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REVIEW

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Neurobiological mechanisms and therapeutic impact of electroconvulsive therapy (ECT)

ANA-MARIA COJOCARU[1,2], ANTONIA IOANA VASILE[2], SIMONA CORINA TRIFU[1–3]

[1] *Department of Psychiatry, Prof. Dr. Alexandru Obregia Clinical Hospital for Psychiatry, Bucharest, Romania*

[2] *Doctoral School, Carol Davila University of Medicine and Pharmacy, Bucharest, Romania*

[3] *Department of Neurosciences, Carol Davila University of Medicine and Pharmacy, Bucharest, Romania*

Abstract

Electroconvulsive therapy (ECT) is an efficient therapeutic resource for psycho-pharmacotherapeutic resistant forms of depression. ECT is a form of electrical brain stimulation involving the induction of a controlled seizure, clinically similar to an epileptic seizure, that is initiated in the prefrontal region of the brain and spreads to the cortex and subcortex, including the diencephalic structures. This is achieved by creating a transcranial electric field and synchronously depolarizing neuronal membranes. The mechanisms of action of ECT are not yet fully understood, but several hypotheses have been proposed to explain how it affects the brain: neurotransmitter changes, neuroplasticity, network connectivity, endocrine system regulation and changes in regional cerebral blood flow and regional metabolism.

Keywords: regional cerebral blood flow, neuroplasticity, hypothalamic–pituitary–adrenal axis.

Introduction

Depressive disorder is one of the most frequent and debilitating mental illnesses. It is evaluated that around one third of major depressive episodes do not achieve remission after two trials with antidepressant treatment associated with psychotherapy, so for these particular, resistant cases electroconvulsive therapy (ECT) can be an efficient therapeutic resource [1].

The electrical impulse generated by ECT electrodes travels through intermediary tissue, stimulating neurons in the brain by modifying their internal electrical environment and ion concentration. This process leads to a group of depolarized neurons firing simultaneously, inducing a convulsion. A generalized seizure affects crucial brain structures including the cortex, subcortex, thalamus, basal ganglia, and limbic system, with certain areas being more prominently involved than others. This convulsive activity is believed to have therapeutic effects in various neuro-psychiatric disorders [2].

ECT holds significant importance in the treatment of several psychiatric conditions for certain advantages of this technique. ECT is known for its quick onset of therapeutic effects, this being the primary indication for its use in situations where there is an imminent risk of harm due to severe depression, suicidality, or catatonia, when it can be a life-saving intervention. It can rapidly alleviate symptoms and stabilize the individual's condition. It can bring rapid improvement in severe psychiatric conditions, especially in cases where other treatments, such as medication or psychotherapy, have been less effective.

ECT is a vital intervention in modern psychiatric practice for numerous individuals dealing with severe mood and psychotic disorders. Despite the emergence of innovative brain stimulation methods and novel pharmaceuticals, no other treatment has matched the effectiveness of ECT in addressing the needs of this specific patient population [3].

Materials and Methods

In this paper, we synthesize information obtained from a systematical examination of the existing literature pertaining to the mechanisms of action of ECT therapy in major depressive episodes. The primary focus was on identifying and analyzing relevant studies, encompassing both experimental and observational research. A thorough literature search was conducted across electronic databases, including *PubMed* (1726 articles) and *Web of Science* (11 749 articles), using specific keywords and search criteria (electroconvulsive therapy AND neuroplasticity OR receptors OR dopamine OR frontal and limbic region OR blood-brain barrier), to ensure a comprehensive coverage of the subject.

ECT as a therapeutic method

ECT is a therapeutic method used in selected cases, which, due to the rapid onset of therapeutic effects, can lead to the remission of severe and treatment-resistant psycho-pathological states. It has indications for use in multiple psychiatric pathologies, including all forms of depression (unipolar, bipolar, and mixed episodes), schizophrenia, mania, catatonia, Parkinson's disease, treatment-resistant and debilitating obsessive-compulsive disorder, and neuroleptic malignant syndrome. The indications for electro-therapy in depressive disorders include emergency treatment

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of depression to achieve a definitive response, increased suicidal risk, compromised somatic status due to depression (nutritional negativism), treatment-resistant depression, depression with psychotic features and last but not least, patient preference [4].

ECT carries the risk of post-procedural adverse effects with varying severity and duration. The most commonly encountered of these is post-therapy confusion syndrome, which typically resolves within 30 minutes to an hour after the intervention. Memory disturbances are among the most noticeable issues arising after ECT and may persist for approximately 1–3 weeks following treatment. There are cases where these disturbances have a more prolonged duration, lasting 6–7 months. These can manifest as retrograde amnesia for events preceding ECT and anterograde amnesia post-therapy, where the individual may struggle to recall well-learned information, such as addresses or phone numbers. Other potential mild adverse effects include headache, nausea, vomiting, dizziness, and muscle pain, while more significant adverse effects, such as prolongation of epileptic-like seizures to *status epilepticus* in patients taking medication that lowers the seizure threshold, thromboembolic events, benign arrhythmias, or fibrillations are possible but rare effects of this procedure.

ECT is performed under general anesthesia and uses an electric stimulus generated by a device using oscillating current with an intensity of 0.5–1 A, exceeding the convulsive threshold of each patient and triggering neuronal depolarization. The chronaxia for human neurons is 0.1–0.2 milliseconds; after excitation, they enter a refractory phase during which they no longer respond even if the excitation continues. The duration of stimulation varies between 0.2 and 8.0 seconds, with the energy used being minimized based on the resistance of the soft and bony tissues traversed. This minimum depolarization threshold is determined for each patient before the administration of the electric shock. The clinical effect is attributed to the synchronous depolarization triggered by electrical stimulation and the entire cascade of neurophysiological, neuroendocrine, and neurochemical effects that follow. After the administration of ECT, the electroconvulsive threshold increases with the progression of the therapy, making the method itself considered to have an anticonvulsant effect.

Introduced in 1938, as a treatment for various mental illnesses, including schizophrenia and severe depression, ECT has undergone continual changes and improvements throughout its history. Initially, the procedure was often performed without anesthesia, leading to significant discomfort for patients. In the mid-20th century, advancements in anesthesia and muscle relaxants improved the safety and acceptability of ECT. Anesthesia made the procedure more comfortable for patients, and muscle relaxants helped minimize physical side effects, such as convulsions. ECT became a subject of controversy due to concerns about its side effects and ethical considerations research. This led to increased regulation of the procedure and refining the technique, in order to achieve a better understanding of its mechanisms of action. While ECT has come a long way since its inception, ongoing research aims to further refine its application, improve patient outcomes, and address concerns related to its usage [5].

Neurotransmitter changes

ECT could have an influence on the release, reuptake, and receptor sensitivity of neurotransmitters, such as serotonin (5-hydroxytryptamine, 5-HT), norepinephrine, and dopamine (DA), and by these changes in neurotransmitter function it could contribute to the improvement of mood and symptoms associated with psychiatric disorders [6].

The serotonergic system plays a crucial role in the mechanism and therapeutic effectiveness of ECT, being well known to be implicated in mood regulation, emotions, and various cognitive functions. Preclinical studies indicate increased serotonergic neurotransmission, with enhanced expression and activity in the hippocampus and prefrontal cortex of both postsynaptic 5-HT1A and 5-HT2A receptors. In human studies, it has been demonstrated that the binding of both 5-HT1A and 5-HT2A receptors is generally reduced after ECT [7]. This pattern aligns with the observed receptor binding changes seen with the administration of antidepressants. The similarity in receptor modulation suggests a shared neurochemical effect, highlighting potential commonalities in the mechanisms of action between ECT and antidepressant medications [8].

The findings from a recent study using positron emission tomography (PET) on patients with major depressive disorder (MDD) revealed a reduction in 5-HT1A receptor binding after ECT. This reduction was observed in multiple regions of the brain, encompassing the hippocampus, amygdala, orbitofrontal cortex, and anterior cingulate cortex (ACC) [9]. A broad decrease in 5-HT2A receptor binding was also observed in areas such as bilateral occipital, medial parietal, limbic and bilateral prefrontal regions of the cortex, along with the indication of 5-HT2A receptor down-regulation, suggesting a potential mechanism that significantly contributes to the antidepressant effects [10, 11].

Several studies analyzed the impact of ECT on the glutamatergic system in patients with MDD. Significantly, a notable rise in *N*-acetylaspartate (NAA) levels and also the glutamine to glutamate ratio, assessed through proton stimulated echo acquisition method spectroscopy (STEAM), was demonstrated to be occurring in individuals who exhibited a positive response to ECT [12]. These changes were evident when comparing ECT responders to non-responders and even in relation to pre-ECT baseline levels. Particularly, ECT was found to normalize the reduction of glutamate levels in specific brain areas like the ACC associated with MDD. These findings collectively suggest a distinct neurotrophic effect of ECT, potentially more pronounced in individuals who respond positively to ECT interventions [13, 14].

Human studies suggest that ECT induces activation of the DA system, at multiple levels, including DA release, neurotransmission, and receptor binding. Evidence indicating alterations in DA receptor expression supports the impact of ECT on the DA system. Preclinical studies reveal an up-regulation of D1 and D3 receptors in the striatum, while human studies suggest a potential reduction in D2 receptor binding localized in the rostral ACC [15]. ECT-induced activation of the DA system likely contributes to the alleviation of depressive and anxious symptoms, accompanied by improvements in motivation, concentration, and attention.

ECT has been found to affect the gamma-aminobutyric acid (GABA) system, the primary inhibitory neurotransmitter in the brain by increasing GABAergic tone and enhance GABA transmission, thus determining its anticonvulsant effects. This effect may involve changes in GABA receptor sensitivity or expression. GABAergic interneurons in the hippocampus, involved in the generation and propagation of seizures, help regulate the balance between excitation and inhibition, thus increased GABA levels can enhance inhibitory activity, suppressing excessive neuronal firing and reducing the likelihood and severity of seizures [16]. Moreover, increased GABAergic activity in the subcortical areas, such as the amygdala, that plays a significant role in regulating emotions and anxiety, can exert an anxiolytic effect, reducing anxiety levels [17].

Neuroplasticity

ECT is believed to induce neuroplastic changes in the brain, promoting neurogenesis and the formation of new synaptic connections in specific areas in the hippocampus, such as the subgranular stratum of the dentate gyrus and the subventricular zone.

Neuroplasticity, which encompasses processes such as synaptogenesis, dendrogenesis, angiogenesis, and neurogenesis, may play a role in the changes observed in hippocampal and amygdalar volume following ECT. Neurogenesis, the generation of neurons from neural progenitor cells, occurs in the dentate subgranular zone of the hippocampus throughout life. Preclinical research has established connections between neurotrophic factors and adult neurogenesis in patients with depression [18, 19].

There is growing evidence supporting the involvement of neurotrophic factors in the formation and maturation of nervous structures, and also in the pathophysiology and therapeutic approaches involved in addressing psychiatric disorders. Post-ECT changes in the concentrations of different biochemical messengers, including neurotrophic factors, had been demonstrated to determine neuroplastic alterations of brain structures. Neuroprotection and enhanced neuronal proliferation are both effects of ECT that promote and support the growth, development, and maintenance of new brain cells. Notably, neuronal proliferation can be triggered in the dentate convolution of the hippocampal area, by a unique electroconvulsive stimulus and these recently created neurons have the potential to survive for months. This suggests a link between ECT-induced changes in neurotrophic factors and structural modifications in the brain, highlighting the complex interplay between biochemical regulation and neural plasticity.

Brain-derived neurotrophic factor (BDNF) holds a prominent role in regulating synaptic plasticity, surpassing all other neurotrophins. Numerous research groups have explored the involvement of BDNF in ECT. The investigation of BDNF in the context of ECT suggests its crucial contribution to the mechanisms underlying synaptic plasticity and potential therapeutic effects [20]. In addition to BDNF, vascular endothelial growth factor (VEGF), fibroblast growth factor 2 (FGF2), and nerve growth factor (NGF) have a significant role in MDD and favorable reaction to treatment [21]. The hippocampus is known to be susceptible to stress and may be particularly influenced by processes involved in immune system response, which could contribute to structural changes and impact antidepressant response [22, 23].

Network connectivity

Neuroimaging research indicates that MDD is influenced by structural and functional abnormalities in components of some networks associated with mood, vegetative states, and cognition. Key regions implicated in these processes encompass the ACC, dorsolateral, dorsomedial, and ventral areas of the prefrontal cortex, as well as subcortical centers, such as the hippocampus, amygdala, thalamus, and striatum. The architecture of white matter (WM) plays a crucial role in determining structural connectivity, that is acknowledged to impact the underlying robustness and endurance of functional linkage. As a result, the microstructural properties of WM may hold significance in understanding the pathophysiology of MDD and its response to treatment [24].

Diffusion tensor imaging (DTI) studies in patients undergoing ECT assessing changes in structural connectivity of the WM, found that ECT induces WM plasticity in tracts connecting frontal and limbic regions of the brain, implicated in emotional control. There is a correlation between increased fiber integrity in these pathways and an improved therapeutic response to ECT. This suggests that the changes in the structural connectivity of these specific WM pathways may contribute to the positive effects of ECT on mood regulation in individuals undergoing treatment [25].

Endocrine system regulation

Patients with mood disorders, particularly depression, often exhibit disturbed levels of stress hormones. Studies consistently show hyperfunction of the hypothalamic–pituitary–adrenal (HPA) axis in individuals with depression [26]. This is characterized by elevated cortisol levels and a reduced suppression of cortisol on the Dexamethasone suppression test. Elevated cortisol levels associated with HPA axis hyperfunction can have detrimental effects on processes such as neurogenesis and gliogenesis. Additionally, high cortisol levels are linked to the atrophy of structures like the hippocampus. These hormonal imbalances may contribute to the pathophysiology of mood disorders and impact the structural integrity of certain brain regions [27].

ECT treatments are associated with normalization of HPA axis, by reducing the cortisol levels to normal in depressed patients, supporting a neuroendocrine mechanism. As an effect, it has been shown to alleviate the inhibitory effects of cortisol on neuroplasticity [28].

Changes in cerebral blood flow and regional metabolism

Alterations in global as well as regional cerebral blood flow (rCBF) have been evidenced in emotional and psychotic disorders, as well as among individuals at an elevated risk of developing psychotic symptoms [29]. Patients with depression show substantial hypometabolism in the frontal gyrus. Additionally, research by Hosokawa *et al.* reveals differences in glucose metabolism patterns between bipolar and unipolar depression [30]. Specifically, bipolar depression

shows hypometabolism in the right ACC, while unipolar depression exhibits low metabolic activity localized in the right temporal convolution, right insula and left cingulate area of the cortex.

Various studies have demonstrated that ECT induces changes in rCBF and glucose metabolism that are related to therapeutic outcome [31, 32]. These alterations have been observed through the use of brain imaging methods, such as single-photon emission computed tomography (SPECT), functional magnetic resonance imaging (fMRI) and PET. Changes in rCBF and regional metabolism induced by ECT had been observed. A decrease in rCBF and glucose utilization in the cortex has been shown to occur after ECT, especially in areas such as the medial and dorsolateral prefrontal cortical zones, upper frontal areas, and temporal cerebral region [33]. Simultaneously, there is an enhancement in blood circulation across key areas of limbic and paralimbic structures involved in emotional regulation, such as the amygdala and parahippocampal gyrus.

In addition, a sudden increase in blood pressure occurs during the seizure resulting from ECT administration, which is considered to determine a transient interruption in the integrity of the blood–brain barrier (BBB). The disruption allows specific neurochemicals to be released from circulation into the brain parenchyma. As a result, certain changes occur in the microenvironment of the brain, including elevated concentrations of BDNF, angiogenesis and neuronal regeneration [34].

Conclusions

Decades of research aimed at unraveling the mechanism of ECT have discovered a complex field of study encompassing various intricate biological processes. These processes include alterations in neuroplasticity, levels of neurotrophic factors and neurotransmitters, functional connectivity, immune mechanisms, and neuroendocrine function. Despite substantial evidence shedding light on the neurobiological mechanisms of ECT, inconsistent research findings hinder the ability to draw definitive conclusions. Additionally, establishing a clear cause-and-effect relationship between these mechanisms and the therapeutic effects of ECT remains challenging. It is not prudent to assume a singular mechanism that comprehensively explains the therapeutic efficacy of ECT.

Conflict of interests

The authors declare that they have no conflict of interests.

References

[1] Li M, Yao X, Sun L, Zhao L, Xu W, Zhao H, Zhao F, Zou X, Cheng Z, Li B, Yang W, Cui R. Effects of electroconvulsive therapy on depression and its potential mechanism. Front Psychol, 2020, 11:80. https://doi.org/10.3389/fpsyg.2020.00080 PMID: 32153449 PMCID: PMC7044268

[2] Trifu S, Sevcenco A, Stănescu M, Drăgoi AM, Cristea MB. Efficacy of electroconvulsive therapy as a potential first-choice treatment in treatment-resistant depression (Review). Exp Ther Med, 2021, 22(5):1281. https://doi.org/10.3892/etm.2021.10716 PMID: 34630636 PMCID: PMC8461517

[3] Kellner CH, Obbels J, Sienaert P. When to consider electroconvulsive therapy (ECT). Acta Psychiatr Scand, 2020, 141(4): 304–315. https://doi.org/10.1111/acps.13134 PMID: 31774547

[4] Kellner CH, Greenberg RM, Murrough JW, Bryson EO, Briggs MC, Pasculli RM. ECT in treatment-resistant depression. Am J Psychiatry, 2012, 169(12):1238–1244. https://doi.org/10.1176/appi.ajp.2012.12050648 PMID: 23212054

[5] Taylor S. Electroconvulsive therapy: a review of history, patient selection, technique, and medication management. South Med J, 2007, 100(5):494–498. https://doi.org/10.1097/SMJ.0b013e318038fce0 PMID: 17534086

[6] Hermida AP, Glass OM, Shafi H, McDonald WM. Electroconvulsive therapy in depression: current practice and future direction. Psychiatr Clin North Am, 2018, 41(3):341–353. https://doi.org/10.1016/j.psc.2018.04.001 PMID: 30098649

[7] Yatham LN, Liddle PF, Lam RW, Zis AP, Stoessl AJ, Sossi V, Adam MJ, Ruth TJ. Effect of electroconvulsive therapy on brain 5-HT_2 receptors in major depression. Br J Psychiatry, 2010, 196(6):474–479. https://doi.org/10.1192/bjp.bp.109.069567 PMID: 20513859

[8] Newman ME, Gur E, Shapira B, Lerer B. Neurochemical mechanisms of action of ECS: evidence from *in vivo* studies. J ECT, 1998, 14(3):153–171. PMID: 9773355

[9] Lanzenberger R, Baldinger P, Hahn A, Ungersboeck J, Mitterhauser M, Winkler D, Micskei Z, Stein P, Karanikas G, Wadsak W, Kasper S, Frey R. Global decrease of serotonin-1A receptor binding after electroconvulsive therapy in major depression measured by PET. Mol Psychiatry, 2013, 18(1): 93–100. https://doi.org/10.1038/mp.2012.93 PMID: 22751491 PMCID: PMC3526726

[10] Baldinger P, Lotan A, Frey R, Kasper S, Lerer B, Lanzenberger R. Neurotransmitters and electroconvulsive therapy. J ECT, 2014, 30(2):116–121. https://doi.org/10.1097/YCT.0000000000000138 PMID: 24820941

[11] Segi-Nishida E. Exploration of new molecular mechanisms for antidepressant actions of electroconvulsive seizure. Biol Pharm Bull, 2011, 34(7):939–944. https://doi.org/10.1248/bpb.34.939 PMID: 21719995

[12] Pinna M, Manchia M, Oppo R, Scano F, Pillai G, Loche AP, Salis P, Minnai GP. Clinical and biological predictors of response to electroconvulsive therapy (ECT): a review. Neurosci Lett, 2018, 669:32–42. https://doi.org/10.1016/j.neulet.2016.10.047 PMID: 27793702

[13] Michael N, Erfurth A, Ohrmann P, Arolt V, Heindel W, Pfleiderer B. Neurotrophic effects of electroconvulsive therapy: a proton magnetic resonance study of the left amygdalar region in patients with treatment-resistant depression. Neuropsychopharmacology, 2003, 28(4):720–725. https://doi.org/10.1038/sj.npp.1300085 PMID: 12655317

[14] Zhang J, Narr KL, Woods RP, Phillips OR, Alger JR, Espinoza RT. Glutamate normalization with ECT treatment response in major depression. Mol Psychiatry, 2013, 18(3):268–270. https://doi.org/10.1038/mp.2012.46 PMID: 22565784 PMCID: PMC3896297

[15] Fosse R, Read J. Electroconvulsive treatment: hypotheses about mechanisms of action. Front Psychiatry, 2013, 4:94. https://doi.org/10.3389/fpsyt.2013.00094 PMID: 23986724 PMCID: PMC3753611

[16] Sackeim HA. The anticonvulsant hypothesis of the mechanisms of action of ECT: current status. J ECT, 1999, 15(1):5–26. PMID: 10189616

[17] Vecera CM, Courtes AC, Jones G, Soares JC, Machado-Vieira R. Pharmacotherapies targeting GABA-glutamate neurotransmission for treatment-resistant depression. Pharmaceuticals (Basel), 2023, 16(11):1572. https://doi.org/10.3390/ph16111572 PMID: 38004437 PMCID: PMC10675154

[18] Joshi SH, Espinoza RT, Pirnia T, Shi J, Wang Y, Ayers B, Leaver A, Woods RP, Narr KL. Structural plasticity of the hippocampus and amygdala induced by electroconvulsive therapy in major depression. Biol Psychiatry, 2016, 79(4):282–292. https://doi.org/10.1016/j.biopsych.2015.02.029 PMID: 25842202 PMCID: PMC4561035

[19] Madsen TM, Treschow A, Bengzon J, Bolwig TG, Lindvall O, Tingström A. Increased neurogenesis in a model of electroconvulsive therapy. Biol Psychiatry, 2000, 47(12):1043–1049. https://doi.org/10.1016/s0006-3223(00)00228-6 PMID: 10862803

[20] Bouckaert F, Sienaert P, Obbels J, Dols A, Vandenbulcke M, Stek M, Bolwig T. ECT: its brain enabling effects: a review of electroconvulsive therapy-induced structural brain plasticity. J ECT, 2014, 30(2):143–151. https://doi.org/10.1097/YCT.0000000000000129 PMID: 24810772

[21] Bocchio-Chiavetto L, Zanardini R, Bortolomasi M, Abate M, Segala M, Giacopuzzi M, Riva MA, Marchina E, Pasqualetti P, Perez J, Gennarelli M. Electroconvulsive therapy (ECT) increases serum brain derived neurotrophic factor (BDNF) in drug resistant depressed patients. Eur Neuropsychopharmacol, 2006, 16(8): 620–624. https://doi.org/10.1016/j.euroneuro.2006.04.010 PMID: 16757154

[22] Sartorius A, Karl S, Zilles-Wegner D. Hippocampal neuroplasticity, major depression and, not to forget: ECT. Mol Psychiatry, 2022, Aug 29. https://doi.org/10.1038/s41380-022-01746-w PMID: 36038727
[23] Ito M, Seki T, Liu J, Nakamura K, Namba T, Matsubara Y, Suzuki T, Arai H. Effects of repeated electroconvulsive seizure on cell proliferation in the rat hippocampus. Synapse, 2010, 64(11):814–821. https://doi.org/10.1002/syn.20796 PMID: 20340175
[24] Lyden H, Espinoza RT, Pirnia T, Clark K, Joshi SH, Leaver AM, Woods RP, Narr KL. Electroconvulsive therapy mediates neuroplasticity of white matter microstructure in major depression. Transl Psychiatry, 2014, 4(4):e380. https://doi.org/10.1038/tp.2014.21 PMID: 24713861 PMCID: PMC4012285
[25] Zeng J, Luo Q, Du L, Liao W, Li Y, Liu H, Liu D, Fu Y, Qiu H, Li X, Qiu T, Meng H. Reorganization of anatomical connectome following electroconvulsive therapy in major depressive disorder. Neural Plast, 2015, 2015:271674. https://doi.org/10.1155/2015/271674 PMID: 26770836 PMCID: PMC4684875
[26] Rojas M, Ariza D, Ortega Á, Riaño-Garzón ME, Chávez-Castillo M, Pérez JL, Cudris-Torres L, Bautista MJ, Medina-Ortiz O, Rojas-Quintero J, Bermúdez V. Electroconvulsive therapy in psychiatric disorders: a narrative review exploring neuroendocrine-immune therapeutic mechanisms and clinical implications. Int J Mol Sci, 2022, 23(13):6918. https://doi.org/10.3390/ijms23136918 PMID: 35805923 PMCID: PMC9266340
[27] Mickey BJ, Ginsburg Y, Sitzmann AF, Grayhack C, Sen S, Kirschbaum C, Maixner DF, Abelson JL. Cortisol trajectory, melancholia, and response to electroconvulsive therapy. J Psychiatr Res, 2018, 103:46–53. https://doi.org/10.1016/j.jpsychires.2018.05.007 PMID: 29775916 PMCID: PMC6457450
[28] Singh A, Kar SK. How electroconvulsive therapy works?: understanding the neurobiological mechanisms. Clin Psychopharmacol Neurosci, 2017, 15(3):210–221. https://doi.org/10.9758/cpn.2017.15.3.210 PMID: 28783929 PMCID: PMC5565084
[29] Suwa T, Namiki C, Takaya S, Oshita A, Ishizu K, Fukuyama H, Suga H, Murai T. Corticolimbic balance shift of regional glucose metabolism in depressed patients treated with ECT. J Affect Disord, 2012, 136(3):1039–1046. https://doi.org/10.1016/j.jad.2011.11.040 PMID: 22209122
[30] Hosokawa T, Momose T, Kasai K. Brain glucose metabolism difference between bipolar and unipolar mood disorders in depressed and euthymic states. Prog Neuropsychopharmacol Biol Psychiatry, 2009, 33(2):243–250. https://doi.org/10.1016/j.pnpbp.2008.11.014 PMID: 19100808
[31] Escobar R, Rios A, Montoya ID, Lopera F, Ramos D, Carvajal C, Constain G, Gutierrez JE, Vargas S, Herrera CP. Clinical and cerebral blood flow changes in catatonic patients treated with ECT. J Psychosom Res, 2000, 49(6):423–429. https://doi.org/10.1016/s0022-3999(00)00190-2 PMID: 11182435
[32] Takano H, Motohashi N, Uema T, Ogawa K, Ohnishi T, Nishikawa M, Kashima H, Matsuda H. Changes in regional cerebral blood flow during acute electroconvulsive therapy in patients with depression: positron emission tomographic study. Br J Psychiatry, 2007, 190:63–68. https://doi.org/10.1192/bjp.bp.106.023036 PMID: 17197658
[33] Volkow ND, Bellar S, Mullani N, Jould L, Dewey S. Effects of electroconvulsive therapy on brain glucose metabolism: a preliminary study. Convuls Ther, 1988, 4(3):199–205. PMID: 11940965
[34] Andrade C, Bolwig TG. Electroconvulsive therapy, hypertensive surge, blood–brain barrier breach, and amnesia: exploring the evidence for a connection. J ECT, 2014, 30(2):160–164. https://doi.org/10.1097/YCT.0000000000000133 PMID: 24800688

Corresponding author
Antonia Ioana Vasile, MD, Doctoral School, Carol Davila University of Medicine and Pharmacy, 37 Dionisie Lupu Street, Sector 2, 020021 Bucharest, Romania; Phone +40727–803 332, e-mail: antoniaioana97.vasile@gmail.com

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