ORIGINAL ARTICLE

Evaluation of the dynamics of energetic changes in the brain stem respiratory centre in the course of increasing disorders of consciousness

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Abstract

The paper, based on extensive research material (150 patients and a 30-people control group) suggests extension of clinical assessment of brain spirography (BSG) in patients with acute stage of stroke. The analysis of dynamic changes occurring in encephalon is made using a mathematical apparatus applied in the theory of chaos. The paper does not only essentially supplement the existing research but it also sets new research challenges with the aim to complement the knowledge of relations between the dynamics of respiratory system and states of consciousness in patients with ischaemic stroke. The results obtained confirm the correctness of the assumed hypothesis indicating, at the same time, a significant diagnostic potential of the method described.

An attempt to understand broad dependencies between energetic changes occurring in the central nervous system at all available levels: molecular, cellular and tissue: was made based on a broad research material on ischaemic stroke of brain stem. The multitude and complexity of the problems seems to be enormous in this case, however it is worth asking fundamental questions which will allow us to understand not only medical implications of this serious disease.

A classic attempt to solve this problem based on the scientifically accepted paradigm of reductionism has not brought satisfactory results. Dividing the nervous system into smaller and smaller parts (**structures**) and searching for their closely corresponding activities (**actions**), is currently being replaced by a systematic approach which considers the nervous system as one entity, and it treats the activities generated by the system not only as a simple sum of component quantities but as a new quality created in this extremely complicated system.

The application of the theory of chaos, also called more and more frequently the theory of complex systems, to describe complex physiological processes is the right consequence of the thesis that the knowledge and observation of these processes is not enough to understand them. It is also essential to know dynamic processes occurring between their various components. The theory of chaos is attempting to answer questions concerning the dynamics of nonlinear systems, however the complexity level of large systems (even one human organ, e.g. brain stem is undoubtedly considered such a system) is too high to allow for accurate calculations, not to mention the organism as one entity.

The name "chaos" can be misleading; physicists consider chaotic states a specific form of self-organization which is characterized by over-orderliness of significantly complex systems. The way in which big

and very complex systems are organized is the subject matter of the theory of chaos research. Nowadays, we already know well that it is the matter and energy which undergo natural self-organizing processes. We will try to demonstrate it on the example of breathing rhythm which starts as a series of accidental discharges in the neural network located in the brain stem respiratory generators.

Contemporary physiology describes breathing rhythm as a result of interactions of a series of feedbacks occurring at various levels of organism functions. The most known ones are regulating exhalation circle and regulating inhalation circle. We are dealing both with the impact of specific known factors such as signals from receptors (cold receptors, baroreceptors, mechanoreceptors, chemoreceptors) and hormones (adrenaline, steroid hormones) and with more hard-to-measure factors, e.g. emotional states like excitement, depression, speaking, singing, etc. It is also a known fact that sensitivity of medulla oblongata chemoreceptors to pH of cerebrospinal fluid (one of the factors affecting breath regulation processes) is decreased during sleep or under anaesthetic. It indicates a connection between the state of consciousness and breathing rhythm. At the same time, it should be noted that all abovementioned individual factors are clearly connected with energetic changes and the systems responsible for energy regulation - locally at the cellular level, and globally at the entire organism level.

If the authors' assumptions are right, then the resulting implications will be particularly evident when comparing a healthy organism condition to a condition with a clear energetic deficit represented as a pathological condition.

If we assume that ischaemic stroke is a kind of energetic deficit understood in a most general way which affects brain tissue, then we should refer it to the most commonly observed and present feature of this tissue in a macro scale - consciousness. In fact, we should treat it as an element of higher awareness but only to the extent it is relevant to our discussion on energetic changes taking place in encephalon and not in cognitive processes occurring in cortex structures. Awareness can be divided into qualitative, which is responsible for cognitive processes, and quantitative, the one we are more interested in now, which covers behaviours related to stimulating and suppressing encephalon, including possibilities its activities regulation.

Although a holistic presentation of processes is much more important in the examination of phenomena occurring generally in brain tissue, we will not avoid using methods of scientific reductionism in even such general definitions as consciousness. Following the path of such reduction further, we reach a place in encephalon called a *reticular activating system,* which has been long associated by various researchers with a place responsible for waking processes and consciousness activating processes.

For that reason, we may assume that consciousness which conditions encephalon activity affects either directly or indirectly the functions of the brain stem respiratory centre. Thus, we may try to define clinimetric parameters of consciousness using the dynamics of breathing rhythm changes. The research method of brain spirography (BSG) consists in recording a breathing curve in various clinical states in appropriately selected time sections. Such breathing curves contain information not only about basic breathing rhythms generated in the brain stem centre but also a very broad set of data including the activities of numerous modulators and feedback elements which appear during unforced natural breathing in various states. In this way, using relevant nonlinear analytical methods, we can read information related directly also to consciousness. Treating the BSG record as a characteristic image presenting the dynamics of changes, we can attempt to define the parameters of energy dynamics in the entire encephalon.

By making certain transformations inside the complicated complex system which contains the brain stem respiratory centre, we can determine the encephalon activity state occurring at various levels of consciousness, as defined in clinimetric terms.

Following the above procedure, we should first examine the breathing curve in a disease condition, such as brain stroke, depending on a parametric equivalent of the patient's state of consciousness defined by a clinical examination. The received results, following their topological analysis using elements applied in examinations of nonlinear systems including the theory of chaos, should answer the following questions:

- Can we directly combine a BSG record parameter with appropriately identified levels of consciousness?
- If yes, is it possible to determine on that basis a general energetic condition activating at a certain moment the centres connected with emerging consciousness?
- If the answers to the above questions are positive, can we then build an efficient support system for diagnosing stroke states which will allow us to monitor insufficiency of brain stem (ITC - insufficientia trunci cerebri) depending on the depth of consciousness disorders?

To answer the above questions, a number of clinical and research works have been carried out which used both BSG examination and a nonlinear analysis of the received signals. Without going further into mathematic details which can be found in specialist magazines (Swierkocka-Miastkowska & Osiński 2007a; 2007b), we can say that we have succeeded in finding interesting interdependencies.

Using a method based on a classical paradigm of research sciences, we have created an interpretation platform which goes beyond this paradigm and covers,

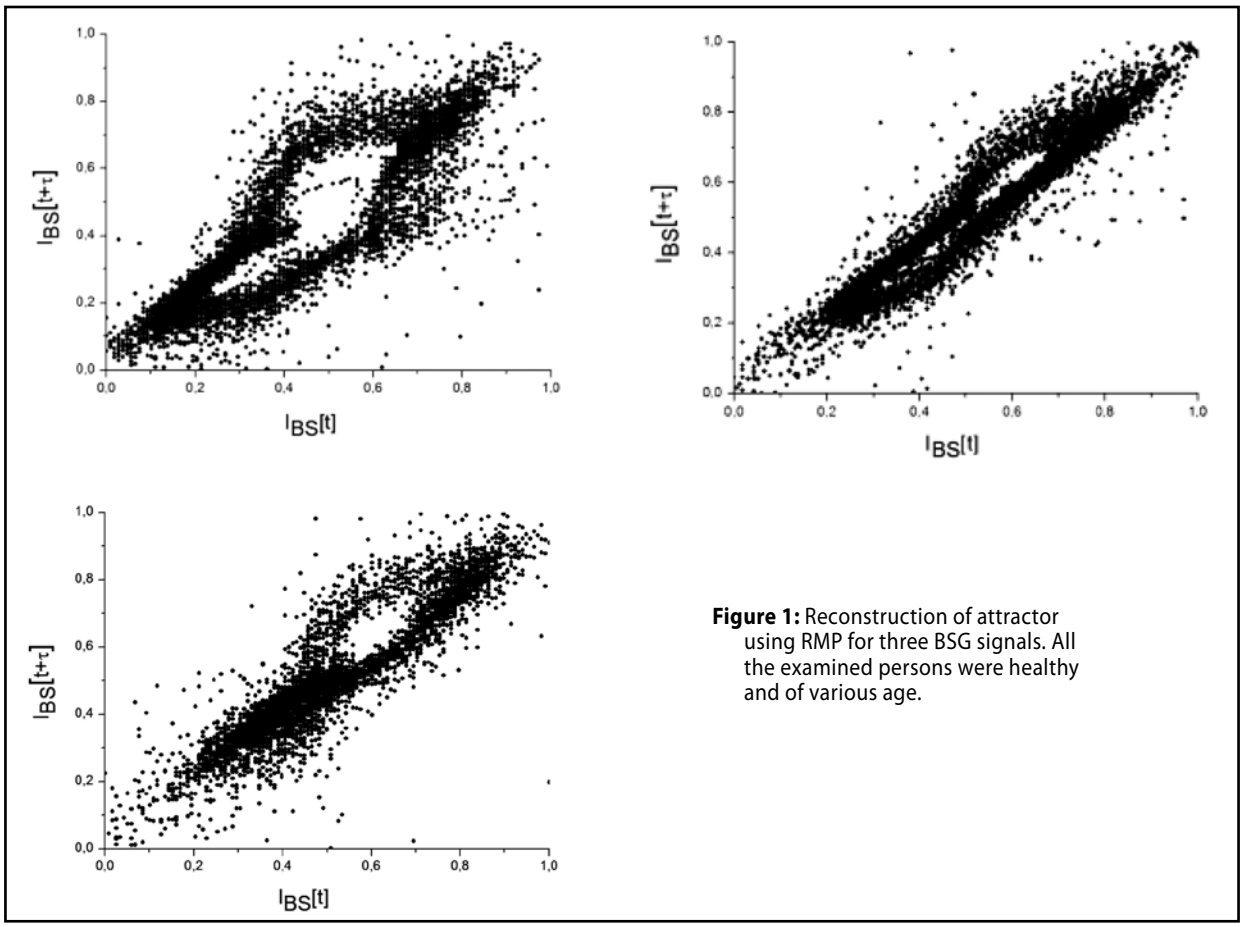

Figure 1: Reconstruction of attractor using RMP for three BSG signals. All the examined persons were healthy and of various age.

as it were, comprehensively (holistically) the analysis of breathing rhythms in connection with the parameters defining disorders of consciousness. It would be highly recommended to determine states of consciousness depending on the current energetic state of encephalon.

For this purpose, we have performed a comparative analysis of BSG signals for a control group of healthy, fully conscious persons of different age. Out of numerous results, ***Figure 1*** presents the RMP (Return Map Plot) image for three examined persons. Even a quick look at the images let us finds immediately some common features of the presented dynamic records, such as: clear RMP symmetry, clearly marked attraction basin and a rather extended peripheral dynamics as an example of potential adaptive possibilities of such energetic system. Numerical computations have also been made to calculate the fractal dimension of the presented images, which could be interpreted as a parameter comprehensively defining the type of dynamics of the examined signal or, using the above mentioned definitions, the energetic state of a given system. Values of the fractal dimensions for the control group fluctuate around a constant value with a good statistical error (Szeliga et al 2000). We will treat mathematical reversal of the fractal dimension value with corrections calculated using the NIH Stroke Scale (NIHSS) as a parameter defining energetic state of the brain stem respiratory system of the examined persons. This parameter identified by us as E_{ITC} factor has a value of 1.5 to 3.5 in this group. ***Figure 1.***

The results obtained for people with brain stroke who were diagnosed with various degrees of consciousness disorders defined in the GSC (Glasgow Coma Scale) look completely different. There is no longer any geometric symmetry and the images appear as "poor" attractor's lines passing multiple times across the same areas in the image (attractor's structure) without being able to reach the right dynamics, or the opposite situation: the trajectories reaching further and further areas losing their energy and failing to achieve the right synchronization effect in a large time scale. In this case, the E_{ITC} factor has also been identified and in all cases it was less than one. This is an indication of a general disorder of energetic changes leading not only to the loss of the breathing rhythm stability but also to energy dissipations which cause energy impoverishment of the system and consequently, lead to deeper disorders of consciousness. Careful examinations of such states should determine more specifically the nature of connections between the definition of consciousness disorders depending on nonlinear parameters of the reconstructed attractor in the form of RMP for individual BSG signals.

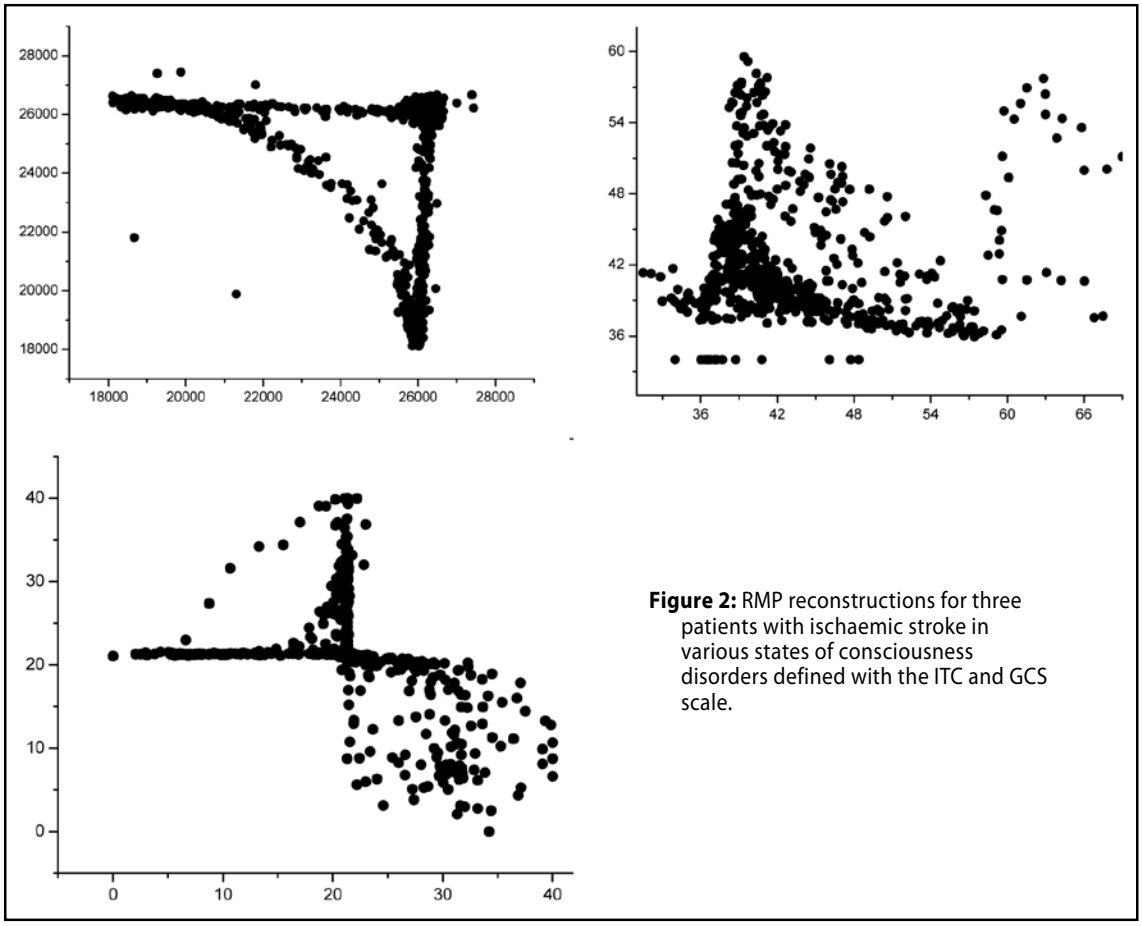

Figure 2: RMP reconstructions for three patients with ischaemic stroke in various states of consciousness disorders defined with the ITC and GCS scale.

A hypothetic future scale should be based more on energy parameters with a possibility to predict pathological behaviours and directly related to accurate nonlinear parameters of BSG signals. The ITC scale – insufficiency of brain stem (Mazur et al 2004), already used in clinical research in Poland, seems to be the most suitable for further development in this direction rather than the NIH Stroke Scale which has been used so far for computations. However, it requires a collection of vast research material for proper analysis, both clinical and mathematical. ***Figure 2.***

Supplementary research will make it possible to define, in a reproducible way, parameters of a new scale, which will allow us to answer positively the above questions. It remains to hope that next generations of both measuring equipment and mathematical algorithms applied will support not only diagnostics but will also create a kind of "early warning system" which, when used in clinical wards, will help implement appropriate procedures at a critical moment to stop progressing disorders of the energetic state of encephalon during a stroke.

From the clinical point of view, breathing rhythm as a parameter closely connected with the organism's energetic state, is not a simple sum of components resulting from subsequently occurring cycles where the major role is played by rhythm generator, breathing system, breathing muscles, etc. It refers not only to selected structures but the entire organism. Breathing rhythm is a periodic system, generated comprehensively by the organism, to supply it with essential energetic substrates and remove waste products of metabolism.

Main modulators which are responsible for the right functions of the breathing rhythm are located in brain stem structures.

From the technical point of view, all possibilities described here are currently possible to implement. Because of its holistic character and diagnostic possibilities, the method described seems to be a perfect tool for diagnosis of consciousness disorders and clinical pathologies of encephalon taking place during brain stroke, as well a significant factor of primary and secondary prevention in brain stroke.

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