Toward an AI-Supported Clinical Pathway for EEG-Guided Transcranial Electric Stimulation in Autism Spectrum Disorder

1st Pasquale Arpaia
University of Naples Federico II
Naples, Italy
pasquale.arpaia@unina.it

2nd Anna Della Calce
University of Naples Federico II
Naples, Italy
anna.dellacalce2@unina.it

3rd Lucrezia Di Marino
University of Naples Federico II
Naples, Italy
lucr.dimarino@studenti.unina.it

4th Luciana Lorenzon
Ismerian Medical Specialist Polyclinic
Treviso, Italy
luciana.cinb.it@gmail.com

5th Luigi Maffei
University of Naples Federico II
Naples, Italy
luigi.maffei@unina.it

6th Nicola Moccaldi
University of Naples Federico II
Naples, Italy
nicola.moccaldi@unina.it

7th Pedro M. Ramos
Instituto Superior Técnico (IST)
Lisboa, Portugal
pedro.m.ramos@tecnico.ulisboa.pt

8th Emanuela Russo
Aequilibria Health
Birkikara, Malta
er@aequilibria.eu

9th Andrea Zingoni
University of Tuscia
Viterbo, Italy
andrea.zingoni@unitus.it

***Abstract*—The formalization of a personalized clinical procedure for the treatment of Autism Spectrum Disorder (ASD) based on electroencephalography-guided transcranial electrical stimulation (tES) is proposed. The clinical method, already practiced in a center of therapy for autistic individuals, has been modeled through a flow chart and a corresponding database in which the inputs and outputs of each action are recorded. The database is designed to serve as the training foundation for an artificial intelligence (AI) system that supports the progressive personalization of the method itself. While tES has shown promise in improving cognitive and behavioral symptoms in ASD, current protocols do not take individual EEG conditions into account. The EEG-guided tES framework is structured as an iterative decision-making process, where stimulation parameters are dynamically adjusted based on neurophysiological and clinical responses. In addition to being modeled, the process has undergone operational qualification through a verification of its correspondence with the clinical intervention performed on two ASD patients: one 15-year-old male patient and one 25-year-old female patient. The study highlights the potential of an adaptive, EEG-driven approach to tES, emphasizing the importance of integrating neurophysiological biomarkers into personalized treatment strategies for ASD, with AI as a prospective tool for further enhancing clinical decision-making.**

***Index Terms*—Electroencephalography, Autism Spectrum Disorder, Artificial Intelligence, Transcranial Electric Stimulation, Personalized Medicine**

I. Introduction

Autism spectrum disorders (ASD) are neurodevelopmental conditions marked by early deficits in social interaction, language acquisition, and cognition [1]. A significant subset of ASD children exhibit EEG abnormalities, ranging from mild slow waves to epileptiform discharges, often detectable only during sleep and requiring extended monitoring. The discharges predominantly affect the frontal cortex, with less frequent involvement of centro-parietal, temporal, and occipital regions. Increasing evidence indicates that dysfunction in the frontal cortex may be crucial to the pathophysiology of ASD [2].

The use of brain stimulation techniques has become increasingly prevalent due to their proven impact on neuroplasticity and brain oscillations [3]. In recent years, transcranial Electrical Stimulation (tES) has emerged as a promising theraupetic approach for treating various neurological disorders. Clinical studies have reported beneficial effects across multiple conditions, including depression, stroke rehabilitation, chronic pain, and neurodevelopmental disorders [4]. TES consists in the application of low-intensity electrical currents to the scalp, inducing acute or long-lasting effects based on the signal specification [5], [3]. Low-intensity direct current (tDCS), alternating current (tACS), and random noise current (tRNS) [6] are among the most widely used techniques. In particular, tDCS consists of applying a weak uniform direct current directly to the scalp, thus modulating the excitation or inhibition of interneuronal circuits [3]. At the microscopic level, it leads to a change in resting threshold, changes in synaptic processes, enhancement of synaptic plasticity and effects on glial cells [7], [8]. Notably, tES, particularly tDCS, has been utilized to mitigate core symptoms of ASD, including deficits in social communication, repetitive behaviors, and cognitive impairments [9], [10]. Increasing evidence supports the efficacy of tDCS in mitigating these symptoms through the modulation of key brain regions, such as the Dorsolateral Prefrontal Cortex

(DLPFC), Motor Cortex (MC), and Temporoparietal Junction (TPJ) [11].

Several studies have explored tDCS's effects on ASD. Qiu et al. [12] showed that tDCS on the frontal cortex improves cognitive functions and neural activity. Zemestani et al. [13] found that tDCS on the DLPFC enhances emotional and behavioral functions in children with ASD and affects Theory of Mind (ToM). Salehinejad et al. [14] noted that tDCS over the vmPFC improves ToM abilities, such as emotion recognition and mental state reasoning, in children with ASD.

The role of electroencephalography (EEG) in the design and assessment of transcranial direct current stimulation (tDCS) treatments for ASD remains limited. Kang et al. [15] employed proxy EEG markers to compare anodal and cathodal tDCS, revealing distinct effects on behavior and excitatory-inhibitory balance, with anodal stimulation showing greater benefits. Furthermore, Kang et al. [16] analyzed EEG complexity using the Maximum Entropy Ratio (MER), highlighting that anodal tDCS over the DLPFC may enhance cortical excitability and restore neural balance, potentially increasing EEG complexity—an indicator of neural processing and connectivity often reduced in ASD. No studies in the literature explicitly link the efficacy analysis of tES to patients' pre-treatment EEG. More broadly, the adopted protocol is justified based on the treated pathology, reflecting an approach still far from personalized medicine. Moreover, tDCS effects depend on different factors, namely (i) the size, the material. and the number of the electrodes, (ii) their positioning and polarity, (iii) the amplitude and the shape of the applied current, (iv) the duration and the frequency of stimulation, as well as (v) the properties of the tissues in the stimulated area [17], [18]. Actually, in most cases, the treatment design exclusively considers current waveform and direction, disregarding the influence of all other stimulation setup parameters [19].

This paper presents a formalized method for the design, implementation, and evaluation of a therapeutic intervention based on EEG-guided tES for ASD patients. The intervention, already in use at a therapy center, has been modeled through a detailed flowchart and a corresponding database that records the inputs and outputs of each action taken. This database serves as the foundation for training an artificial intelligence (AI) system designed to assist therapists in progressively personalizing the intervention. The aim is to optimize the effectiveness of the treatment by refining the stimulation parameters based on the individual neurophysiological and clinical responses of the patient.

II. Method Formalization and database design

The formalization of the clinical pathway is described in Sec. II-A, while the database structure for collecting clinical and EEG data is reported in Sec. II-B.

A. Phases and tools of the Clinical pathway

Below, the method is described as a sequence of actions and respective tools in order to make clear and reproducible EEG-guided tES in patients with ASD.

Registry, anamnestic and clinical data collection. The multidisciplinary team, composed of neurologists and psychologists, is responsible for collecting both registry data, including anamnestic information, and administering psychological tests and questionnaires. Specifically, the anamnestic data collection includes familial, physiological, remote pathological, and proximate pathological history. Subsequently, the following questionnaires are administered to assess behavioural and cognitive symptoms associated with ASD: the Autism Diagnostic Observation Schedule (ADOS) for diagnostic observation of autism, the LEITER QI for cognitive ability assessment, the Vineland Interview conducted with the patient's parents to evaluate adaptive skills, the Wechsler Digit Span Test for working memory assessment, the Autism Treatment Evaluation Checklist (ATEC) to monitor communicative, social, and behavioural progress and the parent's interview regarding obsessive symptoms and behavioural problems.

Pre-treatment EEG data collection and processing. A Quantitative EEG (Q-EEG) is recorded in two conditions: Eyes-Open (EO) and Eyes-Closed (EC). The recording lasts 6 minutes while patients remain seated in a comfortable chair at rest. This is followed by a 30-minute EEG recording during an auditory task in the EO condition. During the auditory task, sounds are presented randomly every 850 ms for 100 ms. These sounds include either a low-frequency tone (1000 Hz) or a high-frequency tone (1300 Hz), as well as complex stimuli consisting of five short tones (frequencies: 500, 1000, 1500, 2000, 2500 Hz). The total number of stimuli is 2000, with an 80% probability for the low-frequency tone and 10% for either the high-frequency or complex tones. The task is passive, meaning participants simply read a book or watch TV while ignoring the sounds. EEG recordings are collected using 19 electrodes placed according to the 10-20 International EEG System, with a sampling rate of 256 Hz. Electrodes are referenced to the earlobes (A1-A2), and the ground electrode is positioned between Fpz and Fz. Impedance is kept below 5 $k\Omega$. During pre-processing phase, EEG signals are filtered between 0.5 and 50 Hz, and the reference montage is changed from linked ears to an average montage. Eye-blink artifacts are corrected using Independent Component Analysis (ICA) by zeroing out components related to eye blinks. Additionally, EEG segments with amplitudes exceeding 50 μV for slow waves (0–1 Hz), 35 μV for fast waves (20–35 Hz), or 100 μV overall are excluded. Finally, manual inspection ensures effective artifact removal, and a minimum of 90 seconds of artifact-free EEG is required for analysis. In the processing phase, resting-state EEG analysis is computed for all channels to quantify the absolute power in the following frequency bands: delta ([1–4] Hz), theta ([4–8] Hz), alpha ([8–13] Hz), low beta ([13–20] Hz), high beta ([20–30] Hz), and gamma ([30–45] Hz). Subsequently, P3a and Mismatch Negativity (MMN) ERP components are extracted from the EEG acquired during the auditory task. P3a is a subcomponent of P300, linked to stimulus-driven attention mechanisms as a response to new and unexpected events [20] [21]. The MMN is an early negative ERP component elicited by an odd stimulus in

a sequence of acoustic stimuli. It is an index of pre- attentive processes and it is more evident when the subject ignores the stimuli [21] [22].

Diagnosis making. Clinical data and EEG analysis are integrated to identify the patient's condition by analyzing symptoms, clinical signs, and diagnostic findings, forming the basis for an accurate diagnosis.

EEG feature modulation targeting. The definition of expected electroencephalographic outcomes based on the analysis of EEG data is posed. In this phase, the *therapeutic rules*, namely the relationship between clinical diagnosis, EEG targets, and clinical outcomes, are defined. These rules allow for the association of a specific clinical condition with EEG signal alterations, the identification of EEG targets to modulate for clinical improvement, and the correlation of EEG changes with symptom reduction.

TES protocol designing. A customised (tES) protocol is created, based on the identified EEG features and the collected clinical data. In this phase, the *treatment rules*, namely the association between EEG feature target and tES protocol parameters, are established. These rules specify the stimulation parameters required to modulate specific EEG features, ensuring targeted neuromodulation for therapeutic efficacy. During this phase, stimulation polarity, electrodes positioning, electrodes dimensions, current waveform, current amplitude, frequency range, stimulation duration and number of sessions are defined.

TES protocol application. TES protocol is implemented according to the defined parameters.

Final treatment assessment. The effectiveness of the tES protocol is evaluated by integrating clinical, psychological, and EEG data. This phase assesses the modulation of targeted EEG features, the correlation between EEG changes and symptom reduction, and the overall clinical improvement, ensuring the updating of therapeutic and treatment rules.

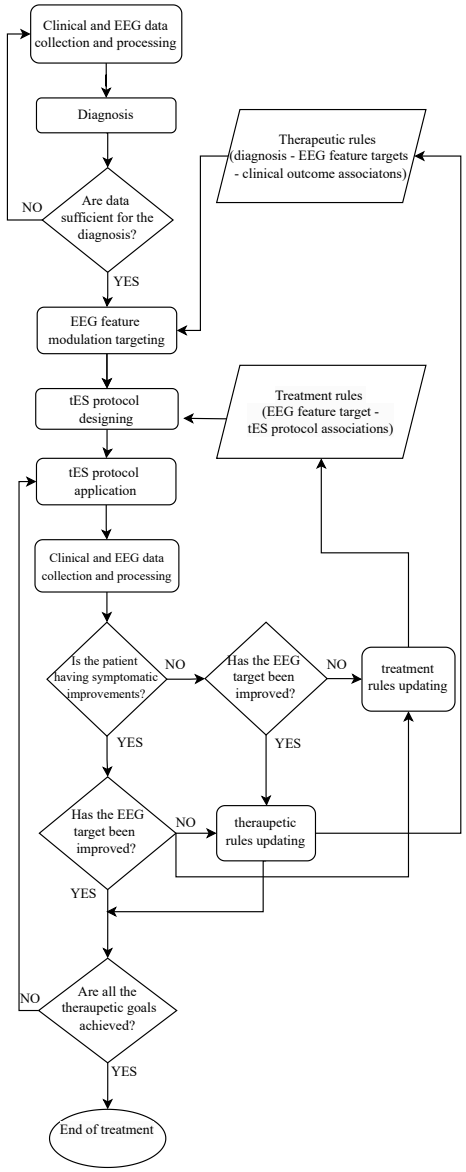

Fig. 1. Flowchart illustrating the decision-making pathway from diagnosis to the evaluation of tES treatment efficacy.

B. Database structure

The structure of the database has been specifically designed to train two AI algorithms, both implemented ad hoc to attempt predicting, respectively, (i) the target features that best fit the clinical diagnosis, made by the doctors, and (ii) the best setup(s) of the stimulation parameters, in terms of successful outcome of the tES.

Emerging clinical evidence suggests that EEG features used in tES treatment may not always correlate with clinical outcomes, indicating a need for continuous refinement in understanding their relationship. To address this, an AI model could be developed to analyze pre- and post-tES assessments, using combinations of EEG features to guide clinical decisions. Each intervention will follow predefined rules for selecting EEG features and stimulation parameters, and post-treatment, different feature combinations will be tested to identify those most closely linked to positive outcomes. Both EEG data and clinical results will be systematically recorded to refine the therapeutic approach.

Given the problem's nature, supervised machine learning is the most appropriate method, as it allows for leveraging expert-interpreted data for prediction. For each patient, paired EEG traces are collected before and after tES, along with physicians' assessments of the patient's condition and the alignment of EEG features with their diagnosis.

This pipeline allows one to have, on the one hand, sets of EEG features and the interpretation by the physicians of the EEG traces carried out using such features, before and after delivering the stimulation. On the other hand, the set of values of the stimulation parameters. The former will be used as predictors for the first prediction task, whereas the latter for the second.

In addition, the response of the physicians about the use-

fulness of the tES, obtained by comparing the status of the patient before and after the stimulation, will serve as the corresponding labels. Based on these considerations, opting for supervised learning algorithms is the logical choice, as will be better clarified later.

Concerning the use of machine learning, this is preferred over more complex algorithms, such as deep neural networks, since these are likely to result in high overfitting, for two main reasons: (i) the low availability of data, which is due to the fact that it is not simple to collect numerous EEG traces of patients with specific diseases; (ii) the high level of noise present in the EEG signal, which could be erroneously learned by too complex models.

A complete list of the acquired data for each sample of the database is reported below.

- Anamnestic and clinical data, including scores from tests and questionnaires administered to patients and patients' parents.
- EEG data collection, including the condition markers (open/closed eyes, cognitive task/resting state), sampling rate, number of acquisition channels and positioning, reference and ground position, acquisition device description, electrode material description, electrode area and shape, contact impedance values for each electrode;
- tES treatment parameters, including stimulation polarity, number of electrodes, electrode position, electrode material, electrode area and shape, current amplitude, offset, current waveform, frequency, contact impedance values for each electrode, stimulation duration, number of sessions, sessions frequency;

The database will be created based on these information and on the aforementioned considerations. In particular, the EEG features, for the first task, and the values of the stimulation parameters, for the second, will be used as input to train the machine learning algorithm, each of them being a predictor. The information about the status of the patient before and after tES treatment, instead, will be merged by the clinical experts, in order to elaborate a binary response about if the patient improved their condition or not. Such a response will be used as a 1 or 0 label in the training phase of the machine learning algorithm.

Obviously, before training the AI algorithm and thus beginning to receive suggestions about how to set the tES parameters, an initial configuration must be decided. This will be done by the expert physicians, by analyzing the patients' medical history and, in particular, their familiar, physiological, and pathological (both remote and proximate) one, plus the answers to a battery of psychological tests. Thus, also this set of data must be added to the database, to properly start the above-described tES teraphy flowchart.

Before and after each stimulation, several EEG traces of every patient will be acquired. For each of them, different features will be considered, so as to enlarge the database for the first prediction task. Also in this case, the physicians will guide the decision about which features to take into account, based on their experience. This allows the total number of feature to be limited.

It is worth noting that the AI algorithm will be employed only when the database will be sufficiently populated (at least one hundred of patients' EEG traces), given the necessity of a conspicuous amount of data to make AI perform the desired task correctly.

III. Operational qualification

The method design was qualified through an observational study of the interventions on two patients diagnosed with ASD with comorbid Obsessive-Compulsive Disorder (OCD) and anxiety.: a 25-year-old female and a 15-year-old male. All the interventions were already planned to be implemented in a rehabilitation center, fully compliant with applicable regulations and standards in Italy for such treatments, including EU Regulation 2016/679 (GDPR) and Legislative Decree No. 101/2018, which govern personal data protection and privacy. A neurologist and a psychologist conducted comprehensive neurological and psychological assessments to establish the diagnosis, define the tES treatment, and evaluate its effects over time. The clinical and electroencephalographic evaluation included both the collection of registry, anamnestic, and clinical data through standardized questionnaires and interviews, and qEEG and ERP analysis as detailed in Sec. II-A. The integration of these EEG features with clinical data guided both the diagnostic process and the development of the customised tES protocol.

For the selection of stimulation parameters, two distinct approaches were adopted based on the patients' baseline EEG and clinical findings. In the case of the female patient, qEEG and ERP analysis did not reveal any significant pathological alterations. Therefore, the stimulation parameters were chosen based on established protocols from the literature on ASD, particularly the approach described by D'Urso et al. [23]. Transcranial Direct Current Stimulation (tDCS) was administered once per day for a month and a half, excluding weekends. Each session lasted 20 minutes with a current intensity of 2 mA. Stimulation was delivered via rubber electrodes enclosed in saline-soaked sponges, positioned using an adapted EEG headset for consistent placement. Anodal stimulation targeted the bilateral pre-Supplementary Motor Area (pre-SMA), with the active electrode (5 × 5 cm) placed 15% of the distance between the inion and nasion anterior to Cz, and the reference electrode (2.5 × 5 cm) positioned at CPz.

In contrast, the male patient exhibited clear electroencephalographic abnormalities consistent with ASD, primarily affecting the fronto-central-parietal regions. Specifically, the abnormalities were observed in the sensory parietal areas and the executive central regions in EO condition. These included a shift in the alpha peak to higher frequencies, above 9 Hz, predominantly in the frontal regions as showed in Fig. 2, an increase in the amplitude of the beta 2 band in the F4 electrode site, and an elevated amplitude of delta-theta waves in the central region (C4). These findings reflect characteristic EEG

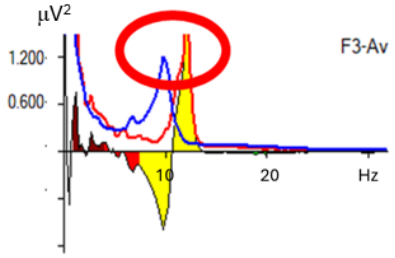

Fig. 2. Power spectra in F3 channel. The blue line represents the normative power trend according to Kropotov et al. [24], the red line represents the male subject's power values, and the colored areas show the difference between the subject's and normative power values. The abnormal peak shift in the Alpha band EEG is highlighted in red.

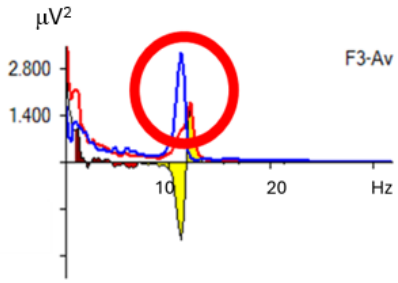

Fig. 3. Comparison of power spectra of the male patient after (blue line) and before (red line) tES treatment in F3 channel. The colored areas represent the difference between the pre- and post-treatment power spectra. The red circle highlights the frequency shift of the alpha peak toward normal conditions following the treatment.

patterns that are commonly associated with ASD, particularly with regard to sensory processing and executive functions.

TES treatments were administered once per day for one and a half months, excluding weekends. The half-sine transcranial stimulation was delivered through two rubber electrodes enclosed in saline-soaked sponges, with the reference electrode consistently placed at CPz, following the International 10-20 EEG system. In each sessions, six 15-minute stimulations with different parameters were used. Two conditions involved anodal stimulation with the anode (5 x 5 cm) between F3 and FC3, with a half-sine waveform at a randomly selected frequency of 20–30 Hz or 4–8 Hz, both with a current amplitude of 1 mA, aiming to reduce beta and theta power, respectively. Other two conditions targeted the same frequency bands but with the anode positioned between F4 and FC4. The final two conditions aimed to enhance alpha power, using anodal stimulation at a fixed frequency of 10 Hz with a 2 mA current, with the anode placed either between F3 and FC3 or between F4 and FC4.

To assess the treatment's efficacy, post-treatment qEEG recordings and clinical evaluations were performed, integrating EEG feature analysis and psychological assessment results. For the female patient, both clinical and EEG data indicated a worsening trend. Clinically, ASD symptoms deteriorated, While qEEG analysis revealed the following abnormalities: a generalized decrease in alpha band power at occipital regions, an increase in beta1 band power at F3 and F4, and an increase in the alpha peak frequency at closed eyes over Cz and O1. Based on these findings, the tES protocol parameters were modified. In particular, two distinct stimulation protocols were administered, each involving the previous both active electrode (5 × 5 cm) covering channels FC1, FC2, and FCz, and the reference electrode (2.5 × 5 cm) positioned at CPz, following the International 10–20 EEG system. In the first stimulation, anodal transcranial alternating current stimulation (tACS) was applied, delivering a current amplitude of 2 mA with a randomly selected frequency within the 8–12 Hz range. In the second stimulation, cathodal tACS was administered with a current amplitude of 1 mA and a randomly selected frequency within the 20–30 Hz range. Conversely, for the male patient, the assessment revealed improvements in both EEG features and clinical symptoms. In particular, the questionnaire to the patient's parent focused on obsessive-compulsive symptoms and anxiety showed an improvement compared to the control, while regarding the Q-EEG findings, there was an increase in alpha amplitude, a reduction in alpha frequency, and a decrease in beta amplitude over the centro-frontal channels in EC condition (Fig. 3).

As a result, the treatment protocol remained unchanged.

tES stimulation will continue for both patients for the same duration and number of sessions as previously conducted until the next EEG and psychological evaluations. These follow-up assessments will determine whether the treatment has achieved the desired effects in terms of clinical outcomes and EEG features. If significant improvements are observed, the treatment will be discontinued. However, if the expected therapeutic benefits are not achieved, the treatment will be repeated with updates to both the therapeutic and treatment guidelines, including potential adjustments to stimulation parameters.

IV. DISCUSSIONS

This study formalizes an existing intervention method for patients with ASD based on EEG-guided transcranial electrical stimulation (tES). The aim is to provide clarity and structure to a clinical practice that was previously guided by empirical approaches moving toward a standardized clinical pathway. The formalization process has helped clinicians conceptualize the existence of two different sets of rules that guide their diagnostic and therapeutic practices: the therapeutic rule, targeting specific EEG features based on diagnosis and therapeutic goals, and the treatment rule, determining the stimulation parameters according to the identified EEG features. By formalizing the method, clinicians employing this innovative approach have gained a clearer and more systematic understanding of the process. The developed flowchart and database systematize the various steps of the intervention and provide a structured way to define and track objectives and their associated indicators. As a result, clinicians now have a more explicit understanding of the iterative nature of their intervention, improving both transparency and predictability in the treatment process. This formalized approach helps refine

clinical practice and can serve as the foundation for future developments. An essential part of this approach is the iterative decision-making structure, where stimulation parameters are adjusted based on neurophysiological and clinical responses. This iterative process has already been operationalized and verified through its application to two ASD patients. While this small sample size is a limitation in terms of generalizability, the verification serves as an initial validation of the method, suggesting that a more personalized and data-driven approach may be beneficial for optimizing treatment. The integration of artificial intelligence (AI) has the potential to enhance this framework by refining clinical decision-making. By analyzing the database, AI could identify patterns in EEG data linked to therapeutic outcomes, optimize stimulation parameters, and improve the selection of relevant EEG features. This would enable more personalized, evidence-based tES interventions. In the future, an AI-driven decision-support system could assist clinicians in adjusting stimulation protocols in real-time, allowing for more adaptive treatments tailored to each patient's neurophysiological profile. However, further research, particularly larger cohort studies, is necessary to refine therapeutic guidelines and improve EEG-based predictions. A comprehensive database combining EEG data with clinical outcomes, along with machine learning models, would enable dynamic adjustments to stimulation parameters for optimal treatment efficacy.

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