# Introduction

Much of the difficulty in treating mental illnesses may be attributed to the poor knowledge we have about the pathophysiology of mental disorders.

Symptoms overlap between multiple diseases, and symptom severity or presence may vary significantly among patients falling into one diagnostic category [@fernandes\_etal17; @kendler16; @newson\_etal20].

Consequently, individuals suffering from mental illnesses are often treated for several months or even years before receiving appropriate medication or adequate psychotherapeutic support [@bzdok\_meyer-lindenberg18]. For example, only about one-third of major depressive disorder patients experience a remission of symptoms after the first treatment with antidepressants. One-third respond after an increased dosage or a supplemented therapy, and one-third experience no improvement in symptoms before discontinuing the treatment [@zanardi\_etal21, @trivedi\_etal06, @souery\_etal11]. These changes in treatment regimens or ineffective treatment may impact patients' quality of life and lead to high healthcare costs [@zanardi\_etal21].

Precision psychiatry offers remedies against the trial-and-error approach in mental healthcare.

In analogy to precision medicine, precision psychiatry takes individual variability in biological, environmental, and lifestyle into account to make adequate treatment recommendations [@council\_etal11; @fernandes\_etal17; @salazardepablo\_etal21].

In contrast to the conventional goal of psychiatric research to develop new treatments effective for a \*majority\* of patients, precision psychiatry switches the focus to the precise selection of an existing therapy for \*a single\* patient or small patient groups [@rush\_etal06; @bzdok\_meyer-lindenberg18; @fernandes\_etal17].

For example, a specific antidepressant may be more effective for one patient than another, even if both suffer from major depressive disorder [@chekroud\_etal16a]. Similarly, a particular psychotherapeutic approach may work better for some individuals than others [@lutz\_etal22].

By using information from multiple sources (e.g., biological markers, brain imaging, physiological records, environmental exposures, demographic information, and self-reported experience), precision psychiatry facilitates understanding complex disease mechanisms that are difficult to reconstruct using traditional diagnostic instruments alone [@fernandes\_etal17; @salazardepablo\_etal21].

Sophisticated modeling techniques may be applied to predict mental conditions being present (diagnostic approach), the development of a condition in the future (prognostic approach), and the response to a specific treatment (predictive approach) at the individual subject level [@salazardepablo\_etal21].

Even moderately successful predictive models offer starting points for treatment selection, thus solving some problems associated with conventional trial-and-error treatment approaches [@bzdok\_meyer-lindenberg18].

The task of deriving individual-level predictions may be particularly well accomplished using artificial intelligence (AI) and machine learning (ML) [@bzdok\_meyer-lindenberg18].

First, the disease definitions provided in the Diagnostic and Statistical Manual of Mental Disorders (DSM) and International Classification of Diseases (ICD) manuals do not always represent the biological or behavioral "reality" [@dalgleish\_etal17; @lener\_iosifescu15; @bzdok\_meyer-lindenberg18]. Instead, many disorders commonly grouped under one umbrella term have turned out to be better captured along a continuum --- similar to autism as a classical spectrum disorder [@cuthbert\_insel13; @bzdok\_meyer-lindenberg18; @vanos16].

Second, patient subgroups may exist that share characteristic disease symptoms but respond differently to a specific treatment.

The classification of a patient on a disease continuum or identifying patient subgroups that respond well to a selected treatment may hardly be accomplished using expert knowledge alone.

Instead, AI modeling approaches may provide more accurate predictions due to their ability to a) integrate information obtained from various sources and b) identify subgroups based on shared characteristics [@bzdok\_meyer-lindenberg18; @dwyer\_etal18].

The superiority of AI in handling complex data inputs makes them more useful for precision psychiatry than classical inferential methods [@chekroud\_etal21].

For example, based on a large set of predictors derived from brain imaging data, @yahata\_etal16 identified a small number of functional connections separating typically developed individuals from individuals with autism. They tested the models on an independent dataset. The model accurately classified 85% of the individuals in the validation sample.

As another example, using functional imaging data from \*n\* = 1,188 mental health patients, @drysdale\_etal17 showed that patients might be clustered into four neurophysiological depression subtypes defined by distinct patterns of dysfunctional connectivity in limbic and frontostriatal networks. The accuracy of their classification model reached 86% in an independent sample. The authors also showed that these subtypes were associated with different clinical symptoms and responsiveness to transcranial magnetic stimulation therapy.

Despite the benefits of using AI to strengthen psychiatric and psychotherapeutic practice through precision psychiatry, implementing these techniques into practice is still at an early stage [@lee\_etal21; @sendak\_etal20; @chekroud\_etal21]. In fact, until 2021, no FDA-approved or FDA-cleared AI applications existed in psychiatry [@lee\_etal21].

However, over the past years, enormous research efforts have been put into developing effective AI-enabled diagnostic, predictive, prognostic, and treatment tools [@shatte\_etal19; @aafjes-vandoorn\_etal21; @vaidyam\_etal19; @miller\_polson19; @nahavandi\_etal22].

By now, some precision psychiatry tools are commercially available. For example, \*Cognoa\* offers digital diagnostic and therapeutic products that include personalized treatment plans based on neuro-imaging data [@vaughanbrent\_abbasabdelhalim19].

Owing to the increasing relevance of AI for implementing precision psychiatry into practice, we use patent analysis to shed light on recent developments regarding AI-enabled diagnostic, prognostic, and predictive tools in the mental health domain.

The global market for mental health software is expected to increase from USD 1.9 billion in 2020 to USD 5.1 billion by 2027 [@researchandmarkets22].

Patent analysis helps comprehend the technology development of AI-enabled tools in mental healthcare and identify solutions that have the greatest chances of market adaptation [@ailia\_etal22; @krestel\_etal21b].

# Materials and Methods

## Database Search

This study was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).

We used the Derwent Innovation (DI) database and its smart search function for the patent search.

The Derwent World Patents Index (DWPI) of DI offers the option to extract additional information on patent novelty, use, advantage, and technical focus.

The smart search function analyses word strings semantically and automatically expands keywords including related relevant terms.

For the final search, we used smart search terms referring to precision psychiatry, artificial intelligence, and mental illness. Because we intended to provide insight into recent developments, we limited our search to patents published after the 1st of January, 2015. Terms relating to precision psychiatry were collected from a systematic review on the same topic [@salazardepablo\_etal21].

For the keywords relating to mental illness, we collected the mental illness groups mentioned in the DSM-V-TR manual [@americanpsychiatricassociation22]. We refined the search term by requiring keywords relating to mental illness to be mentioned in the patent abstract. The DI database was searched up until October 2022 using the search query:

(SSTO=("risk prediction") OR SSTO=("predictive") OR SSTO=("prognostic") OR SSTO=("diagnostic")) AND (SSTO=("ARTIFICIAL INTELLIGENCE") OR SSTO=("MACHINE LEARNING")) AND (SSTO=("psychiatrist") OR SSTO=("psychotherapist") OR SSTO=("mental health") OR SSTO=("mental illness")) AND (ABO=("psychiatr\\*") OR ABO=(psychotherap\\*) OR ABO=("mental health") OR ABO=("mental illness") OR ABO=("mood disorder\\*") OR ABO=("affective disorder\\*") OR ABO=(depress\\*) OR ABO=(Neurodevelopmental) OR ABO=(autis\\*) OR ABO=("ADHD") OR ABO=("conduct disorder\\*") OR ABO=("mood dysregulation") OR ABO=("gender dysphoria") OR ABO=("gaming disorder\\*") OR ABO=("paraphilic disorder\\*") OR AB=("bipolar") OR ABO=(anxi\\*) OR ABO=(obsess\\*) OR ABO=(trauma\\*) OR ABO=(posttrauma\\*) OR ABO=("learning disorder\\*") OR ABO=("social communication disorder\\*") OR ABO=("somatic symptom disorder\\*") OR ABO=(dissociat\\*) OR ABO=("eating") OR ABO=(("sleep") NOT ("sleep apnea")) OR ABO=("sexual disorder\\*") OR ABO=(addict\\*) OR ABO=(substance) OR ABO=("personality") OR ABO=("psychosis") OR ABO=(psychot\\*) OR ABO=("schizo")) AND DP>=(20150101);

We extracted DWPI Patent families. DWPI patent families group together patent records for the same invention filed in different jurisdictions, thus avoiding the retrieval of duplicate entries for the same invention.

## Patent Selection

We summarized the search and review process in Figure X [INCLUDE PRISMA DIAGRAM FOR SEARCH - FOR DATA, PLEASE SEE Search\_results.xlsx]. First, we removed all remaining duplicate entries. Next, the titles, abstracts, descriptions, and claims (DWPI and original) of all patents were examined by AK and X.

We included patents if 1) they reported on the diagnostic (predicting the presence of a condition), prognostic (predicting clinical outcomes in the absence of therapy), and predictive (predicting treatment outcomes) tools; 2) the tools described make predictions on the individual subject level; 3) the tools are designed to make predictions for mentally ill individuals, defined according to established psychometric criteria; 4) the designated user group consists of psychotherapists or psychiatrists.

## Data Analysis

The data was analysed using Excel (Version X) and R (Version X). Based on the focus of the patent described in the patent abstract and claims, the patents were categorized into the four precision psychiatry groups diagnosis, prediction, prognosis, and treatment. Next to the content focus of the patents, we analysed the yearly trend of patent publications between January 2015 and October 2022, the regional distribution of patent publications, top 15 assignees, distribution of IPC classes, patent relevancy (based on DI intelligence), patent strategic importance (based on DI intelligence), probability of grant (based on DI intelligence), domain influence (based on DI intelligence), the number of citing patents. In addition, we conducted text analyses of DWPI abstracts, patent novelty, patent use, and the generated advantage.

# Results