Neuromodulation Strategies

Technique	Main Applications	Remarks
DBS (Deep Brain Stimulation)	Parkinson's disease, essential tremor, dystonia, OCD, epilepsy	Continuous or intermittent stimulation of deep brain nuclei. Adjustable and reversible. Well-established with evolving indications.
Phase-locked Bilateral DBS (PL-DBS)	Bilateral postural tremor, essential tremor, advanced Parkinson's disease	Innovative technique that delivers stimulation synchronized ("phase-locked") to the oscillatory pattern of tremor on both sides. Aims to enhance efficacy while minimizing side effects. Requires real-time sensing and closed-loop stimulation systems.
SCS (Spinal Cord Stimulation)	Neuropathic pain, failed back surgery syndrome, ischemic limb pain	Dorsal column stimulation. Newer systems include adaptive "closed-loop" control.
VNS (Vagus Nerve Stimulation)	Drug-resistant epilepsy, treatment-resistant depression	Intermittent stimulation of the left vagus nerve. Explored for Alzheimer's and autoimmune modulation.

1. Invasive Electrical Stimulation

2. Non-Invasive Electrical Stimulation

Technique	Main Applications	Remarks
tDCS (Transcranial Direct Current Stimulation)	Stroke rehabilitation, chronic pain, depression	Low-voltage direct current stimulation. Modest effects, but safe and portable.
TMS (Transcranial Magnetic Stimulation)	Major depressive disorder, OCD, migraine	FDA-approved. Includes theta-burst protocols and deep TMS variations.
tACS (Transcranial Alternating Current Stimulation)	Experimental: cognition, epilepsy, sleep modulation	Modulates brain oscillations; remains largely investigational.

3. Emerging and Experimental Techniques

Technique	Status	Potential Uses
Optogenetics	Preclinical / Animal studies	Cell-type specific activation/inhibition using light- sensitive proteins. Potential in epilepsy and circuit mapping.
Low-Intensity Focused Ultrasound (LIFU)	Early clinical trials	Non-invasive and highly focal neuromodulation. Investigated for thalamic and subcortical targets.
Closed-loop Neuromodulation	In development	Adaptive systems that monitor neural activity and adjust stimulation in real time. Especially promising for Parkinson's, epilepsy, and pain.

Approach	Examples	Remarks
Targeted pharmacological modulation	GABA agonists, serotonin modulators, dopamine precursors	Traditional neurochemical modulation remains foundational.
Gene and viral therapy	Modified ion channels, optogenetic viral vectors	Experimental; enables durable, localized modulation.
Gut-brain axis interventions	Probiotics, prebiotics, fecal microbiota transplant	Emerging field linking gut microbiota to CNS function and neuromodulation.

4. Chemical and Biological Neuromodulation

5. Future Trends

- **Brain-Computer Interfaces (BCI)**: Control of external devices through neural activity (e.g., prosthetics, communication aids).
- **Multimodal Stimulation**: Integration of neuromodulation with cognitive-behavioral, physical, or pharmacological therapy.
- **Al-driven personalization**: Use of machine learning to optimize stimulation parameters based on patient-specific biomarkers.

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