New Perspectives in Rheoencephalography

Juan J. Perez
Polytechnic University of Valencia, Spain

Enrique Guijarro
Polytechnic University of Valencia, Spain

Pedro Ortiz
Consorcio Hospital General Universitario de Valencia, Spain

José M. Pons
Consorcio Hospital General Universitario de Valencia, Spain

INTRODUCTION

One of the most important advances in biomedical engineering has been the ability to inspect inside the body without opening it. In this sense, rheoencephalography (REG) is an electromedical technique used to assess the cerebral blood flow (CBF) by noninvasive electrical impedance methods, using electrodes attached to the scalp surface. This technique was first proposed by Polzer and Schuhfried (1950), and emerged as an extrapolation of impedance plethysmography applied to the head.

An electric current flowing through a biological tissue causes a potential difference between any pair of electrodes that can be measured. This potential difference depends on the amplitude of the injected current, the shape of the conductor, the arrangement of the electrodes, and the electrical characteristics of the tissue. For instance, the electrical conductivity of the lung tissue is much lower than that of the cerebrospinal fluid (CSF), since alveolar sacs are nonconductive. Furthermore, the electrical conductivity depends on the frequency of the electric current, the orientation of the tissue fibers relative to the current flow, and the amount of extracellular fluid that surrounds the cells. For example, electrical conductivity is higher in the blood than in most tissues, since plasma acts as a true-highway for ions (Malmivuo & Plonsey, 1995).

he ejected blood fills the arterial vascular bed, and a small and abrupt change in the electrical impedance of the tissues occurs, due to two reasons: the cross-sectional area of the tissue increases, and tissue effective conductivity rises. This is the physical principle of impedance plethysmography, and explains why the electrical impedance of any part of the body throbs synchronised to the heartbeat some tens or hundreds of milliohms around a basal impedance value.

BACKGROUND

By injecting an electric current through a pair of electrodes attached to the scalp surface, Polzer and Schuhfried recorded an impedance signal similar to that shown in Figure 1. Classically, these traces have been represented mirrored horizontally, so that the Y axis represents blood volume instead of impedance. They observed that, following the QRS complex, the REG trace increases abruptly suggesting a sudden blood inflow into the cranial cavity. Subsequently, a

Figure 1. Example of a REG signal and an ECG signal obtained in our laboratory

slow descent in impedance brings the REG trace back to its original value, and it is a result of the constant venous outflow. The morphological differences between the REG signals of pathological and normal subjects suggested that REG trace could be caused by the CBF pulsatility.

Nevertheless, despite the medical necessity of a device to evaluate the CBF, REG ability to evaluate the CBF was strongly debated. Detractors argued that the relative low electrical conductivity of the skull causes most of the current injected from the scalp surface to flow through the scalp tissue without crossing the skull. Accordingly, most of the REG information would be of extracranial origin.

The interest in the technique, and the disagreement about the origin of the REG signal, led to extensive research on the topic. For example, a review of the literature classified under the heading of rheoencephalography between 1959 and 1964 reveals some 150 articles, and one book (Namon, Gollan, Shimojyo, Sano, Markovich, & Scheinberg, 1967). Jenkner (1962) published a monograph summarizing his findings on more than 400 animal experiments, and well over 6,000 clinical records, and compared the results with those obtained by other authors. Some other exhaustive literature reviews can also be found in Lechner and Martin (1967), Lifshitz (1970), and Hadjiev (1972).

On the contrary, Perez-Borja and Meyer (1964) and Masucci, Seipel, and Kurtzke (1970) did not find significant differences in the REG signals recorded from normal subjects and from patients with cerebrovascular diseases and neurological deficits; Laitinen (1968) compared REG signals with intracerebral impedance traces, and found them to be substantially different; Masucci et al. (1970) applied the quantitative method proposed by Seipel (1967) to pathological and normal subjects, and found no clinical value of that analytical method; and, finally, Waltz and Ray (1967) analyzed the REG traces recorded from 96 subjects, some of them with partial or complete obstruction of an internal carotid artery or recent ischemic cerebral infarcts, and considered REG inadequate for the clinical evaluation of cerebrovascular disorders.

The interest in REG and its research flagged in the '70s at the same time as transcranial Doppler ultrasound appeared. Nevertheless, despite the lack of agreement on the REG signal origin, some other research groups have still contributed to REG knowledge during the following decades. For instance, Jacquy reported several findings about the use of REG in the study of regional CBF (Jacquy, Dekoninck, Piraux, Calay, Bacq, Levy, & Noel, 1974; Jacquy, Piraux, Jocquet, Lhoas, & Noel, 1977a; Jacquy, Piraux, Jocquet, Lhoas, & Noel, 1977b; Jacquy & Squelart , 1984), and Shender and Dubin (1994) used REG in the study of the CSF displacement on acceleration stress in military aircrafts. Meanwhile, Hatsell (1991) showed mathematically that regional impedance changes in the cortex are hardly observed by REG, whereas Basano et al. (2001) did not find significant differences in the REG signals recorded from brain-dead patients, and those obtained from living patients. In summary, research on REG ability to reflect the intracranial blood flow has coexisted with the use of REG in clinical studies.

REG MODELING

In engineering, models have been extensively used to study theoretical aspects involved in physical processes. In general, the more complex the model is, the closer to reality the results are. On the contrary, a simple model allows the study of each variable separately and independently from all the others. In this sense, only a few theoretical studies about REG ability to inspect the intracranial blood flow were published during the early stages in REG research.

To determine the changes in impedance caused by the blood inflow into an extremity, Nyboer modelled limbs as a cylinder with a constant impedance Z_0 connected in parallel to a second variable-diameter cylinder in such a way that impedance $z_b(t)$ is time-dependent. This second cylinder represents the net blood that flows in the extremity's tissue along time (Figure 2). This simple model provides a relation between the blood volume increment (ΔV), and the impedance increment (ΔZ) as:

$$\Delta V = -\rho_b \left(\frac{L}{Z_0} \right)^2 \Delta Z$$

where ρ_b is the blood resistivity, L is the interelectrode distance, and Z_0 is the basal impedance of the limb (Geddes & Baker, 1989; Nyboer, 1970). Unfortunately, this simple model is not appropriate for REG analysis, since a portion of the current injected from the scalp surface crosses several tissue layers (e.g., scalp, skull,

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