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PRECISION PSYCHIATRY: CHALLENGES AND STRATEGIES IN IMPLEMENTING PREDICTIVE MODELS IN MENTAL HEALTH CARE

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Abstract: Objective: To understand the impact of precision medicine on the management of psychiatric disorders, with the aim of improving early diagnosis through an in-depth analysis of the patient, resulting in a more assertive and favorable prognosis. **Methodology:** This is a bibliographic review conducted on the electronic database PUBMED - Medline (Medical Literature Analysis and Retrieval System), using a specific search question. In the initial search, 105 articles were identified, which were screened based on inclusion and exclusion criteria, considering publications in the English language, in the period from 2020 to 2025 and aligned with the thematic approach. After this process, 20 articles were selected for the study. **Discussion:** The uniqueness and complexity of mental disorders pose challenges for accurate diagnoses, since each individual has unique and unpredictable characteristics. However, precision medicine has emerged as a promising tool in psychiatry, enabling more objective diagnoses and personalized treatments. The use of genetic biomarkers, through phenotyping, would allow for the early detection of predispositions, enabling more targeted and effective therapeutic interventions, minimizing the influence of individual variables. In addition, this approach would reduce psychiatry's reliance on non-specific symptoms and syndromic clinical criteria, making practice more based on concrete evidence. **Final considerations:** In view of the findings, there is a need for further studies and investment in precision medicine, given its high capacity to transform mental health care, providing more effective, individualized treatments based on objective biomarkers**.**
Keywords: Precision medicine, Biomarkers, Phenotyping, Artificial Intelligence.

INTRODUCTION

Precision psychiatry has emerged as an interdisciplinary approach that integrates psychiatry, precision medicine and pharmacogenomics to personalize treatments based on the individual characteristics of each patient. This approach is based on the use of genetic biomarkers, multi-omic data and neuroimaging to predict pharmacological responses, diagnosis and prognosis of psychiatric disorders (Lin *et al.*, 2020). Advances in computational techniques, especially artificial intelligence (AI), have been essential in analyzing large volumes of data, allowing complex patterns to be identified and more accurate predictive models to be formulated (Van Dellen, 2024).

In the context of precision psychiatry, machine learning algorithms have been widely used to predict treatment responses and identify relevant biomarkers. However, methodological challenges remain, such as the need for external validation, the heterogeneity of samples and the integration of different data modalities, which still represent obstacles to the clinical implementation of these models (Manchia *et al*., 2020). In addition, the use of deep learning in psychiatry raises ethical and practical concerns, including the interpretability of the models and the risk of biases in the data (Van Dellen, 2024).

The use of natural language processing (NLP) to analyze clinical records has raised concerns about implicit biases in medical documentation (Cobert *et al.,* 2024).

Precision psychiatry is a promising strategy for improving the diagnosis and treatment of mental disorders. However, the complexity of psychiatric illnesses, characterized by multifactorial etiologies and dynamic interactions between biological, psychological and social factors, makes it essential to identify specific biomarkers that can guide personalized interventions (Lin *et al.*, 2020). Unlike other medical fields, psychiatry still lacks routine objective measures, such as laboratory or imaging tests, which limits the adoption of strategies based on precision medicine (Manchia *et al*., 2020).

Machine learning models that integrate clinical data, neuroimaging and biological information offer great potential for personalizing psychiatric care. However, challenges such as the need for large volumes of high-quality data and privacy concerns still need to be overcome (Lin *et al.*, 2020). In addition, emerging technologies, such as wearable devices and mobile apps, are emerging as innovative tools for continuous patient monitoring, allowing for real-time therapeutic adjustments (Xian *et al.*, 2024).

While other areas of medicine use objective biomarkers to guide diagnoses and treatments, psychiatric disorders are still mostly diagnosed based on syndromic clinical criteria, which are often subjective and dependent on medical evaluation (Lin *et al*., 2020). This makes it difficult to define a reliable gold standard for validating predictive models. Strategies that incorporate multiple variables and approaches based on complex dynamic systems can better capture the interaction between genetic, environmental and clinical factors, allowing for more accurate and individualized predictions (Van Dellen, 2024).

Given this scenario, the aim of this study is to identify and discuss the main challenges and what strategies can be adopted to implement effective predictive models in precision psychiatry, with a view to individualized approaches in mental health care.

METHODOLOGY

A literature review developed according to the criteria of the PVO strategy, which stands for: population or research problem, variables and outcome. This strategy was used to develop the research question: Precision Psychiatry: What are the main challenges and what strategies can be adopted to implement effective predictive models in precision psychiatry, aiming at individualized approaches in mental health care? The searches were carried out using the PubMed - MEDLINE (Medical Literature Analysis and Retrieval System Online) databases. The search terms were used in combination with the Boolean terms "**AND" and "OR"**, using the following search strategy: ("Precision Psychiatry") AND (("Predictive Models") OR ("Machine Learning") OR ("Predictive Modeling")) . From this search, **105** articles were found, which were then submitted to the selection criteria. The inclusion criteria were: articles in English published between 2020 and 2025 and which addressed the themes proposed for this research, studies of the narrative review type, systematic review, meta-analysis, observational studies, experimental studies. The exclusion criteria were: duplicate articles, articles available in abstract form, articles that did not directly address the proposal studied and articles that did not meet the other inclusion criteria. After applying the search strategy to the database, a total of **34** articles were found. After applying the inclusion and exclusion criteria , **20** articles were selected from the PubMed database to make up this study's collection.

DISCUSSION

Precision psychiatry has emerged as an innovative field in personalized medicine, incorporating predictive models based on machine learning (ML) and biomarkers to improve the diagnosis and treatment of psychiatric disorders. The integration of multimodal data, including functional magnetic resonance imaging (fMRI), inflammatory biomarkers and electronic health records, has shown promising results, but also faces significant methodological and ethical challenges (DONG *et al.,* 2024; OSTOJIC *et al.,* 2024). One of the most significant advances in this field is the ability to predict the response to treatment with repetitive transcranial magnetic stimulation (rTMS) in patients with schizophrenia, as demonstrated by Dong et al. (2024), who used a multimodal sequential model, combining structural MRI data and clinical data, achieving a predictive accuracy of 94%. These findings reinforce the role of neuroimaging in stratifying patients and personalizing psychiatric therapies.

Subtyping psychiatric disorders based on neurobiological data has been a growing focus in precision psychiatry. Miranda *et al.* (2021) conducted a systematic review on the use of fMRI as a tool to redefine the classification of psychiatric disorders based on functional biomarkers. The study demonstrated that machine learning techniques can identify distinct neurobiological signatures in conditions such as schizophrenia, major depressive disorder and attention deficit hyperactivity disorder (ADHD). This approach can provide a more accurate stratification of patients, allowing for more appropriate therapeutic interventions. However, the authors point out that the use of fMRI is still at an early stage and faces challenges, such as the need for larger samples, external validation and the standardization of analysis methods. In addition, the limited signal-to--noise ratio of fMRI and its high cost make its

clinical application restricted, encouraging the search for more accessible alternatives for precision psychiatry (Miranda *et al.,* 2021).

Inflammatory biomarkers have also been explored as potential predictors of psychiatric disorders. Kozyrev *et al.* (2023) demonstrated that the combination of interleukin-6 (IL-6), tumor necrosis factor alpha (TNF-α) and C-reactive protein (CRP) with machine learning algorithms such as Random Forest classified patients with schizophrenia with a sensitivity of 0.87 and specificity of 0.52. This study suggests that inflammation plays a central role in the pathophysiology of schizophrenia and can be used to improve diagnostic accuracy. Advances in automated speech pattern analysis have shown potential to provide objective measures in precision psychiatry. Menne *et al.* (2024) demonstrated that acoustic features such as pitch variation and vocal intensity can differentiate patients with Major Depressive Disorder (MDD) from healthy individuals, with a predictive accuracy of up to 93% in machine learning models. These findings are particularly relevant as psychiatric disorders still lack routine objective biomarkers, relying largely on subjective assessments (Lin *et al.,* 2020; Manchia *et al.,* 2020). The use of voice-based models may offer new strategies for tracking and continuously monitoring the severity of depressive symptoms, aiding both diagnosis and the assessment of treatment response.

The integration of multiple data sources, including neuroimaging, inflammatory biomarkers and speech characteristics, strengthens precision psychiatry by offering a more comprehensive picture of psychiatric illnesses. The identification of subtypes of psychiatric disorders through machine learning can also be improved by taking population heterogeneity into account in predictive models. Zhao *et al.* (2024) point out that many current algorithms fail to capture the variability of brain-behavior relationships since they use homogeneous ML approaches. The study proposes the need to transition to heterogeneous models that integrate environmental and sociodemographic factors in the prediction of neuropsychiatric outcomes, allowing for greater precision in the personalization of treatment. However, challenges remain, especially regarding the standardization of these approaches and the external validation of predictive models (Ostojic *et al.,* 2024). To mitigate this problem, it is essential to adopt explainable approaches, such as decision trees, which structure the prediction of results in a hierarchical and transparent way, making it possible to trace which factors influenced the final decision. Linear models also offer greater interpretation by correlating clinical variables directly with psychiatric outcomes. Furthermore, the need for robust validation protocols to consolidate these approaches has been reinforced in recent studies on the impact of neuroimaging in precision psychiatry, including strategies such as unsupervised learning and clustering techniques to define subtypes of psychiatric disorders (Miranda *et al.,* 2021).

The need for robust approaches to deal with multidimensionality is one of the central challenges pointed out by Ostojic *et al.* (2024). The exponential increase in the number of variables in relation to the number of samples can compromise the generalizability of the models. Thus, techniques such as Principal Component Analysis (PCA) and Feature Selection are essential to optimize dimensionality reduction without compromising relevant information (Li *et al.,* 2023).

The impacts of precision psychiatry also extend to the monitoring of mental disorders. Sarisik *et al.* (2024) explored electroencephalography (EEG)-based neurophysiological signatures to differentiate patients with schizophrenia and major depressive disorder, based on reduced central alpha power. These biomarkers can provide objective tools for monitoring and longitudinal follow-up of patients.

Predicting response to treatment is another key aspect of precision psychiatry. Rost *et al.* (2022) demonstrated that predictive models of treatment response in major depressive disorder achieved hit rates of between 61% and 71%, reducing the need for trial and error approaches. The application of these models also extends to risk prediction for specific psychiatric disorders, such as bipolar disorder. Walsh *et al.* (2024) developed a risk prediction model for bipolar disorder based on data from multiple biobanks, demonstrating that the use of machine learning algorithms in electronic health records can enable early identification of the disease, facilitating personalized interventions.

However, ethical and social challenges are also a key concern. Machine learning models can perpetuate algorithmic biases if they are trained on unrepresentative samples, negatively impacting underrepresented groups (Ostojic *et al.,* 2024). Data privacy is also a crucial aspect, requiring strict anonymization and security protocols (Eloranta and Boman, 2022).

The need for causal inference in precision psychiatry has also been highlighted in the literature. Bernstorff and Jefsen (2024) point out that many predictive models are built without taking into account underlying causal relationships, which can compromise the validity of predictions. The development of methodologies that combine prediction and causal inference is essential to ensure that models are clinically useful and reliable.

In view of this, precision psychiatry is at a critical stage of development, with promising advances but also substantial challenges. Improving machine learning techniques, reducing algorithmic biases and integrating multiple data sources are key steps towards consolidating this approach in clinical practice. With collaborative studies, rigorous validation and robust ethical guidelines, precision psychiatry has the potential to transform mental health care, enabling more effective and personalized treatments for patients.

FINAL CONSIDERATIONS

Precision medicine represents a promising advance in the treatment of mental disorders, enabling earlier diagnosis through genetic analysis and therapeutic personalization based on individual biomarkers. This approach allows for a more assertive selection of medication and psychotherapeutic strategies, reducing treatment time and promoting a significant improvement in patients' quality of life. However, for this tool to reach its full potential, new studies are needed that integrate advances in artificial intelligence and the development of new pharmacological approaches. In addition, it is essential to evaluate the application of precision medicine in combined therapeutic approaches, considering the multifactorial nature of mental disorders and the need for multidisciplinary treatments to optimize clinical outcomes.

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