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How Ultrasonic Cerebral Tomosphygmography can Contribute to the Diagnosis of Electrohypersensitivity

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Abstract

Although electrohypersensitivity (EHS) is a detrimental health condition officially acknowledged by the World Health Organisation its characterization as a new pathological disorder remains to be clarified.

In a prospective bioclinical study of EHS- and/or multiple chemical sensitivity (MCS) self-reporting patients, we used both ultrasonic cerebral tomosphygmography (UCTS) and transcranial Doppler ultrasonography to measure intracerebral pulsations with the aim to further characterize the brain abnormalities in these patients. In the present study we describe the UCTS imaging technique and report the results obtained by using this technique in 565 EHS and EHS/MCS cases so far enrolled, among which 535 are fully evaluable according to previously established criteria.

There were 353 patients with EHS (66%) and 182 with both EHS and MCS (34%). Overall, relative to normal controls the results show a significant decrease ($p<0.00001$) in the mean tissue pulsometric index (PI) in the middle cerebral artery (MCA)-dependent areas of temporal lobes, predominantly in the capsulo-thalamic and adjacent areas in more than 80% of the patients.

Since mean tissue PI decrease in temporal lobes may reflect decrease in MCA brain blood flow and/or neuronal metabolic dysfunction, and the capsulo-thalamic area contains both the limbic system and the thalamus, we suggest these two particular brain structures could be associated with some vascular and metabolic impairment. We conclude that UCTS is a simple ultrasound-based technique that can be used in addition to EHS-related biomarker measurement and other imaging techniques for the diagnosis of EHS in EHS- and EHS/MCS-self reporting patients.

Keywords: Ultrasonic cerebral tomosphygmography; Cerebral echodoppler; Electrohypersensitivity; Multiple chemical sensitivity; Pulsometric index

Introduction

In 1997 a group of experts working on behalf of the European Commission used the term "electromagnetic hypersensitivity or electrohypersensitivity" (EHS) to encompass in a unique concept the clinical condition in which EHS-self reporting patients report symptoms they attribute to electromagnetic field (EMF) exposure [1]. In 2004 because of the seemingly increasing worldwide prevalence of EHS, the World Health Organization (WHO) organized an international scientific workshop in Prague (Czech Republic) to clinically define and characterize EHS [2]. Following this workshop, WHO clearly acknowledged EHS as a real pathological condition affecting persons who experience detrimental health effects while using or being in the vicinity of EMF-emitting devices [3]. However, because there was no proven causality between the occurrence of EHS and EMF exposure, the alternative term "idiopathic environmental intolerance (IEI) attributed to electromagnetic fields" (IEI-EMF) was proposed to designate EHS [2].

Whatever the initial environmental stressors that may cause EHS, a major problem lies in the absence of recognized objective criteria for a widely accepted diagnosis of EHS. By using several biomarkers measured in the peripheral blood and the urine of EHS- and EHS and multiple chemical sensitivity (MCS) self-reporting patients, we previously tentatively characterized EHS by showing it is associated with some degree of oxidative/nitrosative stress, inflammation and autoimmune response in many patients [4,5].

Ultrasonic cerebral tomosphygmography (UCTS) is an ultrasound-based imaging technique which has been historically standardized and developed in France to measure intracerebral tissue pulsations [6,7], after the concept of ultrasound-based intracerebral pulsation measurement was pioneered in the USA [8]. The growing interest of using UCTS for the characterization of EHS derives from the fact that EHS-self reporting patients usually do not tolerate classical cerebral EMF-related magnetic resonance imaging (MRI) or computed tomography (CT) scans. We thus rehabilitated this former UCTS technique to measure precisely the intracerebral tissue pulsometric index (PI), not only because it is a non EMF-related ultrasound-based imaging technique, but also because it explores the temporal lobes and so may account for the clinical data showing that patients complaining with EHS have cognitive defects such as loss of short term memory

and attention deficiencies, and auditive and olfactive abnormalities [4,9-11].

In a previous study we showed that EHS and/or MCS bearing patients may present with a significant decrease in mean PI in several tissue areas of temporal lobes, suggesting these abnormalities may correspond to some decrease in brain blood flow (BBF) and/or neuronal dysfunction [4,12].

The present study aims at confirming and extending our previous data by showing UCTs is a well-tolerated non-invasive ultrasound-based technique which can be used routinely in addition to other ultrasound-based imaging techniques such as transcranial Doppler ultrasonography (TDU), and peripheral blood biomarker measurement; to fully identify and characterize EHS and so contribute to the objective diagnosis of this new pathological condition occurring in EHS-self reporting patients, whether it is or not associated with MCS.

	EHS	EHS/MCS	p**	Normal controls	p***	p****
Headache	88%	96%	0.065	0%	<0.0001	<0.0001
Dysesthesia	82%	96%	0.002	0%	<0.0001	<0.0001
Myalgia	48%	76 %	<0.0001	6%	<0.0001	<0.0001
Arthralgia	30%	56%	<0.001	18%	0.067	<0.0001
Ear heat/otalgia	70%	90%	<0.001	0%	<0.0001	<0.0001
Tinnitus	60%	88%	<0.0001	6%	<0.0001	<0.0001
Hyperacousis	40%	52%	0.118	6%	<0.0001	<0.0001
Dizziness	70%	68%	0.878	0%	<0.0001	<0.0001
Balance disorder	42%	52%	0.202	0%	<0.0001	<0.0001
Concentration/Attention deficiency	76%	88%	0.041	0%	<0.0001	<0.0001
Loss of immediate memory	70%	84%	0.028	6%	<0.0001	<0.0001
Confusion	8%	20%	0.023	0%	0.007	<0.0001
Fatigue	88%	94%	0.216	12%	<0.0001	<0.0001
Insomnia	74%	92%	0.001	6%	<0.0001	<0.0001
Depression tendency	60%	76%	0.022	0%	<0.0001	<0.0001
Suicidal ideation	20%	40%	0.003	0%	<0.0001	<0.0001
Transitory cardiovascular abnormalities	50%	56%	0.479	0%	<0.0001	<0.0001
Occular deficiency	48%	56%	0.322	0%	<0.0001	<0.0001
Anxiety/Panic	38%	28%	0.176	0%	<0.0001	<0.0001
Emotivity	20%	20%	1	12%	0.176	0.176
Irritability	24%	24%	1	6%	<0.001	<0.001
Skin lesions	16%	45%	<0.0001	0%	<0.0001	<0.0001
Global body dysthermia	14%	8%	0.258	0%	<0.0001	<0.007

Table 1: Clinical symptom occurrence in EHS and EHS/MCS patients in comparison with normal controls [9]*.

*This data results from the clinical analysis of the 100 first clinically evaluable cases issued from the already published series of EHS and/or MCS patients who have been investigated for biological markers (4). It has been compared symptomatically with data obtained from a series of apparently normal subjects used as controls (9).

** Significance levels (p values) obtained for comparison between the EHS and EHS/MCS groups.

*** Significance levels (p values) obtained for comparison between the EHS and normal control groups.

**** Significance levels (p values) obtained for comparison between the EHS/MCS and normal control groups.

Material and Method

Inclusion criteria

In this study, we defined EHS on the basis of several bio-clinical research criteria we previously established [4]: Absence of known pathology potentially contributing to the observed clinical symptoms such as brain tumor, Alzheimer disease, common psychiatric disorder, ischemic stroke and other possible ischemic disorders; Reproducibility of symptoms each time the patient claims to be exposed to EMFs; Regression or disappearance of clinical symptoms claimed by the patient to be associated with EMF avoidance; As reported in Table 1, clinical symptoms similar or identical to those previously reported in the scientific literature for EHS-self reporting patients [11] and chronic evolution of symptoms meaning patients should have a clinical history of EHS- or EHS/MCS-associated symptoms of more than nine months from the first occurrence of symptoms they attribute to EHS or EHS/MCS. Besides these tentatively proposed EHS-related clinical criteria, we also defined MCS by using the criteria which have been established in 1999 from an international consensus meeting [13].

Therefore, before inclusion, all patients had a face-to-face interview and a general and a neurological clinical examination consisting in the systematic search for tinnitus, hyper- and hypoacusis, ocular abnormalities, dizziness and balance abnormalities, superficial and deep sensibility (Romberg sign) defect as well as motor neuron deficiency.

Moreover we also used several biological criteria. All patients should have a normal systematic biological check-up including hematologic, hepatic, renal and metabolic peripheral blood tests to exclude any non-EHS related pathology. In addition, patients should have a normal carotidian and vertebral echodoppler, and when it has been previously done a normal MRI or CT scan. Also, to be enrolled in this prospective study, patients should be aged between 16 and 85 years, have a body mass index between 18.5 and 25, a normal peripheral blood pressure, no history of pathologies such as cancer, diabetes type II and/or cardiovascular disease, and be in a symptomatic phase of their pathological illness. This study was agreed to the ARTAC/ECERI Scientific/Ethical advisory committee and was conducted according to currently accepted ethical guidelines, including informed written consent approval signed by all patients prior to the study. This non-invasive investigation has been also registered in the European Clinical Trials Database (EudraCT) under the registration number 2018-000493-30.

Ultrasonic cerebral tomosphygmography

The UCTS technique we used was documented in our previous study [4]. Briefly UCTS consists in a non-invasive ultrasound-based computerized technique that allows measuring mean tissue PI by centimeter-thick sections of the temporal lobes from the cortex to the middle line of the brain by using the emission of 2 MHz pulsed ultrasonic waves at different intensity levels from a transmitting ultrasonic source (Figure 1); and by analyzing the reflection of these ultrasonic waves on the different middle cerebral artery (MCA)-dependent vascular and neurologic tissue structures in temporal lobes, more particularly on red blood cells (RBC) in the MCA capillaries that irrigate temporal lobes [6,7].

Mean PI values corresponding to the different temporal lobe tissue sections investigated were directly recorded by the standard UCTS equipment we used (Figure 1). Indeed it has been shown previously that the mean physiological PI values determined in the six standardized MCA-dependent centimeter-thick tissue sections that have been individualized in temporal lobes differ from each other. These different centimeter-thick tissue sections were termed respectively from the cortex to the brain middle line: carotidian, cortical-subcortical, superficial sylvian (or superficial MCA), deep sylvian (or deep MCA), capsulo-thalamic and vertebro-basilar according to the main neurologic structures or vascular cerebral localizations they are associated with, the so called carotidian section corresponding to all measured areas except the vertebro-basilar area (Figure 2).

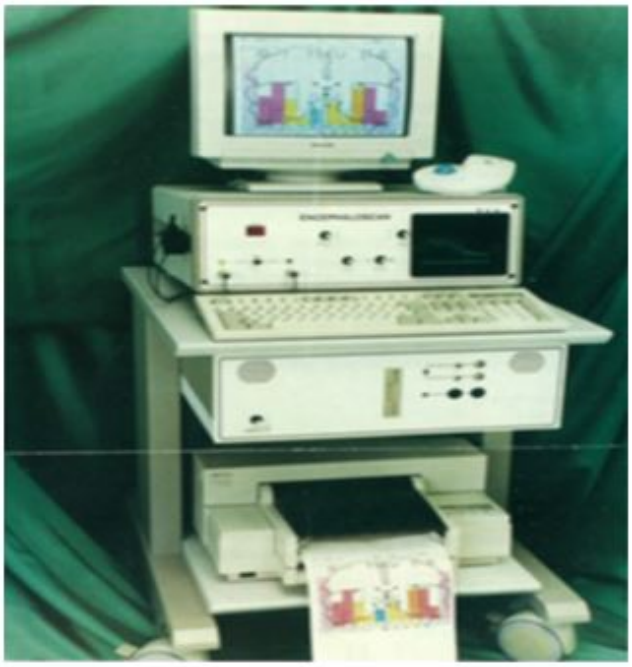

Figure 1: Ultrasonic tomosphygmograph

Addition of the mean PI value obtained at the 3rd cm from the cutaneous cranial surface to the mean PI value obtained at the 4th cm corresponds to the cortical/sub-cortical area; addition of the mean PI values obtained from the 3rd cm to the 5th cm, corresponds to the superficial area of the middle cerebral artery (MCA); and addition of the mean PI values obtained from the 5th cm to the 7th cm, to the deep area of MCA; mean PI value obtained at the 7th cm, corresponds to the capsulo-thalamic area; addition of values obtained from the 3rd cm to the 7th cm, corresponds to the MCA dependent carotidian area; while addition of values obtained from the 8th cm to the 9th cm, corresponds to the vertebro-basilar area.

Thus using UCTS, we were able to measure the mean intra-cerebral PI in each of these different temporal lobe individualized tissue sections in all investigated patients. In our previous ground-breaking article on EHS and MCS, we mentioned the final results we obtained in 727 EHS and/or MCS patients, but we did not report the complete data from which these results were obtained nor the precise methodology we used [4].

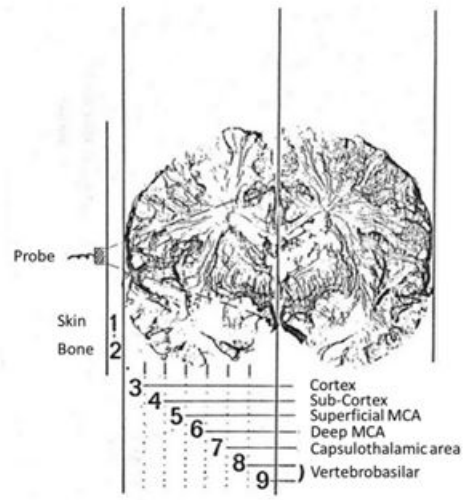

Figure 2: The different tissue sections, from the cortex to the brain middle line of temporal lobes, explored by using a computerized ultrasonic cerebral tomosphygmograph

Comparison to normal controls

Comparison between the mean tissue PI values obtained in the investigated EHS and EHS/MCS patients and the mean tissue PI values obtained in the apparently healthy subjects used as normal concomitant controls was done using the two tailed student t-test. Also the comparison between the EHS and the EHS/MCS groups of patient was done using the two tailed student t-test.

This allowed us to show that in comparison with normal subjects, the MCA-dependent tissue pulsatility in temporal lobes of EHS- or EHS/MCS-self-reporting patients is decreased or even abolished in several areas, more particularly in the capsulo-thalamic area, in one or the two temporal lobes, suggesting that in these areas, decrease in BBF and/or neuronal metabolic dysfunction may have occurred.

Results

Demographic data

In Table 2 are depicted the demographic data. Between 21.08.2014 and 31.08.2017, 565 EHS and EHS/MCS cases were included in this prospective study. However on the 565 included cases, only 535 were fully evaluable for UCTS analysis, 18 cases being not evaluable because inclusion criteria were not fully respected and 12 cases because of a loss of compliance.

Mean age of the evaluable patients is 49.5 years with extreme values between 16 and 85 years. There were 398 female and 137 male, for an overall Female/Male sex ratio of 74%. As indicated in Table 2, the mean age and extreme values were in the same range for the EHS and EHS/MCS groups of patients (49.8 *vs.* 48.9 years and 16-85 *vs.* 21-77 years). By contrast the sex ratio was found to be higher for the EHS/MCS patient group than for the EHS group (86% *vs.* 69%) meaning that the female predominance appears higher for the group of EHS/MCS-self reporting patients. Likewise the sample of 84 apparently healthy subjects we used as normal controls had a mean age of 42.1 years, extreme values between 18 and 74 years and a sex ratio F/M of 72%.

	Normal concomitant controls n=84	EHS* patients n=353 (66%)	EHS-MCS** patients n=182 (34%)	Total patients n=535 (100%)
Age				
Mean	42.1	49.8	48.9	49.5
Median	41	50	50	50
Min	18	16	21	16
Max	74	85	77	85
female	60	242	156	398
male	24	111	26	137
Sex ratio (F/M)	72%	69%	86%	74%

Table 2: Demographic data

* EHS=electrohypersensitivity

** MCS=multiple chemical sensitivity

UCTS pulsometric index measurement

Results are depicted in Tables 3 and 4 and Figure 3. As indicated in Table 3 and Figure 3, for the EHS patient group, as well as for the EHS/MCS patients group, in comparison with the normal control values, we found a statistically significant decrease in the mean tissue PI in the capsulo-thalamic area and both adjacent sections, i.e. the deep MCA and the vertebro-basilar areas with the exception of the cortical/subcortical section of the right and left temporal lobes, the mean tissue PIs measured in the other areas in each temporal lobes-i.e. the superficial MCA, the carotidian and sections were all found to be statistically significantly decreased relative to normal values ($p<0.00001$).

In addition Table 4 indicates about 90% of the EHS or EHS/MCS patients present with decreased mean PI values in the capsulo-thalamic and adjacent areas in one or the two temporal lobes, suggesting these abnormalities may be biologically relevant. Note however that similar abnormalities were found in about 10%-20% of the concomitant healthy controls, meaning that among these apparently normal subjects so far investigated, a small percentage of them may in fact be not biologically normal.

Estimated percentage of patients with abnormal UCTS scan

By computing the number of temporal lobe areas with decreased mean PI values in the apparently healthy subjects used as normal controls, we confirmed that not all these apparently healthy subjects had a normal UCTS scan. We thus determined the cut-off number of areas with decreased mean PI in the apparently healthy subjects, to estimate the percentage of EHS and EHS/MCS patients who could really be discriminated from the apparently healthy presently used concomitant controls on the basis of their UCTS scan. Results are depicted in Table 5. As indicated, the so called healthy controls may present up to 3 decreased mean tissue PI-associated temporal lobe

areas, meaning that the cut-off number being established at 3, the percentage of patients with a pathological UCTS scan in comparison with normal controls is estimated to be 84%, whether EHS is associated or not with MCS (Figure 3).

Temporal lobe	Tissue areas analyzed	Apparently healthy subjects n=84	EHS patients n=353	p**	EHS-MCS patients n=182	p***
Right	carotidian	20.39 ± 4.33	13.48 ± 3.76	<0.00001	13.44 ± 3.62	<0.00001
	cortical-subcortical	6.02 ± 2.90	5.28 ± 2.92	0.12	5.11 ± 2.93	0.07
	superficial MCA	10.38 ± 3.99	8.41 ± 3.04	0.0001	8.11 ± 3.07	<0.0001
	deep MCA	14.40 ± 2.44	8.33 ± 2.85	<0.00001	8.37 ± 2.47	<0.00001
	capsulo-thalamic	5.81 ± 0.96	2.56 ± 3.03	<0.00001	2.36 ± 1.77	<0.00001
	vertebro-basilar	11.04 ± 1.65	8.18 ± 4.17	<0.0001	7.78 ± 1.81	<0.00001
Left	vertebro-basilar	10.95 ± 1.81	6.18 ± 2.39	<0.00001	6.12 ± 2.64	<0.00001
	capsulo-thalamic	5.32 ± 1.38	3.18 ± 2.14	<0.00001	3.24 ± 2.18	<0.00001
	deep MCA	13.89 ± 2.54	9.03 ± 2.99	<0.00001	8.61 ± 2.99	<0.00001
	superficial MCA	11.29 ± 4.25	8.22 ± 3.42	<0.00001	7.84 ± 2.99	<0.00001
	cortical-subcortical	6.88 ± 3.50	5.21 ± 3.07	0.001	5.23 ± 3.02	0.002
	carotidian	20.58 ± 5.09	14.14 ± 4.14	<0.00001	13.82 ± 3.72	<0.00001

Table 3: Mean pulsometric index measurement (± SD) in the different tissue areas investigated in temporal lobes of EHS and EHS/MCS bearing patients relative to normal concomitant controls.

EHS: Electrohypersensitivity; MCS: Multiple chemical sensitivity EHS; SD: Standard deviation.

** Significance levels (p values) obtained by using the two tailed Student t-test for comparison between the EHS-bearing patients and the apparently healthy subjects used as concomitant controls.

*** Significance levels (p values) obtained by using the two tailed Student t-test for comparison between the EHS-MCS-bearing patients and apparently healthy subjects used as concomitant controls.

	Carotidian	Cortico-subcortical	Superficial MCA	Deep MCA	Capsulo-thalamic	Vertebro-basilar
EHS (n=353)	136/353 (38, 8%)	13/353 (3, 7%)	59/353 (17%)	311/353 (88, 4%)	328/353 (92, 9%)	322/353 (91, 2%)
EHS/MCS (n=182)	70/182 (38, 5%)	16/182 (8, 8%)	31/182 (17%)	162/182 (89%)	171/182 (94%)	166/182 (91, 2%)
Normal concomitant controls (n=84)	1/84 (2, 4%)	1/84 (2, 4%)	2/84 (4, 8%)	4/84 (9, 5%)	7/84 (16, 7%)	4/84 (9, 5%)

Table 4: Percentages of patients and normal concomitant controls with decreased mean tissue pulsometric index values in the different temporal lobe areas explored by UCTS*

*Including the right and/or left temporal lobes.

Discussion

Although WHO officially acknowledged EHS as an adverse health condition [3], following the Prague WHO sponsored international workshop on electromagnetic hypersensitivity [2] it was recommended to use the term IEI-EMF to qualify such a pathological condition.

Whatever their causal environmental origin, on the basis of clinical description EHS or similar pathological disorders such as MCS have been ascribed as sensitivity-related illness (SRI) [14], or as toxicant-induced loss of tolerance (TILT) disease [15]; to account for the fact that EHS and MCS patients cannot tolerate weak intensity of man-made EMFs and weak environmental chemical concentrations, respectively. We have previously confirmed the validity of the TILT or SRI concept and proposed that EHS as well as MCS could be considered as being associated with a decrease in the central nervous system tolerance threshold to environmental artificial manmade EMFs and/or chemicals [4]. To substantiate this concept, we have shown that both EHS and MCS can occur in the same patients, and that peripheral

blood reliable disease biomarkers can be measured at similar pathological levels in these two WHO recognized detrimental health conditions, suggesting that EHS and MCS may in fact be two etiopathogenic aspects of a unique pathological disorder [4]. The present UCTS investigation indirectly confirms, our data by showing that the decrease in mean tissue PI in temporal lobes, more particularly in the capsulo-thalamic and adjacent areas is observed whether or not EHS is associated with MCS.

Number of areas with decreased mean PI values	Apparently healthy subjects n=84	EHS patients n=353	EHS-MCS patients n=182
0	54/84 (64.3%)	0	0
1	20/84 (23.8%)	8/353 (2.3%)	4/182 (2.2%)
2	8/84 (9.5%)	17/353 (4.8%)	7/182 (3.8%)
3	2/84 (2.4%)	31/353 (8.8%)	18/182 (9.9%)
4	0	86/353 (24.4%)	43/182 (23.6%)
5	0	94/353 (26.6%)	38/182 (20.9%)
6 and more	0	117/353 (33.1%)	72/182 (39.6%)
	Total	297/353 (84.1%)	153/182 (84.1%)

Table 5: Determination of the cut-off number of areas with decreased mean tissue PI values in the apparently healthy subjects used as normal controls, and estimation of the percentage of patients with a pathological UCTS scan, relative to normal controls. EHS: Electrohypersensitivity; MCS: Multiple chemical sensitivity.

As previously indicated, UCTS measure tissue pulsations of centimeter-thick sections mainly corresponding to the intra-cerebral territories vascularized by MCA, but not the own MCA pulsations. UCTS is thus clearly distinguished from the more frequently used transcranial Doppler ultrasonography (TDU) technique which measure cerebral perfusion pressure upon MCA blood flow velocity [16,17].

It is well known that using transcranial ultrasound techniques such as TDU or UCTS factors which affect cerebral pulsations can be extracranial or intracranial [8]. Among extracranial factors are peripheral vascular changes, such as low systolic arterial pressure. However in this study, all investigated patients had a normal systemic arterial pressure and a normal carotidian and vertebral echo Doppler. This led us to hypothesize that intracranial factors such as local blood flow vascular changes and/or changes in brain tissue metabolism may be involved to account for the low mean tissue PI detected by UCTS in the different temporal lobe areas studied.

In an on-going study, performed jointly with the present study, by using TDU in association with UCTS, we found a statistically significant decrease in MCA blood flow velocity in cases for which we had simultaneously observed a decrease in mean tissue PI in the temporal lobe areas by using UCTS (data to be published).

EHS and EHS/MCS patients are presently associated with a clear cut and statistically significant decrease in mean tissue PI, not only in the capsulo-thalamic and adjacent areas, but in all temporal lobe areas with the exception of the cortico-subcortical area of the right temporal lobe. Note that we have presently no plausible explanation why this area is associated with a normal mean PI value. We have also no definitive explanation regarding the fact that 10%-20% of the healthy subjects used as concomitant normal control, presented with several decreased tissue mean PI-associated areas (no more than 3). However we did not investigate whether these apparently healthy subjects were exposed to environmental stressors. The decrease in mean tissue PIs values observed in the temporal lobes of EHS and EHS/MCS patients appears to mainly involve the capsulo-thalamic area and so the limbic system and the thalamus it contains. This area is particularly critical, because in addition to the limbic system and the thalamus, it may comprise the multisensory parieto-temporal cortex zone as it has been shown in rats [18]. A simple hypothesis could be that the decreased mean PI values measured in this area and adjacent territories may be associated with a decrease in MCA-related BBF. This hypothesis is supported by other findings which have shown that mobile phone-associated exposure to pulse-modulated radiofrequency EMF, can affect regional BBF [19,20]; and that BBF disruption may consequently disturb sleep and waking EEG [21]. Moreover, it has been clearly established experimentally that 900 MHz or 2.45 GHz microwave short term or chronic exposure in rats can trigger neuronal dysfunction and even apoptosis of hippocampal pyramidal cells [22,23] and cerebellum Purkinje cells [24,25], through oxidative stress induction.

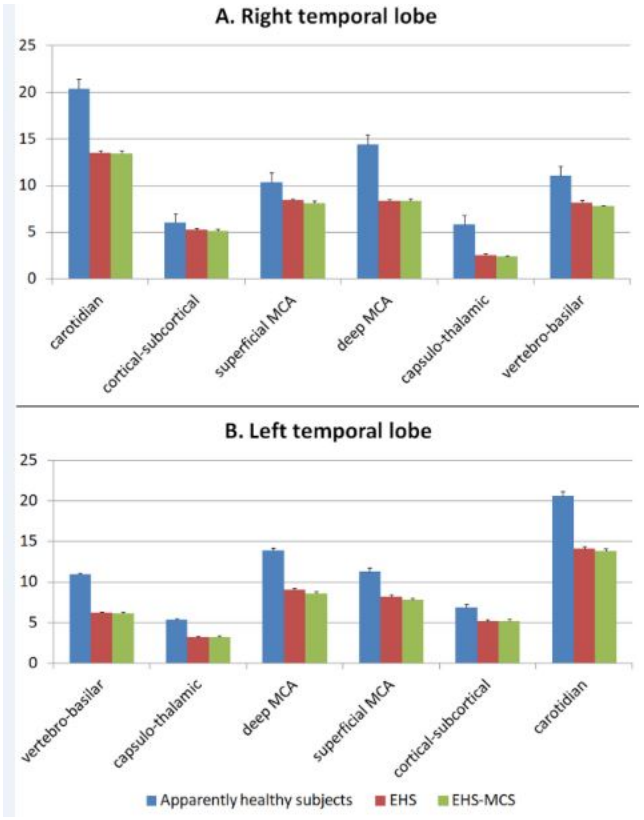

Figure 3: Mean tissue pulsometric index in different temporal lobe areas in EHS- and EHS/MCS-bearing patients in comparison with reference values obtained from a series of 84 apparently healthy subjects used as concomitant normal controls.

EHS: Electrohypersensitivity; MCS: Multiple chemical sensitivity

So, the statistically significant decrease in mean tissue PI values evidenced in the MCA-dependent areas of temporal lobes may similarly be associated with some brain tissue metabolic changes in the limbic system and the nearby brain connected neuronal structures. Such pathological changes could indeed be related to oxidative stress-induced BBB opening [26] and/or to brain hypoxia caused by EMF-induced BBF decrease and/or EMF-induced haemoglobin deoxygenation [27,28].

In the present study, all patients who have been investigated before inclusion with a brain MRI or CT scan had a normal MRI or CT scan, so abnormalities in the limbic system and/or in the thalamus could not be detected by using these classical EMF-related routinely used imaging techniques to characterize and diagnose EHS. However by using more sophisticated imaging techniques such as positron emission tomography (PET) or functional MRI (fMRI), it has been possible to evidence some metabolic hyperactivity in the limbic amygdale of MCS patients (PET studies) [29], and some abnormal default mode network, including decreased BBF and/or metabolic activity within bi-frontal lobes in the brain of EHS patients (fMRI studies) [30].

It is concluded from the present data that UCTS is a useful and simple well-tolerated non-invasive ultrasonic technique which can be used in association with other imaging techniques for the objective characterization of EHS and its diagnosis in EHS- and EHS/MCS-self reporting patients.

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Author Contributions Statement

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material has not been submitted to or published in any other publication.

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- Critical revision of the article: D. Belpomme, P. Irigaray
- Final approval of the version to be published: D. Belpomme, P. Irigaray, P. Lebar

Conflict of Interest

All the authors declare no financial conflict of interest.

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