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# Classification of methods in transcranial Electrical Stimulation (tES) and evolving strategy from historical approaches to contemporary innovations

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## HIGHLIGHTS

- Cranial Electrotherapy Stimulation is a descendant of Electrosleep.
- Transcutaneous Cranial Electrical Stimulation is a descendant of Electroanesthesia.
- There is a need for better reporting of dosages and devices used.
- There is a shift to basic dosages in contemporary approaches.

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## ABSTRACT

Transcranial Electrical Stimulation (tES) encompasses all methods of non-invasive current application to the brain used in research and clinical practice. We present the first comprehensive and technical review, explaining the evolution of tES in both terminology and dosage over the past 100 years of research to present day. Current transcranial Pulsed Current Stimulation (tPCS) approaches such as Cranial Electrotherapy Stimulation (CES) descended from Electrosleep (ES) through Cranial Electro-stimulation Therapy (CET), Transcerebral Electrotherapy (TCET), and NeuroElectric Therapy (NET) while others like Transcutaneous Cranial Electrical Stimulation (TCES) descended from Electroanesthesia (EA) through Limoge, and Interferential Stimulation. Prior to a contemporary resurgence in interest, variations of transcranial Direct Current Stimulation were explored intermittently, including Polarizing current, Galvanic Vestibular Stimulation (GVS), and Transcranial Micropolarization. The development of these approaches alongside Electroconvulsive Therapy (ECT) and pharmacological developments are considered. Both the roots and unique features of contemporary approaches such as transcranial Alternating Current Stimulation (tACS) and transcranial Random Noise Stimulation (tRNS) are discussed. Trends and incremental developments in electrode montage and waveform spanning decades are presented leading to the present day. Commercial devices, seminal conferences, and regulatory decisions are noted. We conclude with six rules on how increasing medical and technological sophistication may now be leveraged for broader success and adoption of tES.

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FEAST
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Interferential
Stimulation
tACS
Historical
Dosage
Contemporary
Electrotherapy
Cranial
Transcerebral
Transcutaneous
History
Direct
Alternating
Pulsed



**Contents**



## 1. Scope and approach

Transcranial Electrical Stimulation (tES) encompasses all forms of research and clinical application of electrical currents to the brain non-invasively using (at least one) electrodes on the head. The dose of tES is defined by the electrode montage and the stimulation waveform applied to the electrode (Peterchev et al., 2012). There has been a resurgence of interest since 2000, but "modern" tES developed incrementally over a century. This review provides the first comprehensive organization of approaches and dose used in modern tES since 1900. Though 'dose' is used historically in different context, throughout this review we follow the strict convention of Peterchev2012 (Peterchev et al., 2012), where tES dosage is defined by electrode parameters (including number, position, shape, and composition) and all details of stimulation waveform (including intensity and general waveform, and when relevant pulse shape, amplitude, width, polarity, and repetition frequency; duration of and interval between bursts or trains of pulses, and interval between stimulation sessions and total number of sessions).

This process involves defining the litany of terminology that has developed and evolved around tES. We explain the terminology as used contemporarily by researchers. Particular attention is paid to historically linked categories of tES, "streams", of which we identify four that span decades plus "contemporary" approaches (Fig. 1): (1) Cranial Electrical Stimulation (CES) descended from Electrosleep (ES) through Cranial Electro-stimulation Therapy (CET), Transcerebral Electrotherapy (TCET), and NeuroElectric Therapy (NET); (2) Electroanestheisia went through several periods of waning interest and resurgence when new waveform variations were proposed including Transcutaneous Cranial Electrical Stimulation (TCES), Limoge, and Interferential Stimulation; (3) Polarizing or Direct Current Stimulation includes recent transcranial Direct Current Stimulation, Transcranial Micropolarization, High-Definition transcranial Direct Current Stimulation (HD-tDCS) and Galvanic Vestibular Stimulation (GVS); (4) Electroconvulsive Therapy (ECT), initially called Electroshock Therapy, evolved in technique and dose, such as Focal Electrically Administered Seizure Therapy (FEAST); (5) Finally, we categorize "contemporary" approaches that have been explored intensely over the last decade, such as transcranial Alternating Current Stimulation (tACS), transcranial Sinusoidal Direct Current Stimulation (tSDCS), and transcranial Random Noise Stimulation (tRNS). Though analogs to these contemporary approaches can be identified in earlier literature, contemporary methods contain dose features that motivate us to consider them novel as a category. Contemporary approaches to some extent reflect a "reboot" of tES approach, typically employing basic, well documented, and well-defined waveforms (e.g. one sinusoid; Paulus, 2011) in contrast to the increasingly complex waveforms developed (though not always justified) over decades in some streams.

As our technical focus is on dose clarification and classification, we minimize comments on the clinical efficacy or safety of



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