

Modern Brain Imaging Methods in the Diagnosis of Autism Spectrum Disorders

Nowoczesne metody obrazowania mózgu w diagnostyce zaburzeń
ze spektrum autyzmu

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Abstract

Modern imaging techniques, particularly functional magnetic resonance imaging (fMRI), are increasingly being applied in research on autism spectrum disorder (ASD). The aim of this paper was to review the current literature on brain imaging methods used in the diagnosis of ASD. The significance of advanced neuroimaging techniques – such as magnetic resonance imaging (MRI), functional MRI (fMRI), magnetic resonance spectroscopy (MRS), and positron emission tomography (PET) – was discussed, alongside contemporary data analysis approaches, including artificial intelligence and connectome analysis. The use of these tools enables a detailed investigation of both structural and functional brain alterations in individuals with ASD. Among the observed changes are increased amygdala volume, disrupted neural connectivity, and reduced activity in brain regions responsible for social and language processing. When combined with machine learning algorithms, fMRI shows considerable potential as a future diagnostic tool in ASD.

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Keywords: autism spectrum disorders; functional magnetic resonance imaging (fMRI); brain imaging

Streszczenie

Nowoczesne metody obrazowania, szczególnie funkcjonalny rezonans magnetyczny (fMRI) znajduje coraz szersze zastosowanie w badaniach nad zaburzeniami ze spektrum autyzmu (ASD). Celem niniejszej pracy było dokonanie przeglądu literatury w tematyce metod obrazowania mózgu stosowanych w diagnostyce ASD. Przedstawiono znaczenie zaawansowanych technik neuroobrazowania, takich jak rezonans magnetyczny (MRI), funkcjonalny rezonans magnetyczny (fMRI), spektroskopia rezonansu magnetycznego (MRS), tomografia pozytonowa (PET), a także nowoczesnych metod analizy danych, w tym sztucznej inteligencji i analizy konektomu. Zastosowanie tych narzędzi pozwala na szczegółowe zbadanie zarówno strukturalnych, jak i funkcjonalnych zmian w mózgu osób ze spektrum autyzmu (ASD), gdzie obserwuje się m.in. zwiększoną objętość ciała migdałowatego, zaburzenia łączności neuronalnej oraz obniżoną aktywność obszarów mózgu odpowiedzialnych za przetwarzanie informacji społecznych i językowych. W połączeniu z algorytmami uczenia maszynowego fMRI ma istotny potencjał jako przyszłościowe narzędzie diagnostyczne w ASD.

Słowa kluczowe: spektrum autyzmu; funkcjonalny rezonans magnetyczny (fMRI); obrazowanie mózgu

Introduction

In recent years, non-invasive brain imaging methods have rapidly developed, enabling more precise assessment of the brain's structure, biochemistry, and function. These techniques have greatly enhanced our understanding of brain activity, both in healthy individuals and those with neurological and psychiatric disorders (1, 2). These technologies are of particular importance in the study of developmental disorders (3), such as Autism Spectrum Disorders (ASD), which manifest in early childhood and significantly impact the lives of patients (4).

ASD is a complex disorder with a multifactorial etiology, encompassing a wide range of symptoms – from mild communication difficulties to severe deficits in speech and behavior (5). Diagnosing ASD is challenging and time-consuming, and early detection

is crucial for effective treatment. Modern techniques such as MRI, fMRI, PET, and MRS allow for the identification of structural and functional changes in the brains of individuals with ASD and the assessment of atypical patterns of neural activity (6).

Increasing attention is also being given to brain connectome studies, which may lead to the development of biomarkers for earlier ASD diagnosis (7). The findings from neuroimaging studies not only expand our knowledge of the mechanisms underlying autism but also open up new therapeutic possibilities, tailored to the individual characteristics of a patient's brain (8).

Imaging methods in the diagnosis of ASD

Structural magnetic resonance imaging (MRI) has revealed a range of abnormalities in the brains of individuals with autism spectrum disorder (ASD). One of the most consistently reported findings is the presence of atypical brain growth trajectories (9). In children with ASD, there is an initial phase of accelerated brain growth, characterized by an increase in total brain volume during infancy and early childhood. This early overgrowth phase is typically observed within the first four years of life (10, 11). Several studies have demonstrated that during this period, children with ASD exhibit a total brain volume that is approximately 5-10% larger than that of age-matched typically developing controls (10, 12). This enlargement appears to be associated with increases in both gray matter (GM) and white matter (WM) volumes (11, 13). Interestingly, this pattern of brain overgrowth does not persist into later childhood and adolescence. Instead, brain growth appears to plateau, and total brain volume becomes comparable to, or even slightly reduced relative to, typically developing peers (11, 14). These findings suggest that early brain overgrowth may represent a critical neurodevelopmental hallmark of ASD, potentially contributing to the emergence of clinical symptoms. Moreover, the subsequent normalization or arrest of brain growth during later developmental stages might reflect underlying alterations in neurodevelopmental processes, such as synaptic pruning, myelination, or neuronal connectivity (15). Recent studies from 2023 and 2024 have further advanced our understanding of these abnormalities through the application of novel imaging analysis techniques. Research utilizing contrastive variational autoencoders (CVAE) has demonstrated that structural MRI features can successfully classify ASD in children as young as 11 months, with classification accuracy exceeding 97% (16). Additionally, studies combining radiomic feature extraction with machine learning approaches, such as support vector machines (SVM), have confirmed associations between abnormalities in white matter and ASD, achieving prediction accuracies greater than 89% (17).

Emerging technologies, including AI-driven brain mapping tools, are opening new avenues for the detailed exploration of early brain developmental trajectories, offering promise for the early diagnosis and better understanding of ASD and other neurodevelopmental conditions (18).

Radiologists have focused on the corpus callosum and reported reduced volumes in several of its subregions, including the anterior (genu and rostrum), middle (body), and posterior (isthmus and splenium) parts, in both juveniles and adults with autism spectrum disorder (ASD). Using spin-echo (SE) T1-weighted MRI, they examined the size of the anterior, body, and posterior subregions of the corpus callosum in individuals with ASD. Their findings revealed a significantly smaller average size of the body and posterior regions of the corpus callosum in autistic patients compared to typically developing controls.

One of the notable neuroanatomical findings in individuals with autism spectrum disorder (ASD) is an increased amygdala volume. A systematic review and meta-analysis by Stanfield et al. (2008) found that this enlargement is typically observed in children with ASD, but not in older individuals. The study reported significant age-related differences in the effect sizes for both the left and right amygdala. Specifically, the amygdala appears to be enlarged in younger children with ASD, but this difference diminishes with age. By adolescence, the amygdala volume in individuals with ASD tends to approximate that of typically developing peers (19). These findings suggest a developmental trajectory in which early amygdala overgrowth normalizes over time (Figure 1).

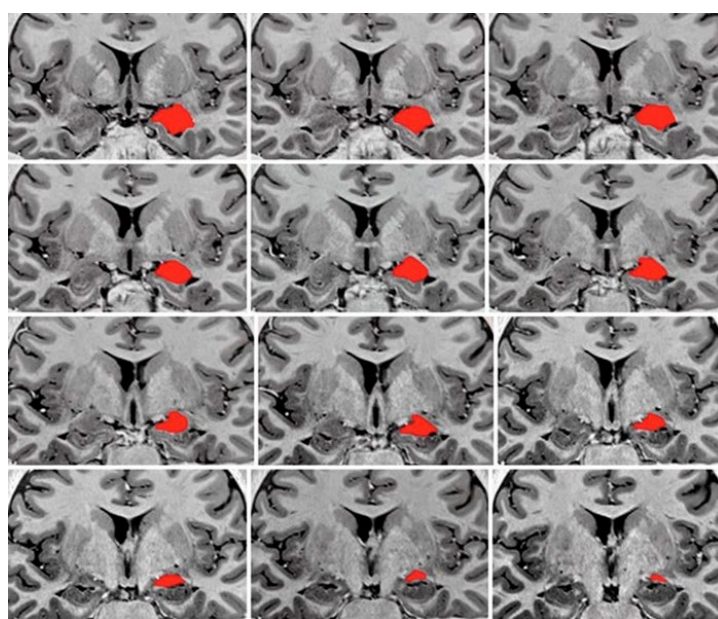


Figure 1. Planimetry. Increased volume of the amygdala.

Source: author's own work.

Several studies have reported abnormalities in the structure of the prefrontal white matter, cingulate gyrus, and internal capsule in individuals with autism spectrum disorder (ASD). Additionally, reduced gray matter (GM) density has been consistently observed in the frontal and temporal lobes (20). These structural differences may be associated with the core cognitive and behavioral features of ASD, including deficits in social communication and executive functioning (Table 1).

Table 1. Atypical Brain Structure Volume and Symptoms in ASD (author's own work).

Brain area	Deficits in ASD
Increased volume of Broca's area	Impaired speech expression
Increased volume of Wernicke's area	Impaired speech comprehension
Increased volume of fronto-temporal regions	Impaired social behavior
Increased volume of the amygdala	Difficulties in emotional processing and regulation
Increased volume of the orbitofrontal cortex, basal ganglia, and cerebellum	Repetitive, stereotypical behaviors
Increased volume of the corpus callosum	Low intelligence quotient (IQ)

It is also important to highlight findings from studies employing more advanced MRI modalities, such as diffusion-weighted imaging (DWI) and functional MRI (fMRI). In particular, atypical values of the apparent diffusion coefficient (ADC) and reduced fractional anisotropy (FA) in short association fibers have been identified as characteristic neuroimaging features in patients with ASD (Figure 2) (21). These abnormalities may reflect

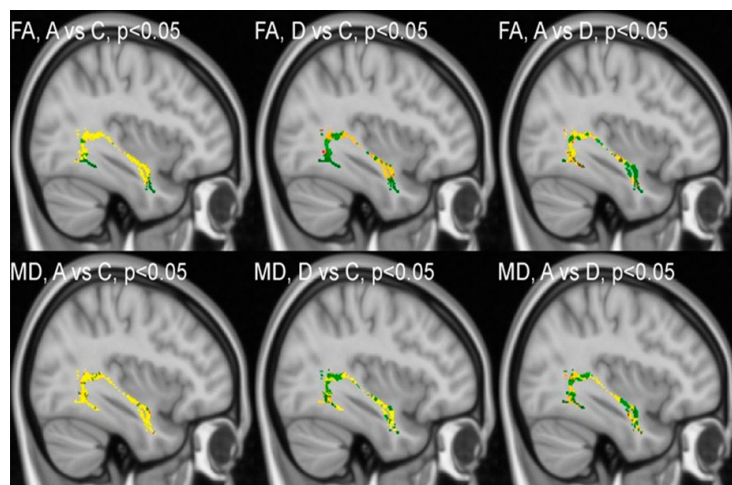


Figure 2. FA measurement from the arcuate fasciculus. Decreased FA values – typical for ASD.

Source: author's own work.

microstructural disorganization in white matter pathways, which can contribute to altered neural connectivity observed in this population.

Functional magnetic resonance imaging (fMRI) is a technique that allows for non-invasive, real-time monitoring of brain activity. Unlike conventional MRI, fMRI shows how the brain functions both during tasks and at rest. It relies on the measurement of the BOLD signal, which records changes in blood oxygenation in active areas of the brain, reflecting local alterations in blood flow. fMRI allows for tracking changes in brain activity in response to stimuli, tasks, and during resting state (resting state fMRI), enabling the analysis of functional connections between different brain regions (Figure 3, part A). This technique has wide applications in neuropsychology, psychiatry, and research on development and neurodevelopmental disorders such as autism, ADHD, and schizophrenia, helping to identify areas responsible for various functions and atypical patterns of activity.

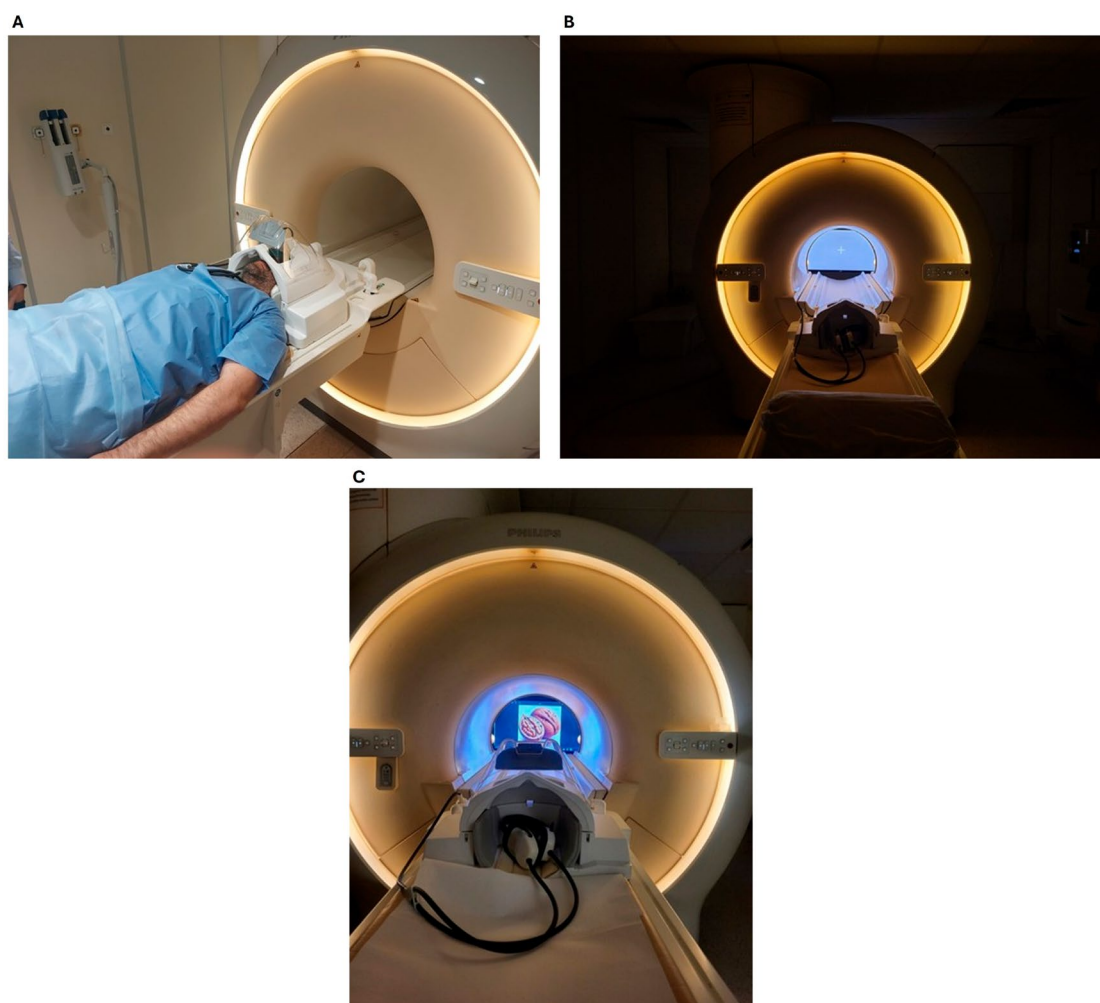


Figure 3. Overview of fMRI methodology and imaging setup (A – Patient positioned in the MRI scanner prior to functional imaging, B – Resting-state fMRI – patient’s view inside the scanner during data acquisition, C – Task-based fMRI).

Source: All pictures are obtained from authors own work.

Despite promising research findings, fMRI still does not provide sufficiently consistent data to develop a universal method for assessing individuals with ASD. Limitations include clinical variability, differences in research designs, and challenges in maintaining standard conditions, particularly with young children. In ASD studies, both task-based paradigms and resting-state imaging are used. To date, research has mainly focused on adolescents and adults, but recent studies suggest that brain organization differences can be detected as early as 2 years of age. Hull et al. (2017) described changes in interhemispheric connectivity and language areas, and developed a classification model with 72% sensitivity and 84% specificity, suggesting the potential of fMRI in early ASD diagnosis (22).

Resting-State and Task-Based fMRI in ASD Diagnostics

In autism diagnostics, both resting-state and task-based fMRI are used (Figure 3, part B). Resting-state fMRI analyzes spontaneous fluctuations in the BOLD signal without the involvement of tasks, which facilitates studies in children and individuals with difficulties in cooperation. However, its diagnostic effectiveness (48-82%) is mainly limited to group analyses. Task-based fMRI (Figure 3, part C), which requires the completion of specific tasks, achieves higher effectiveness (80-97%) in individual diagnosis. Both resting-state and task-based fMRI have distinct advantages and limitations; their complementary use – particularly when combined with machine learning approaches – may improve diagnostic accuracy in ASD (23, 24). Resting-state fMRI is clinically more practical due to its lower demands on the patient, while task-based fMRI provides greater precision in assessing specific functional deficits in ASD (Figure 4). The combination of both

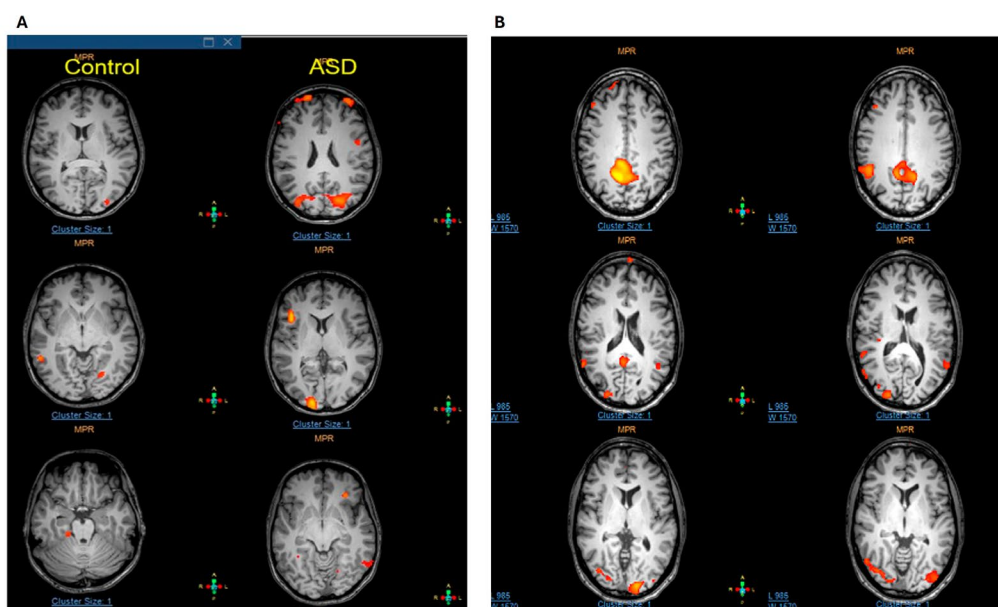


Figure 4. Activity Analysis of task-based fMRI (A – Control Group vs. ASD Group, B – ASD Group).
Source: author's own work.

methods, especially with the use of artificial intelligence, could enhance diagnostic accuracy in the future. Research has shown that in individuals with ASD, the same task leads to greater activation of the visual cortex, indicating a dominance of low-level sensory processing, while in neurotypical individuals, activation of the attention network and higher cognitive functions prevails.

Individuals with ASD often have difficulty recognizing emotions, particularly sadness and happiness. In the case of sadness, they exhibit reduced amygdala activity and avoidance of eye contact, while in the case of happiness, they show delayed responses and less frequent smiling reciprocity. These difficulties may stem from dysfunction in the prefrontal cortex and impaired processing of facial expressions (Dalton et al., 2005; Pelphrey et al., 2002) (Figure 5) (25, 26).



Figure 5. Example images from facial emotion recognition.

Source: generated by AI.

The fusiform gyrus in the temporal lobe is responsible for facial recognition; in individuals with ASD, it shows reduced activity, which is associated with difficulties in identifying faces, emotions, and maintaining eye contact. fMRI studies use tasks such as: recognizing familiar faces (familiarity assessment), identity matching (comparing two faces), and facial emotion recognition (associating emotions with facial expressions) to analyze the neural mechanisms of facial stimulus processing in ASD (27).

Reduced activity in the superior temporal sulcus (STS) in individuals with ASD is linked to difficulties in perceiving biological motion, interpreting gestures, facial expressions, and intentions. This manifests in problems distinguishing social and interactive movements.

fMRI studies use tasks assessing the naturalness of movement (videos showing either normal or impaired movement) to analyze STS activity and its role in motion processing deficits in ASD (28). Reduced activity in Broca's area in individuals with ASD is associated with difficulties in language expression, such as monotone intonation, limited fluency, and a lack of spontaneity in speech. fMRI studies use tasks assessing emotion recognition in speech, spontaneous speech production, and sentence repetition with appropriate intonation to better understand these impairments (29). Low activity in Wernicke's area in individuals with ASD is linked to difficulties in speech comprehension, particularly with complex sentences. fMRI reveals weakened activity in this structure and reduced connections to other language-related areas. Tasks assessing the meaning of simple and complex sentences help to uncover these deficits (30).

Individuals with ASD often have difficulties processing social stimuli, such as biological motion, facial recognition, and emotion recognition. Key regions involved in these processes include the superior temporal sulcus (STS) – for analyzing motion and gaze, the fusiform gyrus (FFA) – for facial recognition, and the amygdala – for processing emotions and threat.

Example task (task-based fMRI): Emotion recognition on faces – participants are shown faces expressing various emotions (😊 happiness, 😡 anger, 😞 sadness, 😨 fear). The task involves assigning the correct emotion label to the displayed face by selecting one of the options: "happiness", "sadness", "anger", or "fear".

Moreover, patients with ASD often exhibit high activity in the parietal-occipital regions, which is associated with advanced visuospatial abilities. These brain areas, responsible for spatial manipulation and visual perception, contribute to success in fields such as mathematics, architecture, and engineering. However, individuals with ASD may have difficulties processing sensory stimuli and engaging in social interactions. The high activity in these regions does not always correlate with social skills, leading to challenges in communication and understanding the emotions of others.

Example task (task-based fMRI): Visuospatial manipulation – 3D figure task. Participants are shown two 3D figures. Their task is to assess whether the figures are identical but rotated in space, or if they are different. Activation of the parietal cortex is observed during this task, indicating the involvement of areas responsible for spatial thinking.

Positron Emission Tomography (PET) in Autism Spectrum Disorder

Positron emission tomography (PET) is a molecular neuroimaging method that allows the visualization and quantification of metabolic and neurochemical processes in vivo. Although it is not used as a standard diagnostic tool in autism spectrum disorder (ASD), PET has provided valuable insights into the pathophysiology of the disorder and remains an important research technique in clinical neuroscience. Most PET studies in ASD have employed [^{18}F] fluorodeoxyglucose ([^{18}F]FDG) to assess regional cerebral glucose metabolism, which reflects synaptic activity. Findings consistently demonstrate reduced metabolic rates in the prefrontal and temporal cortices, as well as in the cerebellum, compared with neurotypical controls. Altered hemispheric asymmetry, particularly within language-related and social cognition regions, has also been described (34). These abnormalities suggest dysfunction within large-scale neural networks subserving communication and executive functioning. Beyond glucose metabolism, PET enables the study of specific neurotransmitter systems using selective radioligands. Alterations in serotonin transporter (SERT) binding have been reported in ASD, pointing to dysregulation of serotonergic signaling (35). In addition, abnormal binding of metabotropic glutamate receptor 5 (mGluR5) tracers, such as [^{18}F]-FPEB, has been observed in the cerebellum and parietal cortex (36), suggesting an imbalance between excitatory and inhibitory neurotransmission – a mechanism frequently proposed in ASD pathophysiology.

Another area of interest is neuroinflammation. PET studies using ligands targeting the translocator protein (TSPO), a marker of microglial activation, have shown increased binding in some ASD cohorts, implying a potential neuroimmune contribution (35). However, results remain inconsistent due to small sample sizes, methodological differences, and challenges in quantifying TSPO binding in the developing brain.

Clinical case reports illustrate how PET findings can occasionally guide individualized therapeutic approaches. For instance, Żarnowska et al. (2018) described a child with global cortical hypometabolism who demonstrated both metabolic and behavioral improvement following the introduction of a ketogenic diet (37). Although anecdotal, such cases highlight the potential translational relevance of PET findings.

Despite its promise, the routine use of PET in children with ASD is limited by ethical and practical constraints. The need for radiotracers entails exposure to ionizing radiation, and sedation is often required to minimize motion artifacts. Furthermore, PET is costly, and the lack of standardized acquisition and analysis protocols hinders cross-study comparisons. Consequently, PET remains primarily a research tool, not a clinical diagnostic method.

Nevertheless, PET offers unique molecular-level information that complements structural and functional MRI. By integrating PET findings with other imaging modalities, future studies may help to identify neurobiological subtypes of ASD and improve the understanding of its heterogeneous mechanisms. Standardization of imaging protocols and larger, multicenter studies are essential for translating these discoveries into clinically useful biomarkers.

Conclusions

Functional magnetic resonance imaging (fMRI) is increasingly used in research on autism spectrum disorders (ASD), allowing for the assessment of functional brain activity both at rest (resting state) and during task performance (task-based). This technique enables the identification of characteristic activation patterns and disruptions in functional connectivity, particularly in areas related to the processing of emotions, language, and social information.

Studies show that individuals with ASD exhibit reduced activity in areas such as the fusiform gyrus, amygdala, Broca's area, Wernicke's area, and the superior temporal sulcus, which translates into difficulties in facial recognition, emotion interpretation, and speech processing. On the other hand, increased activity in the parietal-occipital regions may explain preserved or above-average visuospatial abilities.

The use of fMRI methods, especially when combined with machine learning algorithms, holds significant potential for early ASD diagnosis, achieving classification accuracy above 80%. Although fMRI currently primarily serves as a research tool, advancements in this technology could make it a valuable support for individual diagnostics in the future.

References

1. Kabasawa H. MR Imaging in the 21st Century: Technical Innovation over the First Two Decades. *Magn Reson Med Sci* 2022; 21(1):71-82. DOI:10.2463/mrms.rev.2021-0011.
2. Yousaf T, Dervenoulas G, Politis M. Advances in MRI Methodology. *Int Rev Neurobiol* 2018; 141:31-76. DOI:10.1016/bs.irn.2018.08.008.
3. Alamri A, Aljadhari YI, Alrashed A, et al. Identifying Clinical Clues in Children With Global Developmental Delay / Intellectual Disability With Abnormal Brain Magnetic Resonance Imaging (MRI). *J Child Neurol* 2021; 36(6):432-439. DOI:10.1177/0883073820977330.
4. Wang L, Wang B, Wu C, et al. Autism Spectrum Disorder: Neurodevelopmental Risk Factors, Biological Mechanism, and Precision Therapy. *Int J Mol Sci* 2023; 24(3):1819. DOI:10.3390/ijms24031819.
5. Hodges H, Fealko C, Soares N. Autism spectrum disorder: definition, epidemiology, causes, and clinical evaluation. *Transl Pediatr* 2020; 9(Suppl.1):S55-S65. DOI:10.21037/tp.2019.09.09.
6. Okoye C, Obialo-Ibeawuchi CM, Obajeun OA, et al. Early Diagnosis of Autism Spectrum Disorder: A Review and Analysis of the Risks and Benefits. *Cureus* 2023; 15(8):e43226. DOI:10.7759/cureus.43226.
7. Wang J, He Y. Toward individualized connectomes of brain morphology. *Trends Neurosci* 2024; 47(2):106-119. DOI:10.1016/j.tins.2023.11.011.
8. Rafiee F, Rezvani Habibabadi R, Motaghi M, et al. Brain MRI in Autism Spectrum Disorder: Narrative Review and Recent Advances. *J Magn Reson Imaging* 2022; 55(6):1613-1624. DOI:10.1002/jmri.27949.
9. Avino TA, Barger N, Vargas MV, et al. Neuron numbers increase in the human amygdala from birth to adulthood, but not in autism. *Proc Natl Acad Sci USA* 2018; 115(14):3710-3715. DOI:10.1073/pnas.1801912115.
10. Courchesne E, Campbell K, Solso S. Brain growth across the life span in autism: age-specific changes in anatomical pathology. *Brain Res* 2011; 1380:138-45. DOI:10.1016/j.brainres.2010.09.101.
11. Courchesne E, Redcay E, Kennedy DP. The autistic brain: birth through adulthood. *Curr Opin Neurol* 2004; 17(4):489-96. DOI:10.1097/01.wco.0000137542.14610.b4.
12. Schumann CM, Amaral DG. Stereological analysis of amygdala neuron number in autism. *J Neurosci* 2006; 26(29):7674-9. DOI:10.1523/JNEUROSCI.1285-06.2006.
13. Hazlett HC, Poe M, Gerig G, et al. Magnetic resonance imaging and head circumference study of brain size in autism: birth through age 2 years. *Arch Gen Psychiatry* 2005; 62(12):1366-76. DOI:10.1001/archpsyc.62.12.1366.
14. Redcay E, Courchesne E. Deviant functional magnetic resonance imaging patterns of brain activity to speech in 2-3-year-old children with autism spectrum disorder. *Biol Psychiatry* 2008; 64(7):589-98. DOI:10.1016/j.biopsych.2008.05.020.
15. Amaral DG, Schumann CM, Nordahl CW. Neuroanatomy of autism. *Trends Neurosci* 2008; 31(3):137-45. DOI:10.1016/j.tins.2007.12.005.

16. Ma R, Xie R, Wang Y, et al. Autism Spectrum Disorder Classification in Children based on Structural MRI Features Extracted using Contrastive Variational Autoencoder. arXiv preprint arXiv:2307.00976. 2023.
17. Song J, Chen Y, Yao Y, et al. Combining Radiomics and Machine Learning Approaches for Objective ASD Diagnosis: Verifying White Matter Associations with ASD. arXiv preprint arXiv:2405.16248. 2024.
18. Gkintoni E, Panagioti M, Vassilopoulos SP, Nikolaou G, Boutsinas B, Vantarakis A. Leveraging AI-Driven Neuroimaging Biomarkers for Early Detection and Social Function Prediction in Autism Spectrum Disorders: A Systematic Review. *Healthcare (Basel)* 2025; 13(15):1776. DOI:10.3390/healthcare13151776.
19. Stanfield AC, McIntosh AM, Spencer MD, et al. Towards a neuroanatomy of autism: A systematic review and meta-analysis of structural magnetic resonance imaging studies. *European Psychiatry* 2008; 23(4):289-299. DOI:10.1016/j.eurpsy.2007.05.006.
20. Aoki Y, Abe O, Nippashi Y, et al. Comparison of white matter integrity between autism spectrum disorder subjects and typically developing individuals: A meta-analysis of diffusion tensor imaging tractography studies. *Molecular Autism* 2013; 4(1),25. DOI:10.1186/2040-2392-4-25.
21. Sundaram SK, Kumar A, Makki MI, et al. Diffusion tensor imaging of frontal lobe in autism spectrum disorder. *Cereb Cortex* 2008; 18(11):2659-2665. DOI:10.1093/cercor/bhn031.
22. Han J, Zeng K, Kang J, et al. Development of Brain Network in Children with Autism from Early Childhood to Late Childhood. *Neuroscience* 2017; 367:134-146. DOI:10.1016/j.neuroscience.2017.10.015.
23. Deshpande G, Libero LE, Sreenivasan KR, et al. Identification of neural connectivity signatures of autism using machine learning. *Front Hum Neurosci* 2013; 7:670. DOI:10.3389/fnhum.2013.00670.
24. Liu M, Li B, Hu D. Autism Spectrum Disorder Studies Using fMRI Data and Machine Learning: A Review. *Front Neurosci* 2021; 15:697870. DOI:10.3389/fnins.2021.697870.
25. Dalton KM, Nacewicz BM, Johnstone T, et al. Gaze fixation and the neural circuitry of face processing in autism. *Nat Neurosci* 2005; 8(4):519-26. DOI:10.1038/nn1421.
26. Pelphrey KA, Morris JP, Michelich CR, et al. Functional anatomy of biological motion perception in posterior temporal cortex: an FMRI study of eye, mouth and hand movements. *Cereb Cortex* 2005; 15(12):1866-76. DOI:10.1093/cercor/bhi064.
27. Schultz RT, Grelotti DJ, Klin A, et al. Abnormal activation of the social brain during face perception in autism. *Hum Brain Mapp* 2003; 19(3):131-9. DOI:10.1002/hbm.10123.
28. Herrington JD, Nymberg C, Schultz RT. Biological motion task performance predicts superior temporal sulcus activity. *Brain Cogn* 2011; 77(3):372-81. DOI:10.1016/j.bandc.2011.08.010.
29. Knaus TA, Silver AM, Lindgren KA, et al. fMRI activation during a language task in adolescents with ASD. *J Int Neuropsychol Soc* 2008; 14(6):967-79. DOI:10.1017/S1355617708081216.

30. Just MA, Cherkassky VL, Keller TA, et al. Cortical activation and synchronization during sentence comprehension in high-functioning autism: evidence of underconnectivity. *Brain* 2004; 127(Pt 8):1811-21. DOI:10.1093/brain/awh199.
31. Hazlett EA, Buchsbaum MS, Haznedar MM, et al. Regional glucose metabolism within cortical Brodmann areas in healthy individuals and autistic patients. *Neuropsychobiology* 2004; 49(2):115-126. DOI:10.1159/000076412.
32. Chugani DC, Muzik O, Behen M, et al. Developmental changes in brain serotonin synthesis capacity in autistic and nonautistic children. *Ann Neurol* 1999; 45(3):287-295. DOI:10.1002/1531-8249(199903)45:3<287::AID-ANA3>3.0.CO;2-9.
33. Suzuki K, Sugihara G, Ouchi Y, et al. Microglial activation in young adults with autism spectrum disorder: PET study using ¹¹C-PK11195. *Brain* 2013; 136(11):3426-3435. DOI:10.1093/brain/awt287.
34. Keeratitanont K, Srikam C, Plengpanich W, et al. Brain laterality evaluated by F-18 fluorodeoxyglucose PET/CT in patients with high-functioning autism spectrum disorder. *Front Mol Neurosci* 2022; 15:901016. DOI:10.3389/fnmol.2022.901016.
35. Zürcher NR, Bhanot A, McDougle CJ, Hooker JM. A systematic review of molecular imaging (PET and SPECT) in autism spectrum disorder. *Neurosci Biobehav Rev* 2015; 52:56-73. DOI:10.1016/j.neubiorev.2015.02.010.
36. Fatemi SH, Folsom TD, Kneeland RE, et al. Metabotropic glutamate receptor 5 tracer [¹⁸F]-FPEB displays altered binding potential in autism. *Cerebellum Ataxias* 2018; 5:8. DOI:10.1186/s40673-018-0089-5.
37. Żarnowska I, Choińska A, Ješko H, et al. A case report of clinical and 18FDG PET findings in autism: ketogenic diet as a therapeutic approach. *Metab Brain Dis* 2018; 33(4):1187-1192. DOI:10.1007/s11011-018-0233-0.