Electrohysterographic volume conductor modeling

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Abstract

The electrohysterogram is the signal associated to the action potentials propagating through the smooth muscle cells of the uterine muscle (myometrium). Generation and propagation of action potentials initiate the mechanical contraction of the myometrium. Uterine contractions are often the first sign of labor; therefore, when occurring pre-term, they need to be promptly suppressed by tocolytics. Accurate monitoring of the uterine activity is therefore essential. The methods currently employed in clinical practice for uterine activity monitoring could support the selection of patients at higher risk of pre-term delivery within few days, but they are either invasive or not sufficiently accurate for effective prognosis and, therefore, prompt treatment of premature birth69 [1]. During a contraction, the electrohysterographic (EHG) signal can be recorded non-invasively by standard Ag-AgCl contact electrodes placed on the abdomen. Many studies demonstrated that the analysis of the EHG signal may play a key role for accurate monitoring of the uterine contractions, prediction of labor, and improvement of perinatal outcome [1]. However, many issues related to the conduction pattern of electrical activation are still unsolved. An important contribution for studying non-invasively the conduction properties of EHG signals and for the development of novel monitoring technology can be provided by modeling techniques. At the myometrium level, the cellular action potential generation and the excitation-contraction coupling have been recently accurately modeled as a function of a large number of electrophysiological parameters related to ionic concentrations [2]. The myometrium-skin volume conductor, instead, has been only partially investigated and it is typically considered as a homogeneous infinite layer [2]. As a result, the myometrium-skin conduction properties are assumed only dependent on the distance between source and recording site. Nevertheless, a complete understanding of the volume conductor effect on the measured signals is fundamental to support the development of accurate prognostic and diagnostic tools based on the EHG signal analysis. In this study, a myometrium-skin conduction model is developed that consists of a four-layer model obtained by extension of simulation studies reported in the literature for the skeletal electromyogram [3]. The volume conductor effect is formalized in the spatial frequency domain by a transfer function that accounts for the physical and geometrical properties of the biological tissues interposed between the source of electrical current in the myometrium and the recording site on the skin. The intracellular action potential is mathematically modeled by a Gamma probability density function [4]. After model reduction, the potential recorded on the skin surface depends on five parameters, of which three are related to the source signal shape and two are given by the thickness of the fat and the abdominal muscle. For validation, the EHG signal was recorded by a grid of 64 high-density electrodes on five pregnant women at term with uterine contractions. The model parameters were identified by a least squares optimization method using a subset of electrodes. The parameters representing fat and abdominal muscle thickness were also measured by echography. The average correlation coefficient and the standard deviation between the echographic and EHG estimates were equal to 0.94 and 1.9 mm, respectively. No bias was present. These results suggest that the model provides an accurate description of the EHG action potential and the volume conductor, with promising perspectives for future applications.

References

[1] R. E. Garfield et al., “Methods and devices for the management of term and preterm labor,” Ann. N. Y. Acad. Sci., vol. 943, pp. 203–224, 2001.

[2] S. Rihana and C. Marque, “Preterm labor-modeling he uterine electrical activity from cellular level to surface recording.” in IEEE EMBS Proc. Int. Conf, 2008, pp. 3726–3729

[3] D. Farina and A. Rainoldi, “Compensation of the effect of sub-cutaneous tissue layers on surface EMG : a simulation study,” Med. Eng. Phys., vol. 21, pp. 487–496, 1999.

[4] D. F. Stegeman, J. H. Blok, H. J. Hermens,, and K. Roeleveld, “Surface EMG models: properties and applications,” J Electromyogr Kines, vol. 10, pp. 313–326, 2000.