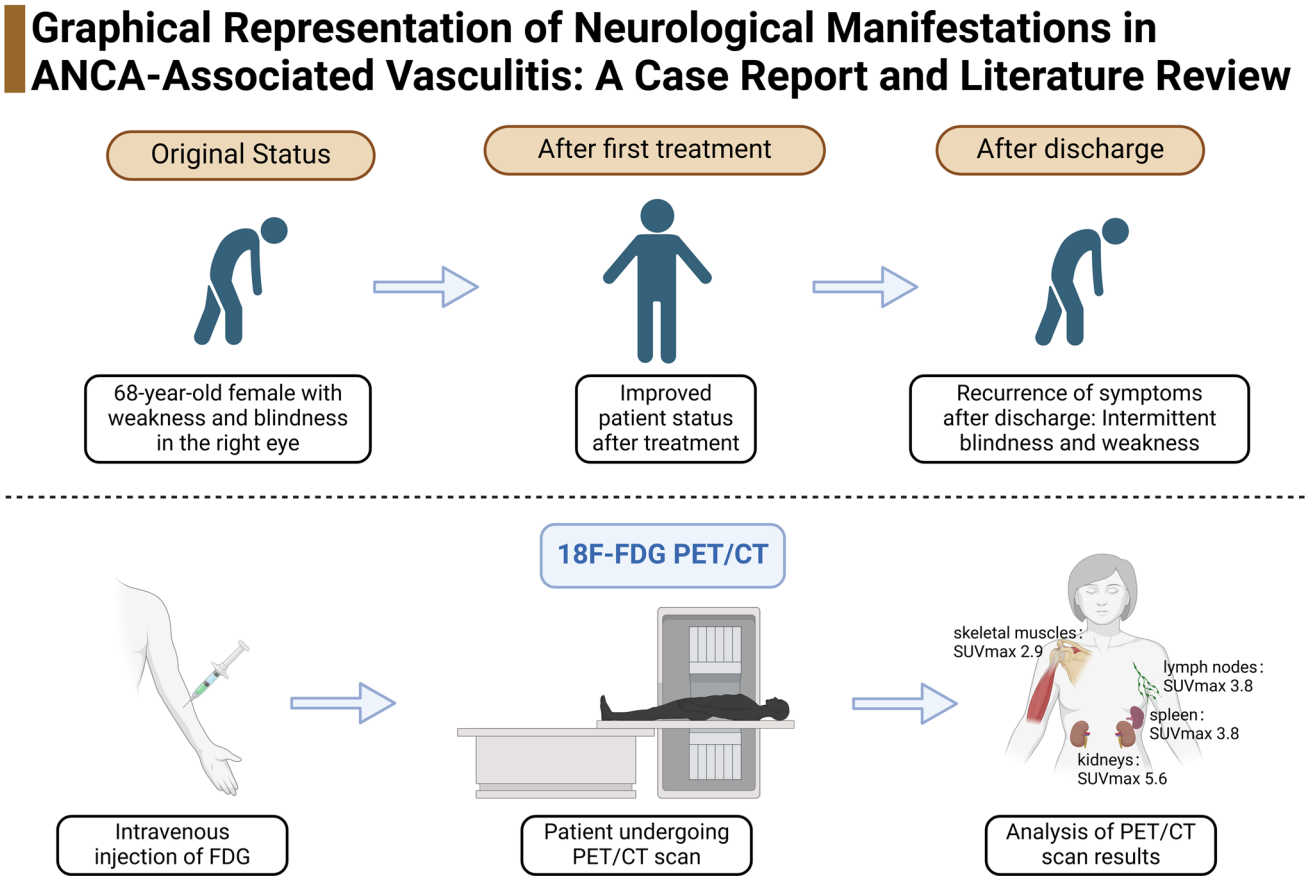
Graphical abstract



Keywords ^{18}F-fluorodeoxyglucose positron emission tomography/computed tomography · Anti-neutrophil cytoplasmic antibody-associated vasculitis · Neurological damage · Peripheral nerve damage · Abnormal glucose metabolism · Clinical diagnostic value

Introduction

Anti-neutrophil cytoplasmic antibody (ANCA)-associated vasculitis (AAV) is a group of autoimmune diseases characterized by necrotizing inflammation of small- to medium-sized blood vessels, typically associated with circulating ANCA antibodies [1]. AAV includes several distinct disease phenotypes such as granulomatosis with polyangiitis (GPA), microscopic polyangiitis (MPA), and eosinophilic granulomatosis with polyangiitis (EGPA), with GPA formerly known as Wegener's granulomatosis [2]. Despite their varied clinical presentations, these diseases can all lead to multi-organ involvement and significant functional impairment.

Over the past two decades, significant progress has been made in understanding the pathophysiological mechanisms of AAV. This progress is particularly notable in the interactions between ANCA antibodies and neutrophils, as well as the activation of the complement system, which ultimately leads to inflammation and damage of the vascular walls [3]. The two main types of ANCA antibodies—those targeting myeloperoxidase (MPO-ANCA) and those targeting proteinase 3 (PR3-ANCA)—are closely associated with different disease phenotypes and clinical progressions. These discoveries have not only enhanced our understanding of the disease mechanisms, but also facilitated the development of new therapeutic strategies.

Furthermore, with advancements in diagnostic technology and innovative treatment methods, the management of AAV has shifted from relying on cytotoxic drugs to using targeted biologics for disease induction and maintenance of remission [4]. Despite these advancements, AAV treatment still faces many challenges, including the reduction in long-term glucocorticoid use due to its association with severe complications. In this context, this case report focuses on the clinical presentation, diagnostic process, and management of an AAV patient, emphasizing the application of

modern diagnostic tools such as ^{18}F-fluorodeoxyglucose positron emission tomography/computed tomography (^{18}F-FDG PET/CT) for internal lesion identification and activity assessment [5]. These advanced diagnostic tools not only provide new methods for disease monitoring, but also significantly enhance the personalization and precision of treatment.

Over the past few decades, PET/CT, specifically ^{18}F-FDG PET/CT, has played a crucial role in cancer diagnosis and treatment monitoring. This technique utilizes the radioactive glucose analog ^{18}F-fluorodeoxyglucose (FDG) to visualize glucose metabolism in body tissues, aiding physicians in detecting and assessing the presence and progression of malignancies and other inflammatory diseases [6]. The widespread application of ^{18}F-FDG PET/CT in oncology provides critical diagnostic information, particularly in cases where tumor location or lesion nature is challenging to determine. For example, in monitoring the treatment of systemic autoimmune diseases like large vessel vasculitis, this technology has demonstrated significant diagnostic value, effectively evaluating treatment response and monitoring disease recurrence [7]. Additionally, ^{18}F-FDG PET/CT has shown high efficiency in identifying primary tumors in patients with unknown primary cancers, guiding subsequent treatment plans [8]. Beyond cancer diagnosis, ^{18}F-FDG PET/CT has proven valuable in diagnosing infective endocarditis by identifying metabolic activity in cardiac and extracardiac infection sites, thereby increasing diagnostic sensitivity and specificity, especially in infections involving implanted valves and other cardiac devices [9].

This study detailed a case of a 68-year-old female patient presenting with limb weakness and sudden blindness as the initial symptoms of AAV. After initial hospitalization, the patient's symptoms temporarily improved, but she experienced recurrent limb weakness and intermittent blindness, accompanied by chills and fever, after discharge. Laboratory tests revealed that the patient was positive for perinuclear-ANCA (P-ANCA) with significantly elevated myeloperoxidase (MPO) levels, while other immunological indicators were normal. ^{18}F-FDG PET/CT imaging showed diffuse increased radiotracer uptake in the kidneys, spleen, skeletal muscle, and right axillary lymph nodes, suggesting systemic involvement. Through multidisciplinary collaboration, combined with clinical manifestations and autoantibody detection, the diagnosis of AAV was confirmed. This study utilized ^{18}F-FDG PET/CT imaging technology to successfully identify and evaluate occult lesions in AAV patients at an early stage, demonstrating the significant role of this technology in assessing multisystem involvement. Particularly when conventional imaging showed no abnormalities, ^{18}F-FDG PET/CT provided comprehensive lesion distribution, guiding the development of more precise treatment plans. It enhanced understanding of AAV presenting with neurological damage and expanded the application of ^{18}F-FDG PET/CT in immunological diseases, underscoring its important scientific and clinical value.

Case presentation

The patient is a 68-year-old woman who presented with a sudden onset of limb weakness and acute vision loss in the right eye approximately two months prior without any apparent cause. The symptoms improved after about 5–6 h, but the vision in her right eye remained blurred. On August 17, 2021, she was admitted to our hospital's infectious disease department due to a fever and was later transferred to the nephrology department. During her previous hospitalization at a local hospital, tests including liver and kidney function, cerebrospinal fluid analysis, biochemical tests, bacterial and fungal smears, acid-fast bacilli smear, and cryptococcus tests showed no significant abnormalities. Imaging studies, including lower limb vascular ultrasound, bilateral carotid artery ultrasound, head and neck CTA, and fundus examination, indicated peripheral neuropathy, pneumonia, and retinal artery occlusion. The patient was treated with mecobalamin, betahistine, and flunarizine, along with oral prednisone. After approximately 12 days of inpatient treatment, her symptoms improved, and she was discharged.

During the initial hospitalization, the patient received mecobalamin tablets (500 μg daily), betahistine (100 mg twice daily), and flunarizine (10 mg daily) primarily to treat peripheral neuropathy. Concurrently, the patient was administered prednisone (starting at 30 mg per day, with a gradual taper to discontinuation) to control inflammation and immune-mediated pathology. During the hospital stay, the patient's limb weakness improved, gait became more stable, and right eye vision blurriness also showed improvement. The patient was discharged once the condition stabilized.

After discharge, the patient experienced recurrent episodes of limb weakness and intermittent blindness, accompanied by chills and subjective fever, with a temperature of approximately 37°C. These symptoms subsided after sweating for 4–5 h. An electromyography (EMG) test at the local hospital showed no abnormalities. For further evaluation, the patient visited our hospital. Physical examination upon admission revealed mild pitting edema in both lower limbs, reduced muscle strength, normal muscle tone, and a heart murmur. Laboratory tests using indirect immunofluorescence showed positive P-ANCA, MPO at 123.4 RU/ml, negative cytoplasmic-ANCA (C-ANCA), and proteinase 3 (PR3) levels less than 2 RU/ml. Other tests, including the ANA panel, ENA antibody panel, anti-streptolysin O antibody, and rheumatoid factor (RF), were all negative, strongly suggesting the presence of AAV. Complete blood count revealed a white blood cell count of 23.51×10^9/L, indicating infection or inflammation; a red blood cell count

of 2.66×10^{12}/L and hemoglobin level of 72 g/L, indicating anemia; and a platelet count of 513×10^{9}/L, with neutrophils comprising 88.0%, suggesting bacterial infection. Biochemical analysis showed creatine kinase (CK) at 33 U/L, uric acid (UA) at 0.513 mmol/L, blood urea nitrogen (BUN) at 19.0 mmol/L, and creatinine (Cr) at 275 µmol/L, indicating severe renal impairment. The estimated glomerular filtration rate (eGFR) calculated using the EPI formula was 14.7 ml/min, confirming renal insufficiency. Urinalysis showed red blood cell count (RBC) at 52.6/µL and 1 + hematuria; urine albumin-to-creatinine ratio (ACR) was 306.13 mg/g, indicating glomerular damage. Abdominal ultrasound revealed enhanced echogenicity of both kidneys, with no other abnormalities. Abdominal CT showed no significant abnormalities. Ophthalmological consultation suggested retinal vasculitis.

To investigate the presence of tumors and determine the cause of fever, an ^{18}F-fluorodeoxyglucose (FDG) PET/CT scan was performed. The results showed that both kidneys were well-formed with no density abnormalities. However, there was diffuse increased radiotracer uptake in the renal parenchyma, primarily concentrated in the renal cortex, with a maximum standardized uptake value (SUVmax) of 5.6. Additionally, the radiotracer distribution boundary between the renal parenchyma and the renal pelvis was blurred (Fig. 1A), indicating possible inflammation or related pathology. This finding is consistent with the common renal involvement in AAV. The spleen was enlarged with diffuse increased radiotracer uptake (SUVmax 3.8) (Fig. 1B). There was also diffuse increased radiotracer uptake in the skeletal muscles, particularly in the bilateral upper limbs and neck-back region, with a SUVmax of 2.9 (Fig. 1C). Extensive subcutaneous edema was observed, along with crescent-shaped low-density areas at the posterior edges of both thoracic cavities, which were more pronounced on the right side. Several lymph nodes in the right axilla (largest approximately 1.2×0.7 cm) also showed increased radiotracer uptake (SUVmax 3.8). Although there are no universally accepted diagnostic criteria, the ^{18}F-FDG PET/CT scan identified four hidden lesions: kidneys, spleen, skeletal muscles, and right axillary lymph nodes. Combined with the patient's clinical presentation and autoantibody tests, and through multidisciplinary collaboration, a diagnosis of AAV was ultimately established.

After being diagnosed with AAV, the patient received a treatment regimen that included intravenous methylprednisolone, cyclophosphamide, and intravenous immunoglobulin (IVIG). In the initial phase, the patient was administered 500 mg of methylprednisolone daily via intravenous injection for 3 days, followed by 250 mg daily for 1 week. Cyclophosphamide was administered intravenously at a dose of 500 mg every 2 weeks for immunosuppressive therapy. Additionally, the patient received three IVIG infusions at a dosage of 0.4 g/kg body weight each day for 5 consecutive days. During the treatment period, the patient's symptoms gradually improved, with reduced limb weakness, partial restoration of vision, normalization of body temperature, and decreased inflammation markers.

Discussion

AAV is characterized by pauci-immune necrotizing small vessel vasculitis and affects multiple organ systems [10–12]. The etiology and pathogenesis of AAV are currently unclear. However, research suggests that environmental factors (such as microbial infections, silica and silicate dust, air pollution, and drugs like cocaine, minocycline, and isoniazid), genetic predispositions, and immune responses are closely related to the development of AAV [13–15]. According to the 2012 revised classification criteria for vasculitis, AAV includes MPA, GPA, and EGPA [16–18]. There are few studies evaluating the clinical utility of ^{18}F-FDG PET/CT in diagnosing AAV. Lu Dongyan reported that GPA primarily affects the ear, nose, and throat (ENT) region, lungs, and kidneys; MPA primarily affects the kidneys and spleen; and EGPA primarily affects the ENT region, lymph nodes, and bone marrow [19, 20]. In this case, the patient presented with recurrent limb weakness and intermittent blindness as initial neurological symptoms, followed by fever, hematuria, proteinuria, and renal dysfunction indicative of rapidly progressive glomerulonephritis. It is rare for AAV to present initially with neurological symptoms [21, 22].

Neurological damage can be categorized into peripheral nerve damage and central nervous system damage. Peripheral nerve involvement includes peripheral nerves and cranial nerves III to XII, while central nervous system involvement includes the brain, spinal cord, and cranial nerves I and II [23–25]. Among the three types of AAV, peripheral nerve damage predominantly manifests as multiple mononeuropathy and/or polyneuropathy. Clinical symptoms are similar and often include limb pain, numbness, muscle weakness with sensory dullness, and muscle atrophy [26, 27]. GPA-induced central nervous system damage is mainly due to granuloma compression, presenting as optic nerve or retinal ischemia and blindness, followed by vasculitic lesions causing hemiplegia, seizures, intracranial or subarachnoid hemorrhage, and cerebral infarction. MPA-related central nervous system damage primarily manifests as brain parenchymal lesions, frequently resulting in seizures and altered consciousness. EGPA less commonly affects the central nervous system but can present with stroke, diffuse ischemic injury, cortical dysfunction, cerebral hemorrhage, and cerebral infarction [28, 29].

The main findings of this study are illustrated which shows the complex clinical progression of AAV with

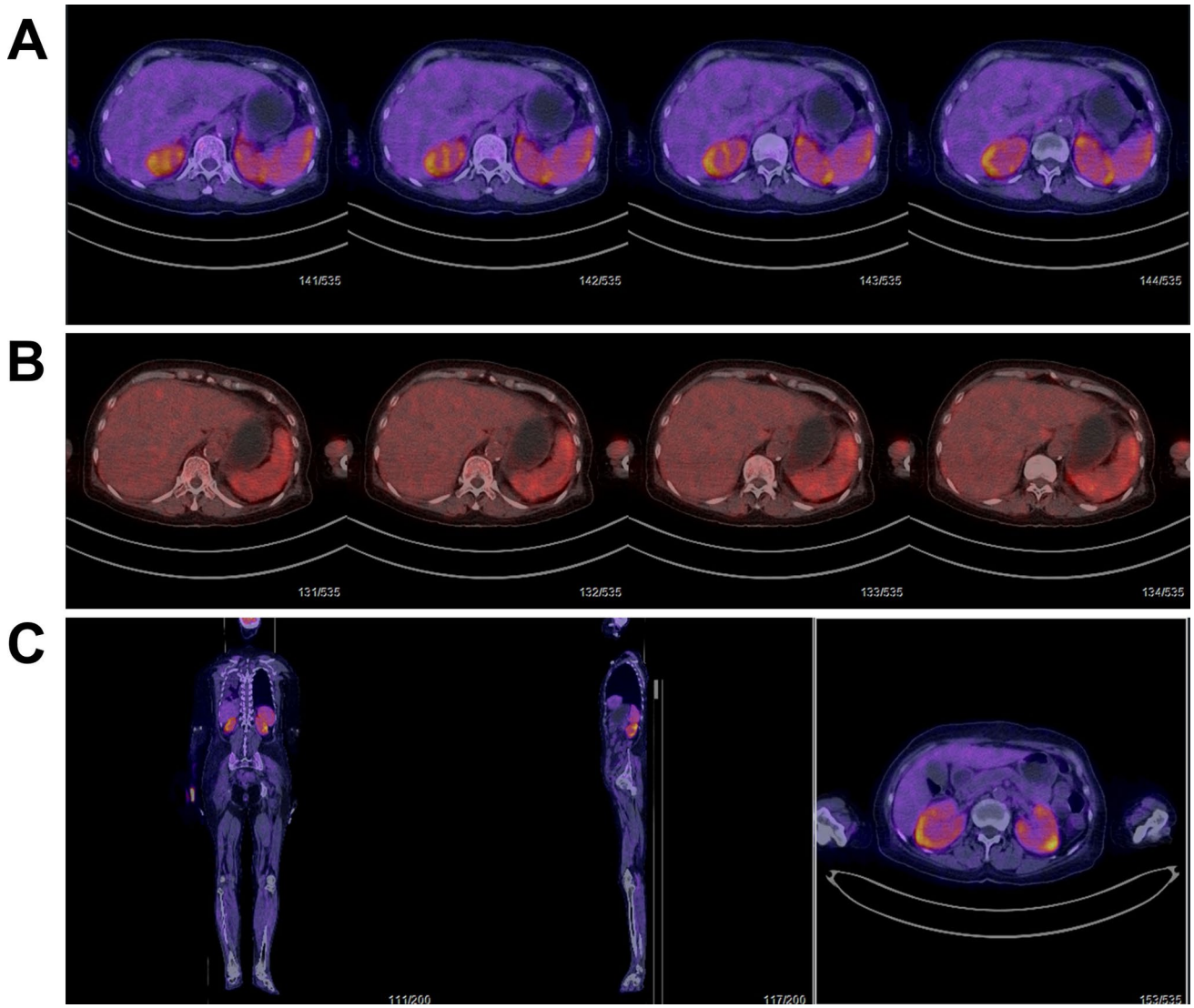


Fig. 1 ^{18}F-FDG PET/CT imaging of FDG uptake in multiple organs of a patient with AAV. *Note* This figure presents the ^{18}F-FDG PET/CT images of a patient with AAV, illustrating the FDG uptake in the kidneys and throughout the body from various planes and angles. **A** Transverse images showing FDG uptake in the kidneys, with significantly increased uptake indicating possible inflammatory activity. Sequential images from left to right display different levels of kidney FDG uptake. **B** Transverse images further illustrate FDG uptake in the kidneys and surrounding tissues. Sequential images from left to right display abdominal FDG uptake at different levels, with significantly increased uptake in the kidney regions, particularly in Figs. 1B-2 and 1B-3. **C** Whole-body PET/CT images showing FDG uptake in the kidneys and other organs, providing an overall distribution map of the disease. The images highlight FDG uptake throughout the body, with particularly notable uptake in the kidney regions

neurological manifestations. The figure emphasizes the critical role of ^{18}F-FDG PET/CT in identifying and monitoring disease activity, providing valuable insights for clinicians and researchers in diagnosing and treating AAV with neurological involvement. In this case, the patient's EMG at an external hospital showed no significant abnormalities; however, ^{18}F-FDG PET/CT imaging at our facility revealed abnormal FDG metabolism in the skeletal muscle, particularly in the upper limbs and cervical regions. EMG results indicated multiple peripheral nerve damage, affecting both myelin sheaths and axons of motor and sensory nerves. Thus, ^{18}F-FDG PET/CT can detect neurogenic skeletal muscle damage earlier than EMG, aiding in the identification of hidden lesions and providing an objective basis for AAV classification. Additionally, this patient's ultrasound and CT imaging showed no significant abnormalities in the kidneys or spleen. Traditional imaging techniques are relatively limited in assessing disease activity and the extent of involvement, while ^{18}F-FDG PET/CT can image tissues and organs with abnormal glucose metabolism, addressing these

limitations. Blood tests revealed several abnormal indicators, including significantly elevated white blood cell counts, suggesting infection or inflammation; markedly reduced red blood cell counts and hemoglobin levels, indicating anemia; and increased creatinine and urea levels, with a reduced estimated glomerular filtration rate, indicating severe kidney dysfunction. Urinalysis showed increased red blood cell counts and positive occult blood, suggesting hematuria and glomerular injury. ^{18}F-FDG PET/CT imaging detected lesions involving the kidneys and spleen, aiding in the early assessment of disease activity and extent and potentially preventing medical emergencies. Domestic scholars have reported cases of spontaneous kidney rupture and spleen rupture associated with AAV. Therefore, early detection of kidney and spleen involvement through PET/CT can help clinicians anticipate and prevent complications.

We conducted a comprehensive literature search in the PubMed database using the keywords "ANCA-Associated Vasculitis" and "^{18}F-FDG PET/CT." Articles published from 2010 to 2024 were thoroughly reviewed and summarized. Our study indicates significant advancements in the diagnosis and management of AAV over the past two decades. The introduction of ^{18}F-FDG PET/CT has provided clinicians with more precise tools for detecting and evaluating the activity and extent of AAV. As shown in Table 1, we summarized the clinical presentations, diagnostic methods, treatments, and prognoses of patients in the nine most relevant articles. These studies offer valuable insights that aid in understanding and optimizing the management strategies for AAV.

These studies demonstrate the diverse applications of ^{18}F-FDG PET/CT in diagnosing AAV. This technique not only enhances the early detection of occult lesions, but also provides critical information for assessing treatment responses and prognoses. Particularly in challenging cases, ^{18}F-FDG PET/CT can identify lesions that conventional imaging techniques may miss, significantly improving diagnostic accuracy and therapeutic outcomes. For example, with advancements in diagnostic technology and innovative treatment methods, the management of AAV has shifted from relying on cytotoxic drugs to using targeted biologics for disease induction and maintenance of remission [4]. Geetha et al. (2020) noted that through randomized controlled trials, AAV treatment has evolved from a fatal disease to a chronic condition with a relapsing course and associated morbidity [1]. This shift underscores the importance of modern therapeutic strategies, including diagnostic tools like ^{18}F-FDG PET/CT, in managing AAV. Furthermore, the study by Kronbichler et al. (2020) indicates that the targeted treatment of AAV is more closely related to the ANCA serotype rather than the disease phenotype [3].

Yaseen et al. (2023) highlighted new treatment methods developed over the past two decades that have significantly improved overall prognosis and survival rates [2]. Additionally, Sacoto et al. (2020) detailed the clinical, radiological, and therapeutic characteristics of pulmonary involvement in AAV patients, emphasizing the importance of PET/CT in managing these complex cases [5]. Van der Geest et al. (2021) conducted a systematic review and meta-analysis on the value of [^{18}F]FDG PET/CT in monitoring large vessel vasculitis treatment, indicating its moderate diagnostic accuracy in detecting active large vessel vasculitis [7]. Moreover, Hadad et al. (2020) evaluated the clinical significance and economic impact of incidental ^{18}F-FDG PET/CT findings in oncology, further supporting its broad application in various clinical settings [6]. Burglin et al. (2017) demonstrated through a systematic review and meta-analysis that ^{18}F-FDG PET/CT has significant capability in identifying primary tumors in adults with cancer of unknown primary origin, highlighting its importance in complex cases [8]. Lastly, Sathyamurthy and Elangovan (2024) discussed the application of ^{18}F-FDG PET/CT in reclassifying possible diagnoses of infective endocarditis, showing its enhanced diagnostic sensitivity and specificity [9].

In summary, the application of ^{18}F-FDG PET/CT in diagnosing and monitoring AAV not only facilitates early detection and precise localization of lesions, but also provides a crucial tool for evaluating treatment response and long-term prognosis [1, 5, 7]. This technology enhances the personalization and precision of AAV management, significantly improving patients' quality of life and survival rates. This study evaluates the clinical value of ^{18}F-FDG PET/CT in diagnosing AAV presenting with neurological damage. The results indicate that this technique has significant advantages in the early detection of neurogenic skeletal muscle damage and occult lesions, aiding in the accurate classification of AAV and early warning of major organ involvement, thereby enhancing clinical diagnosis and treatment outcomes.

Key conclusions are as follows: ^{18}F-FDG PET/CT can detect neurogenic skeletal muscle damage and occult lesions in AAV patients early, significantly improving early diagnostic rates. PET/CT imaging can precisely locate the activity and extent of lesions, providing comprehensive lesion distribution for patients with systemic involvement, thus offering crucial evidence for early diagnosis and prognosis evaluation. The research demonstrates that PET/CT imaging is valuable for accurate classification of AAV and early warning of major organ involvement, facilitating the development of more precise treatment plans and improving clinical diagnostic and therapeutic outcomes. This study extends the application of ^{18}F-FDG PET/CT in immunological diseases, showcasing its critical role in evaluating multisystem involvement. PET/CT imaging holds significant advantages in locating and assessing the activity of lesions across multiple systems, guiding the formulation of more precise treatment plans. For cases

Table 1 Summary table of literature on ANCA-associated vasculitis and ^{18}F-FDG PET/CT

Journal	Authors	PMID	Year	Case Presentation	Diagnosis	Treatment	Outcome
Am J Kidney Dis	Geetha D, Jefferson JA	31,358,311	2020	N/A	ANCA-Associated Vasculitis	Randomized controlled trials have refined the therapy	Transformed AAV from a fatal disease to a chronic illness with relapsing course and associated morbidity
Postgrad Med	Yaseen K, Mandell BF	35,831,990	2023	N/A	ANCA-associated vasculitis	New treatments developed in past two decades	Significant improvement in general outcomes and survival rates
Int J Mol Sci	Kronbichler A, Lee KH, Denicolò S, et al	33,023,023	2020	N/A	ANCA-Associated Vasculitis	Targeted therapies	More closely related to ANCA serotype than to disease phenotypes
Lancet	Kronbichler A, Bajema IM, Bruchfeld A, Mastroianni Kirsztajn G, Stone JH	38,368,016	2024	N/A	ANCA-associated vasculitis	Targeted biological medications	Improved patient outcomes and better survival, focus on long-term morbidities
Presse Med	Sacoto G, Boukhlal S, Specks U, Flores-Suárez LF, Cornec D	32,650,042	2020	N/A	ANCA-associated vasculitis	Management of pulmonary involvement in AAV	Details various pulmonary involvement in AAV and their clinical, radiological and therapeutic characteristics
Dan Med J	Hadad ZSH, Afzelius P, Sørensn SM, Jurik AG	33,046,200	2020	The study assesses the occurrence, clinical significance and economic impact of incidental ^{18}F-FDG PET/CT findings in oncology	Incidental ^{18}F-FDG PET/CT findings	N/A	Identification of clinically relevant lesions or conditions
Eur J Nucl Med Mol Imaging	van der Geest KSM, Treglia G, Glaudemans AWJM, et al	33,942,141	2021	Systematic review and meta-analysis on the value of [^{18}F] FDG PET/CT for treatment monitoring in large vessel vasculitis	Large vessel vasculitis (LVV)	Monitoring treatment response	Moderate diagnostic accuracy for detecting active LVV
Medicine (Baltimore)	Burglin SA, Hess S, Høilund-Carlsen PF, Gerke O	28,422,888	2017	Systematic review and meta-analysis on the ability of ^{18}F-FDG PET/CT to detect the primary tumor in adults with extracervical metastases from cancer of unknown primary	Cancer of unknown primary (CUP)	Detection of primary tumor	Pooled detection rate (DR) of 40.93%

Table 1 (continued)

Journal	Authors	PMID	Year	Case Presentation	Diagnosis	Treatment	Outcome
Indian Heart J	Sathyamurthy I, Elangovan I	38,185,328	2024	Review on the use of ^{18}F-FDG PET/CT in reclassifying the probable diagnosis of infective endocarditis (IE)	Infective endocarditis (IE)	Diagnosis confirmation/reclassification	Enhanced sensitivity and specificity in diagnosing IE
Recent Results Cancer Res	Lopci E, Fanti S	32,594,402	2020	Summary of non-FDG PET tracers and their impact on clinical practice in cancer imaging	Various cancers (non-FDG tracers)	N/A	Introduction and impact of novel PET tracers

where conventional imaging fails to reveal abnormalities, PET/CT can detect occult lesions early, preventing misdiagnosis and missed diagnoses. However, this study is a single case report with a small sample size, limiting its ability to fully reflect the widespread applicability of ^{18}F-FDG PET/CT in AAV. Currently, there is no universally accepted diagnostic standard for ^{18}F-FDG PET/CT, which may lead to inconsistencies across different studies. The high cost and technical requirements of PET/CT equipment may also restrict its widespread use in resource-limited areas. Future research should involve multicenter, large-sample clinical studies to validate the broader applicability and reliability of ^{18}F-FDG PET/CT in diagnosing AAV and establish standardized diagnostic protocols and procedures to enhance consistency and accuracy. Combining PET/CT imaging with other diagnostic methods, such as EMG and autoantibody detection, can form a comprehensive diagnostic and treatment strategy, improving the management of AAV. Technological advancements should aim to reduce the cost of PET/CT scans, promoting their clinical adoption. In conclusion, ^{18}F-FDG PET/CT holds significant scientific and clinical value in the early diagnosis, lesion localization, and activity assessment of AAV, but further research and technological improvements are needed to overcome existing limitations and enhance its effectiveness. Future studies should aim to refine and expand the use of this technology, providing better diagnostic and therapeutic services for patients with AAV.

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Author contributions Song Yang and Haibo Tan conceived and designed the study. Song Yang performed the experiments. Song Yang and Haibo Tan analyzed the data. Song Yang and Haibo Tan wrote the manuscript. All authors reviewed and approved the final version of the manuscript.

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Data availability All data can be provided as needed.

Declarations

Conflict of interest The authors declare no competing interests.

Ethical approval This study was approved by the clinical ethics committee Huashan Hospital, Fudan University.

Informed consent This study has received approval from the Ethics Committee and strictly adheres to both national and international ethical guidelines for medical research, including the relevant provisions of the Declaration of Helsinki. All cases involved in this study have provided informed consent, with patients fully understanding the nature and potential risks of the research. During the study, we placed a strong emphasis on protecting the privacy and personal information of participants, ensuring that all data were processed anonymously. The study guarantees that all diagnostic and treatment measures were in the best interest of the patients and that all decisions within the research were made with the patients' informed consent.

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