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Transcranial magnetic stimulation versus electroconvulsive shocks – neuroanatomical investigations in rats *

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Since the time of introducing ECT to the clinical practice, the method always raised questions regarding possibility that the current running through structures of a brain may evoke structural changes and as a result of theses evoke convulsive attacks. Pathological changes (swelling, gliosis, atrophy, necrosis) were observed most often after "mega"-schemes including series of several to several hundreds ECT treatments. Regime used nowadays including only 8-12 ECT sessions seems to be entirely safe. There are however only a few experimental works dealing with this problem.

In 1992 researches started on new neurophysiological technique - transcranial magnetic stimulation (TMS) in depression. The advantage of this method is that it does not seem to evoke convulsive attacks. Prolonged rapid rate TMS (rTMS) seems to be particularly efficient in treatment of depression. Despite thousands of works describing various functional effects of TMS, there are obviously no researches on structural effects of the technique. In the case of experimental researches on animals a few works were published and their results seems to be ambiguous.

We have examined the influence of prolonged repetitive rTMS ($B = 1.4$ T, $t = 5.5$ min, $f = 30$ Hz), and standard ECT ($I = 150$ mA, $t = 0.5$ s, $f = 50$ Hz) on the structure of brain tissue in rats. Both groups of animals ($n=10$) received 12 stimulation sessions. After the treatment the animals were routinely processed for electron microscopy (EM) and for light microscopy (LM).

The microscopy light - did not show, ECT or rTMS to evoke structural changes in brain stimulated of animals – in comparison with the control group. Differences between both groups succeeded to obtain only by electron microscopy technique. In brains of animals that underwent ECT were found numerous and considerably edematous and degenerative changes. Brains of animals that underwent rTMS showed existence only of small edematous changes, whose intensity was significantly less than in at animals after ECT.

Our investigations suggest that the technique of ECT shows considerable neurotoxic potential. In comparison to ECT - the rTMS method seems to be more safe.

Key words: electroconvulsive shocks, transcranial magnetic stimulation, neuropathological investigation, rat

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Introduction

In 1998 it was exactly 60 years since the first epileptic attack in a patient with psychosis was evoked with electric current in a Roman Psychiatric Hospital treating psychotic patients [1]. Literature provides proofs that even much earlier physicians tried to make use of, e.g., electric fish discharges or, a little later, of a Leyden jar (precursor of a condenser) in treatment of mental disorders. However, it is Cerletti and Bini, who are recognised as authors of modern seismic therapy. At present, electroconvulsive therapy (ECT) is one of the numerous and highly varied shock methods (cardiasoleand and pentatrasole shocks, insulin and atropin comas), which not only survived to our time, but is also considered as an exceptionally effective method [cit. after 2]. Initially, ECT was applied very extensively: in psychoses, depression or even in neurotic syndromes. With the development of pharmacotherapy the areas of ECT application were strongly limited, and now it is used only in the cases of severe endogenous depressive syndromes. Despite its' high effectiveness (estimated as higher than that of antidepressant drugs) and the proved cellular action mechanisms (tissue receptors, neurotransmitter systems, ionic channels) – similar, to a certain extent, to the action of antidepressant drugs – ECT is recognised as the second choice method. This situation is caused not only by the complicated procedure of electroconvulsive therapy (short-time anaesthesia, muscle relaxation, oxygen ventilation), but also by the complex equipment (ECT apparatus, anaesthetic equipment).

The basic difficulties in extensive application of ECT seem to issue from doubts of moral and ethical character that are still evoked by this therapy. Electroshock seems to be a word horrible enough not only for patients but also for a large part of the medical personnel. To diminish the odium, doctors often use the abbreviation ECT as the name of this method; in some countries, names like electro-narcosis, electro-sleep, electro-plexion or electro-stimulation are also used. The ECT method was described as a "barbarian anachronism", "penal shock", "annihilation method", or "the method destroying the patient's brain and personality", and since that time many a man considers it a symbol of inhumane and restrictive psychiatry [3]. For a non-professional it seems savage, since it consists in sending electric current through the skull and brain, and the public opinion most frequently associates application of ECT with repression, backwardness and helplessness of psychiatric treatment.

Fear of ECT is connected with the fear of evoking permanent changes in brain tissue [14, 24] with all clinical, behavioural and emotional consequences of this situation. Literature dealing with neuro-anatomic effects of ECT is rich, and discusses both clinical investigations and experiments on animals [6, 7, 8, 9, 10, 11]. The results reveal great discrepancies regarding the occurrence of neuro-structural changes after ECT administration, or their lack. This is why we started our own neuro-histopathological investigations on structural effects of ECT series administered to rats. The results were compared with those obtained in animals submitted to a prolonged transcranial magnetic stimulation – a new neuro-physiological method considered as antidepressant.

Electroshocks and non-convulsive electric stimulation in animals

The authors of ECT – Cerletti and Bini – were the first to conduct experiments on animals, which were aimed to confirm safety of the method [12]. Administering series of electroshocks to dogs, they proved that even 40 operations of this kind did not evoke specific changes in the central nervous system. Changes in brain cells of dogs occurred as late as after 70 operation repeated at short intervals. The changes were of oedematous character.

In the subsequent years, investigations of neuroanatomical effects were continued with the use of various electric current parameters (frequency, intensity, stimulation time) applied to different species of mammals, primates included. In his monograph, Krzy¿owski presents a survey of anatomo-pathological changes observed in the older experimental studies [2]. They have been listed in table 1.

Table 1

Neuroanatomical changes observed in animals after electroshocks [modified after 2]

AUTHORS	ANIMAL	METHOD	RESULTS
Cerletti U., Bini L.; 1938	dog	40 treatments 70 treatments	no changes swelling
Heilbrunn G., Liebert E.; 1941	rabbit		no changes
Alpres B.J., Hughes J.; 1942	cat		vascular changes; small punctual ecehymosises
Echlin F.A.; 1942	dog		hypoxia swelling vasospasms
Hadenbrock S., Ewald G.; 1942	monkey		no changes
Heilbrun G., Weil A.; 1942			no changes
Neuburger K.T., Whithead R.W., Rutledge E.K., Ebaugh F.G.; 1942	dog		neuron atrophy vascular changes
Globus J.H., van Harreveld A., Wiersma C.A.; 1943	dog	30 s (!), 200-700 mA	no changes
Alexander L., Lövenbach H.; 1944	cat	500-1800 mA > 200 mA	narrowing of light of vessels dilating of light of vessels
Lindbeck W.L.; 1944	dog	multiple ECT	ischemic changes
Winkelman N.W., Moore M.T.; 1944	cat		no changes
Ferraro A., Roizen L., Hefland M.; 1946	monkey		hypoxia swelling
Kreienberg W., Ehrhard W.; 1947			narrowing of light of vessels

Siekert R.G., Williams S.C., Windle W.F.; 1950	monkey		no changes
Hartelius H.; 1952			no changes
Ungher J., Voinescu S., Volanski D., Stoica J.; 1958	dog		atrophy
Mölbert E., Baumgartner G., Ketelsen U.P.; 1967	cat		neuronal changes, nucleus damage, cellular membranes degeneration, mitochondrial damage
Hostetter G., 1968	rat		hippocampus atrophy
Sommer H.; 1971			no changes
Lippman S.; 1985			no changes

More recently, fewer studies have been conducted on macro-structural effects of ECT. In the 1970s and 1980s research was made on the influence of acute and prolonged electric stimulation of the central nervous system tissue (brain, cerebellum and spinal cord) with the current not evoking convulsive attacks [13, 14, 15, 16, 17, 18]. These investigations were conducted, i.a., to provide an answer to the question concerning safety of the newly introduced methods of treatment of some neurological disorders. In treatment of disorders like epilepsy, dystonia or some chronic pain syndromes, doctors tried to use electric stimulation with electrodes implanted in the central nervous system and connected with an external miniature stimulator. The described method has not been widely applied in clinical conditions, mostly due to definite technical problems (foreign body in the organism meant an open door for infection) and to objections of ethical and moral character. Threats connected with possible structural injury to nerve cells resulting from electric current flow were mentioned on further places (table 2).

Table 2

Neuroanatomical changes observed in animals after non-convulsive electrical stimulation

AUTHORS	ANIMAL	RESULTS
Agnew W.A. et all..; 1975	cat	from light to heavy ultrastructural cellular damage
Pudenz R.H. et all., 1975	cat	reversible (after 1 week) damage of blood-brain-barrier
Brown W.J. et all.; 1977	monkey	pachymeningeal thickness, Purkini cells damage, glial cells expansion, axonal degeneration, collagen intercallations, polisaccharide aggregation
Agnew W.F. et all.; 1983	cat	no changes
Agnew W.F. et all.; 1985	cat	little cellular and vascular

Single electric impulses were used at the beginning of the 1980s to examine the so-called evoked motor potentials. This technique was a precursor of the method of transcranial magnetic stimulation described below. However, due to its significant level of painfulness it was not widely applied in clinical practice. Experiments on animals performed with this method revealed that electric stimulation evoked structural changes not only within nerve tissue of the brain but also in the meninges and soft tissues of the head. In their character, these changes were injuries to blood vessels with subsequent extravasations and haemorrhagic changes [19, 20]. However, the currents used in this method were of a relatively high tension – exceeding 1000 Volt.

Electroconvulsive therapy in people

As we have already mentioned in the introduction, fear of potential brain damage was probably the most important factor causing unfavourable connotation of ECT technique. The bias against ECT was based mostly on the results of experiments on animals. It is thus understandable that the possibility of conducting neurostructural investigations in hospital conditions was limited. More than half a century of administration of ECT to persons with various mental disorders had provided a large number of death cases of patients who died in the period of electroconvulsive therapy or shortly afterwards. Literature also reports cases of patients who died during or directly after ECT administration. Table 3 presents neuroanatomical data collected in patients subjected to ECT [cit. after 2]. The observed macro- and microscopic changes were of non-specific character. Some of these changes might be connected with the patients' old age. However, the relation between the detected structural changes and the ECT operation itself remains an open question [21, 22]. Some authors detected similar changes in cells and on sub-cell level in patients with epilepsy [23].

Table 3

Casuistic papers about anatomopathological changes in patients after ECT [modified after 2].

AUTHORS	PATIENT AGE	NUMBER OF TREATMENTS	TIME BETWEEN THE LAST TREATMENT AND DEATH	RESULTS
Alpers B.J., Hughes J.; 1942	45	46	2 months	punctual hemorrhage in cortex, medulla and cerebellum
	79	6	5 months	arteriosclerosis, congestion, cellular and fibrous gleiosis
Cash, Hockstra	47	5	2 hours 10 min	no changes
Clute	59	1	7 days	arteriosclerosis

Corsellis, Meyer	27	6	immediately after	perivascular changes, periventricular and perivascular gleiosis
	40	45	immediately after	little perivascular hemorrhages, astrocitar and fibrous gleiosis
Cucchi	60	3	40 min	arteriosclerosis, diffuse subarachnoidal ecehymosises
Ebang	57	13	95 min	diffuse degeneration, astrocitar gleiosis
	57	3	immediately after	necrosis in cortex, hippocampus and medulla, astrocitar and fibrous gleiosis
Gayle, Neale	-	-	-	cyst in V ventricle
Goodman	31	3	15 days	swelling, endothel changes, diffuse gleiosis
Gralnik A., 1944	35	2	2 days	swelling and hyperemia, vascular syphilis
	60	2	3 days	arteriosclerosis, big fibroblastoma
Jeffer	61	8	12 min	arteriosclerosis
	70	6	12 min	arteriosclerosis
Larsen, Vraa-Jensen	45	4	36 hours	swelling and small hemorrhages in subelectrode areas, neuronen thinning in frontal lobes, gleiosis
Maclay	58	3	20 min	fat emboli
	48	2	2 hours	intracerebral hemorrhages
	57	1	50 min	little hemorrhages into pons and medulla prolongata
	28	2	immediately after	softening in mesencephalon, temporal and parietal lobe
	52	2	immediately after	little hemorrhages into wall of IV ventricle and medulla prolongata
Madow L.; 1956	34	7	immediately after	little perivascular hemorrhages

Martin B.A.; 1986	47	6	9 days	little hemorrhages
	40	4	15 days	little hemorrhages
	52	11	12 days	arteriosclerosis
	52	8	24 days	little hemorrhages
Medlicott	54	1	some weeks	cerebral hemorrhage
Meyer, Tearc	53	1	12 hours.	fat emboli in cerebrum and cerebellum
Napier	46	1	6 hours.	-
	62	2	40 min.	cortical atrophy
Riese	30	2	48 hours	swelling, hemorrhage into medulla oblongata, hypoxia
	55	2	10 min	arteriosclerosis, little hemorrhages, degeneration, gleiosis
Sprage, Taylor	48	6	12 days	hemorrhage into the left temporal lobe and hippocampus
Solomon	20	19	15 hours	-
Will, et al.	48	1	20 min	acute brain swelling, central chromatolisis
Liban E., Halpern A., Różański N.; 1951	47	7	7 days	diffuse subarrachnoidal ecehymosises, sinus trombosis, swelling
Levy	-	-	-	vascular dilatation with hyperemia

Cofey C.E. et all.; 1991	35 patients	MRI: before, immediately after and 6 moths after ECT	no signs of structural CNS damage

The development of medical technology in recent decades brought about the possibility of evaluation of macroscopic brain structure in vivo. Neuroimaging methods like computed tomography (CT) or magnetic resonance imaging (MRI) allow for structural investigations with a fraction of millimetre accuracy. The above mentioned techniques have been used to assess the results of ECT. In 1991, Coffey's group examined 35 patients subjected to ECT [24]. With the use of MRI they did not detect the occurrence of any structural changes – either directly after ECT administration or 6 months afterwards.

To what extent the results of clinical investigation results may differ is shown in the report by Shah et al. of 1998 [25]. MRI examinations conducted in 20 patients with depression revealed the existence of cortical atrophy limited to the left temporal lobe and both hippocamps (particularly to the left one). The examinations covered

patients with the diagnosis of drug resistant major depression, and some of the patients had been subjected to at least 6 ECT operations. However, the authors were not able to state whether the detected neurostructural changes were connected with the primarily chronic disorder (i.e., depression itself) or were the result of its treatment (pharmacotherapy and/or ECT). Some other authors also admitted similar ignorance [26, 27]. Others, in turn, claim that brain atrophy detected in patients with depression is a direct result of the applied ECT or prolonged pharmacotherapy [28, 29, 30, 31]. A number of authors associate the intensity of structural changes with the parameters of the applied electric current [32].

Transcranial magnetic stimulation

In 1985, a new neurophysiological method consisting in application of a strong impulsive magnetic field to the patient's head was introduced in neurological diagnostics [after 33]. This techniques, called transcranial magnetic stimulation (TMS) proved to be an exceptionally valuable instrument in studies on speech, memory, sight, hearing and motor systems. In the recent years we have witnessed attempts at application of this method for therapeutic aims: in depression, Parkinson's disease, multiple sclerosis and pain syndromes. The first author of this work suggested application of TMS technique in treatment of depression as early as 1992 [33]. Till today, ca. 150 patients with depression have been subjected to magnetic stimulation procedure all over the world. Several reports have been published of clinical studies conducted according to the procedure of third phase examinations of chemical substances (drugs) of antidepressant character. The obtained results clearly confirm the antidepressant effect of TMS technique [34, 35, 36].

The great interest in TMS technique issues from its high safety level. In contrast to the hitherto applied methods of electric stimulation, the examined person remains beyond the electric system of the stimulator. Magnetic stimulation itself is not painful, unpleasant or burdening for a healthy person (diagnostic examinations) or for a patient (therapy).

We must not forget, however, that TMS consists in direct application to the examined person's head of a strong magnetic field whose induction might sometimes amount to 3 Tesla. Hence, despite the significant safety of the TMS technique, we must not forget about some possible dangers or risk connected with it. The description of undesired side effects of TMS is beyond the frames of this work. So far, no death case of a person subjected to TMS has been described, hence we have no autopsy data comparable to those collected from persons subject to ECT. Neither do we know of any clinical studies with the use of CT or MRI techniques that would confirm macrostructural changes evoked by transcranial magnetic stimulation (TMS). On the other hand, there are several studies in which experimental animals were subjected to TMS [37, 38, 39, 40, 41, 42]. The results of these studies are collected in table 4; they show that it was only the Japanese group that managed to detect structural changes in ca 50% of the rats subjected to TMS [38, 39].

Table 4

Neurostructural changes observed in animals after non-convulsive transcranial magnetic stimulation

AUTHORS	ANIMAL	METHOD	RESULTS
Ravnborg M., Knudsen G.M., Blinkenberg M.; 1990	30 rats	B = 1,9 T, 50-60 impulses, 1 series	no influence on permeability of blood-brain barrier
Sgro J.A, Ghatak N.R., Stanton P.C., Emerson R.G., Blair R.; 1991	31 rats	B = 3,4 T, 8 Hz, 10.000 impulses in 20 min	no changes
Matsumiya Y., Yamamoto T., Yarita M., Miyauchi S., Kling J.W.; 1992	25 rats	B = 2,8 T, 100-5381 impulses, 1 series	microvacuolar changes in neuropil of cortical layers 2-6 in 50% of animals
Counter S.A.; 1993	16 rabbits	B = 2 T, 1000 imp., 100 imp. / treatment, 4-12 moths of stimulation	microscope: normal structure, no changes of damage; MRI: no macrostructural changes

In turn, Prato et al. [43] detected the blood-brain barrier damage in animals submitted to the action of a strong constant magnetic field generated by a MRI scanner.

Aim of the work

The aim of this work was to evaluate the influence of repeated transcranial magnetic stimulation and electroshocks in rats on the possible occurrence of structural changes in their central nervous system.

Material and method

The examinations were performed on 30 male Wistar rats weighing 200-300 g, kept 5 animals per cage in standard conditions (environment temperature 22-230°C; 12 hours cycle of light and dark phases; food and water ad lib.).

A group of 10 rats was subjected to magnetic stimulation with the use of a prototypical magnetic stimulator MS 3, constructed in collaboration with the Electro-technology Institute in Warsaw (Andrzej Pawlaczyk, DSc; Andrzej Domino, MSc); Experimental Unit of Research Equipment and Automatics of the Academy of Mining and Metallurgy (Jacek Seńkowski, DSc, Paweł Kwasnowski, MSc) and Electro-mechanics Department in Cracow (Stanisław and Dariusz Gierlik). During the experiments, the stimulator produced an impulsive magnetic field of induction B = 1.4 T and frequency f = 30 Hz. The time of field increase was 120 μs. Total time of one series of magnetic stimulation was 5 min and 30 s (corresponding to 10,000 impulses of magnetic field). The animals were subjected to 12 stimulations (one operation a day) executed in midday period every second day.

Another group consisted of 10 rats subjected to electroshocks applied with ear-electrodes (clips). The ECT apparatus ZK-2 generated electric current of the following parameters: I = 150 mA; t = 0.5 s; f = 50 Hz. Overall, the animals received a series of 12 ECT operations according to a schedule similar to that of TMS.

The remaining ten animals constituted a control group.

The animals were anaesthetised with Venbutal narcosis (100mg/kg) 24-48 hours after the last stimulation. Then, for 4,5 hours they were perfused with a solution of buffered formalin (for light microscopy) or with Karnofsky's fixative (for electron microscopy). After the perfusion, the acquired brains were additionally fixed in the same solutions as those used for perfusion. The brains fixed in this way were submitted to neuropathological examination.

The fixed animal brains for light microscopy examination were selected in the plane perpendicular to the longitudinal axis of brain, dividing them into 5 cross-sections of equal thickness, which were then transferred in a standard way to paraffin blocks, and cut. The fragments were stained with the following methods: hematoxylin-eosin, Klüver-Barrer's method and PAS. Besides, fragments were stained immunohistochemically with the use of cow antibodies against GFAP (glio fibrillary acid protein – astrocyte marker) in a 1:100 titre with 24 hour incubation. For immunohistochemical examination we used primary antibody and the remaining re-agents produced by DAKO.

For electron microscopy we used samples of brain tissue taken from the following areas: frontal and temporal cortex, lenticular and caudate nucleus, thalamus, cerebellum, medulla oblongata and corpus callosum. The fixed tissue samples were rinsed four times in 7% saccharose solution, then osmosed for 2 hours, transferred to a standard Spurr type polymer, and cut. Ultrathin fragments placed on copper net trays were fixed and stained with uranylacetate and lead citrate (Vanable's re-agents). Preparations were examined with ZEISS EM 900 microscope. At the moment of examination, the pathomorphologist (D.A.) did not know the group assignation (control, ECT, TMS) of animals from which the examined samples were taken.

Results and discussion

Table 5 presents the complete set of examination results.

Examinations in light microscopy (LM) did not detect any pathological changes in the groups of animals subjected to ECT or to TMS. This regarded both histological methods an GFAP expression preservation. Microphotograph 1a represents the hippocampus area of the rat subjected to ECT. The histological picture does not differ from normal. Also, immunohistochemical expression of GFAP was similar in all three groups of animals. Microphotographs 1b and 1c represent samples of cortex of rats after ECT and TMS respectively. GFAP-positive delicate fibrillar astrocytes, like those in both photographs, did not differ from control cases either as regards their number or intensity of expression. Glio fibrillary acid protein (GFAP) produced by astrocytes and especially by reactively "agitated" astrocytes, is recognized as a neurotoxicity marker [44], and its' increased expression accompanies, i.a., ischaemic changes [45].

Table 5

Neuropathological changes in rat brains which underwent electroshocks and transcranial magnetic stimulation

TRANSCRANIAL MAGNETIC STIMULATION RTMS	ELECTROCONVULSIVE SHOCKS ECT
light microscopy LM:	
no changes	no changes
electron microscopy EM:	
THALAMUS AND CEREBELLUM: vacuolization of pericapillar glial cell (less than after ECT)	CORPUS CALLOSUM: extracellular edema PARIETAL CORTEX: lipofuscin aggregates THALAMUS AND CEREBELLUM: significant vacuolization of glial cell especially around capillaries SEVERE REGIONS OF BRAIN: ballooned mitochondrial cristae

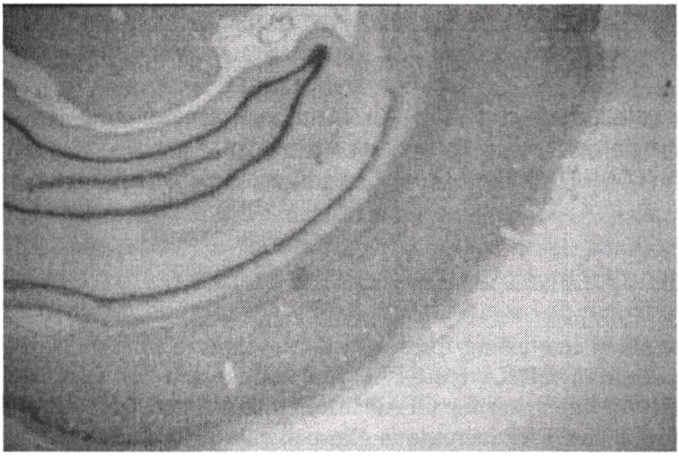
What is particularly interesting for our studies – experiments with ECT in mice revealed an increase of mRNA for GFAP [46]. Fujiki and Steward also detected an increased mRNA expression for GFAP in mice stimulated with TMS [47]. Also, a transitory, short-time GFAP increase in glio-cell culture subjected to magnetic stimulation has been reported recently [48]. Statistically significant increase of GFAP in cells occurred three days after stimulation, but it came back to normal on the fifth day. However, the above mentioned authors not only applied a different model of experiment (cell culture and a single ten-second stimulation), but also evaluated GFAP expression in a different way (the so-called immunoblot). It is worth emphasising that no morphological changes of glia were detected after magnetic stimulation, and therefore the lack of morphologically noticeable increase of GFAP expression in our experiment need not contradict the above mentioned report. Our results indicate only that probably a long-time reaction of glia to TMS does not occur, which is in accord with observations reported by Chan et al. [48].

Taking into account the strict relation between astrocytes and neurons (for which astrocytes perform, i.a., protective functions in the process of excitotoxicity), the existing data may allow for formulation of the hypothesis that TMS, through a delicate modulation of astrocyte activity, can improve the functioning of neurons [49].

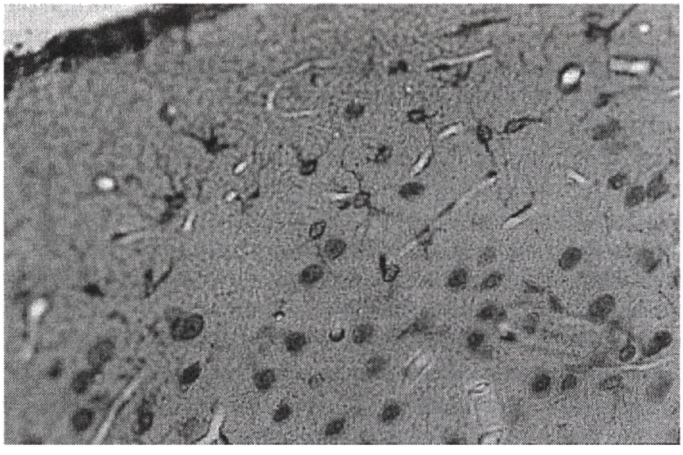
In the ultrastructural examinations (electron microscope), we detected pathological changes of moderate intensity in the group subjected to ECT, and of slight intensi-

ty in the group subjected to TMS. These changes, assuming the form of oedemic dilatation of extracellular space, occurred mostly in corpus callosum of rats after ECT (photo 2b). Both in the group after ECT and that after TMS we detected distention and vacuolar changes of processes of the perivascular glial cells, but in the group after ECT they were distinct (photo 3) while in the group after TMS they were very slight. Oedema of astrocytes or of their processes is typical of early ischaemic changes [45, 50], and is sometimes observed as a result of action of neurotoxic factors [51]. The slight oedema of mitochondria (and especially of crests) detected in the brains after ECT (photo 4), though hardly marked, may also be connected with hypoxia [52] and/or with free radicals activity [53].

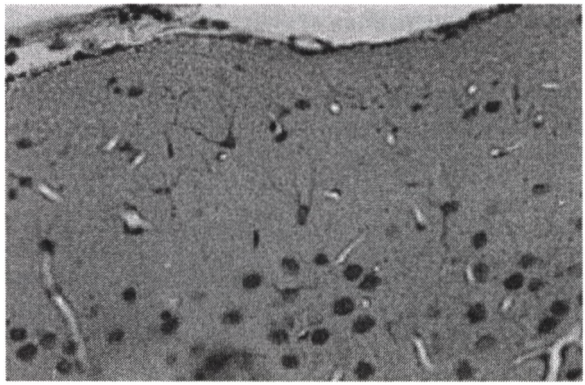
Photo 1. **Structure of rat brains after ECT and TMS in light microscopy: a) hippocampus after ECT (Klüver-Barrer, ocular: 2x); b) frontal cortex after ECT (GFAP; ocular: 40x); c) parietal after TMS (GFAP; ocular: 40x).**



a

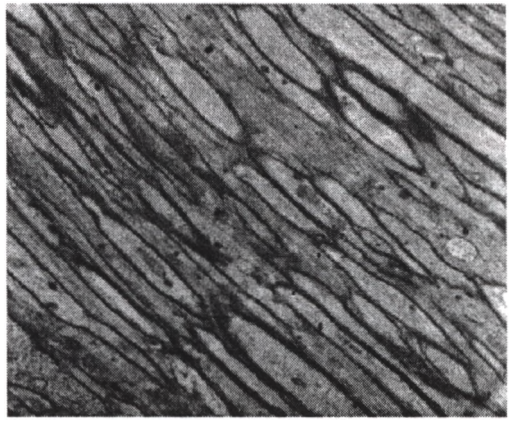


b

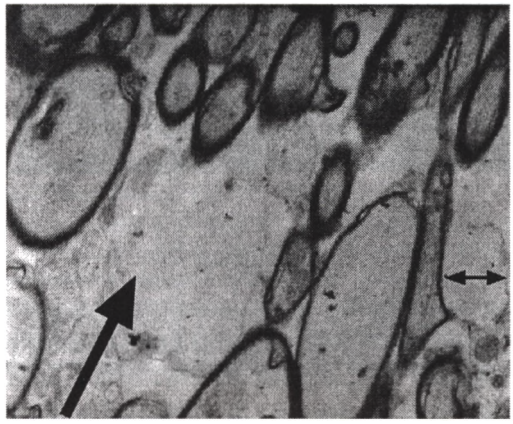


c

Photo 2. **Corpus callosum: normal structure in rats after rTMS (a) and slightly extacellular edema (↑) in animals after ECS (b); ↔ = 1μm**



a



b

Photo 3. **Thalamus: vacuolization of glial cell especially around capillries (↑) in rats after ECS; ↔ = 1 μm**

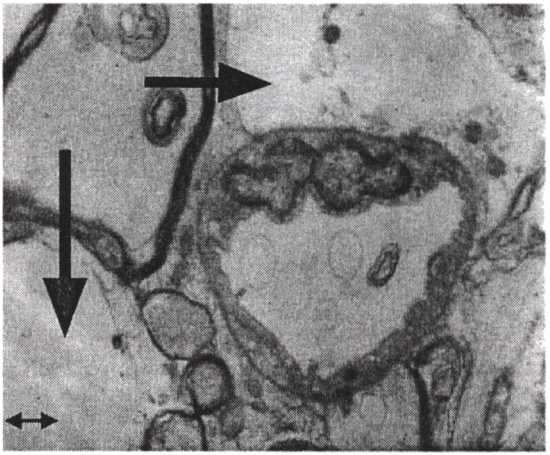
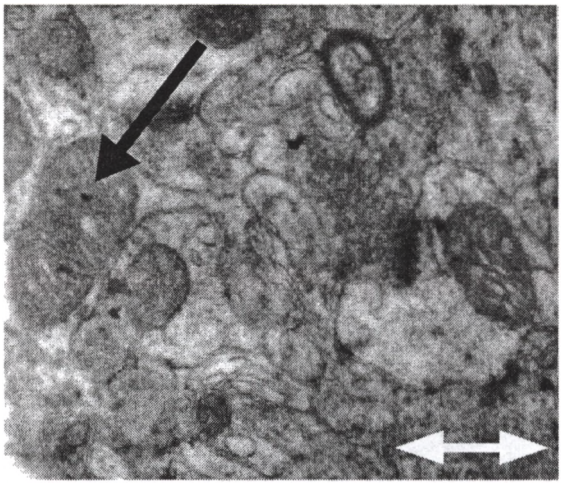


Photo 4. **Little ballooned swelling of mitochondrial ctistae (↑) in rats after ECS; powiększenie: ↔ = 1 μm**



Conclusion

The obtained results suggest that electroconvulsive therapy – despite its recognised high clinical effectiveness – is characterized by a neurotoxic potential. Neurostructural changes evoked by ECT could be detected only in electron microscopy and were of oedemic or degenerative character. On the other hand, oedemic changes ob-

served after TMS were of moderate intensity – they never amounted to the intensity observed after ECT. Therefore, TMS technique seems safer than the corresponding electric method in the form of ECT.

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