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Consistency of cutaneous electrical activity of the human colon with respect to serosal slow waves: A simulation study

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ABSTRACT

The serosal slow waves in the human colon are complex, since their amplitude and frequency vary over time. Therefore, this study employed a simulation to investigate the consistency between serosal slow waves and cutaneous electrical activity by evaluating whether changes of the cutaneous waveform features due to anatomical and physiological parameters are detectable in the cutaneous electrical activity. The simulation results indicated that (a) changes in the dipole moment involve detectable changes in the amplitude of the cutaneous electrical activity; (b) changes in the annular band velocity induce modifications in the cutaneous signal frequency; and (c) changes in the anatomical factors affect both the amplitude and the frequency of the cutaneous signal. Therefore, we observed that there is consistency between serosal slow waves and cutaneous electrical activity. On these bases, we think that modifications in the cutaneous electrical activity observed in our study could represent the marker of specific physiological motor activity of the colon, and such information can improve the recording of the experimental measurements of the cutaneous electrical activity of the colon in humans.

1. Introduction

In recent years, it has been reported that the pattern of the variations in the features present within bioelectrical signals has been associated with the function of the internal organs of the human body, since this pattern can frequently provide information regarding the signal source [1]. Such variations have to be picked up with surface electrodes to be considered useful, as this technique is not invasive and is well tolerated. Therefore, the acquisition and processing of bioelectrical signals recorded from the cutaneous surface is becoming a common tool for evaluating the health status of a patient. However, before using such measurements for diagnostic purposes, the likely value of the measurements must be assessed [2].

Typical applications of cutaneous recordings in clinical studies include, among others, the electrocardiogram (ECG), the electroencephalogram (EEG), and the electrogastrogram (EGG) [3].

To be utilized in the clinical field, dysfunctions of the gastrointestinal tract would first be recognized with implanted electrodes. Then, the usability of the cutaneous recordings would be confirmed by simultaneous recordings made with both techniques. Currently, this is not possible because of ethical issues. Therefore, computer modelling can be a valuable tool that replaces the need for expensive and sometimes very uncomfortable experiments. The literature on the modelling of the human stomach is extensive [4–17]. Fewer studies have been developed to simulate the electrical activity of the colon [18–23]. Generally, the models are divided into the following categories: relaxation oscillator models [4–5]; dipole-based models [6–10,18–21]; and volume conduction models [11–17]. The coupled relaxation oscillator models are very simple. They are able to reproduce the features of the gastric slow waves, but do not indicate the link with the underlying physiology and cannot simulate recordings from the abdominal surface. The dipole-based models consider anatomical and electrophysiological particularities of the organ. They are useful to simulate the serosal waveform of the slow waves [6,9,18,20] and of the burst activity (electrical response activity) [10,18], the effect of changes in the dipole moment value on the amplitude, and the effect of changes in the velocity of depolarization–polarization of cells on the frequency. In addition, they are used to simulate: (a) the cutaneous slow waves [10,19,21]; (b) the effects of the electrode positioning [10,19,21] and the inter-electrode distance [19,21] on the amplitude; and (c) the effect of increases in the distance between the electrodes and the field source [6,21]. They are simple and only a short time is required to execute the simulation programme. Volume conduction considers the effects of the biological tissue on the transmission of electric or magnetic fields from an electric primary

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current source towards measurement sensors. Volume conduction models focus on the description of the geometry and conductivity of tissue in which the current flows and on the description of the primary current source in the tissue. Volume conduction models are a basis for source analysis in electrocardiography, magnetocardiography, electroencephalography, and magnetoencephalography. The first volume conduction models relative to the EGG represent the abdomen with one or more cylinders and the stomach with a vertical axis [12–13]. Recent studies are developing models to simulate the magnetic signal and to integrate physiological and anatomical knowledge of the tissue structure at cellular level [14–17]. These models are very accurate and allow the organ shape to be represented in three dimensions. However, they are complex and a long time is required to execute the simulation programme.

Until now, no clinical application of the electrical signal of the human colon has been made to evaluate its health status, probably because previous experimental studies on serosal slow waves revealed that they are complex, that is, not regular in amplitude, frequency, and waveform [24–28]. A possible explanation for such complexity is related to modifications of the anatomical factors such as the geometrical size of haustra, which can induce changes in frequency and amplitude [20].

Therefore, the aim of this work was to use computer simulation to evaluate the consistency between serosal slow waves and cutaneous electrical activity by examining whether the changes of the features (waveform, amplitude, and frequency) due to physiological and anatomical parameters are recognizable in the cutaneous electrical activity.

2. Method

The model to simulate the generation of slow waves was based on the electric dipole [6–10,18–21]. The model took into account both the geometry of the ascending colon and the myoelectrical dynamics of the cells. Geometrically, the ascending colon was represented by a set of truncated ellipsoids in an orthogonal system of coordinates *Oxyz* (Fig. 1a). The electrical potential generated at a point P located in the vicinity of the ellipsoid set was calculated with the integral

$$\boldsymbol{V}(\mathbf{r}) = \frac{1}{4\pi\varepsilon}\iint_S \frac{\boldsymbol{\rho}\cdot\mathbf{D}}{\rho^3}dS \qquad (1)$$

where ε is the mean of the permittivity of the medium between the signal source and the electrodes, S is the area of the δ wide annular polarized band, dS is an infinitesimal area segment of the δ-wide annular band, $\mathbf{r}$ is the vector distance between a point P located anywhere in the space near the set of ellipsoids and the origin O of the coordinates system $Oxyz$, $\boldsymbol{\rho}$ is the vector distance between the point P and the infinitesimal area segment dS, and $\mathbf{D}$ is the vector dipole density of the annular band (Fig. 1a). The relationship between the vector of the dipole density $\mathbf{D}$ and the vector of the equivalent dipole moment $d\mathbf{p}$ has been described as $\mathbf{D} = d\mathbf{p}/dS$.

The abdominal surface is represented by means of a plane α (Fig. 1b). A plane β, parallel to the plane α, cuts the colon. The two planes were supposed to be separated by a dielectric of permittivity ε equal to 2.213545E−4 C^2/Nm^2, corresponding to the mean value of the abdominal layers (muscle, fat, and skin). As reported elsewhere [29], diagrams showing the permittivity values of many body tissues are presented. To simplify our modelling problem, the medium was considered as homogeneous. The assumption of homogeneity greatly simplifies the modelling problem [6–10]. As previously reported [8–10], the free space permittivity ε_0 is used.

The cutaneous electrical activity was simulated by calculating the temporal variation in the electrical potential difference

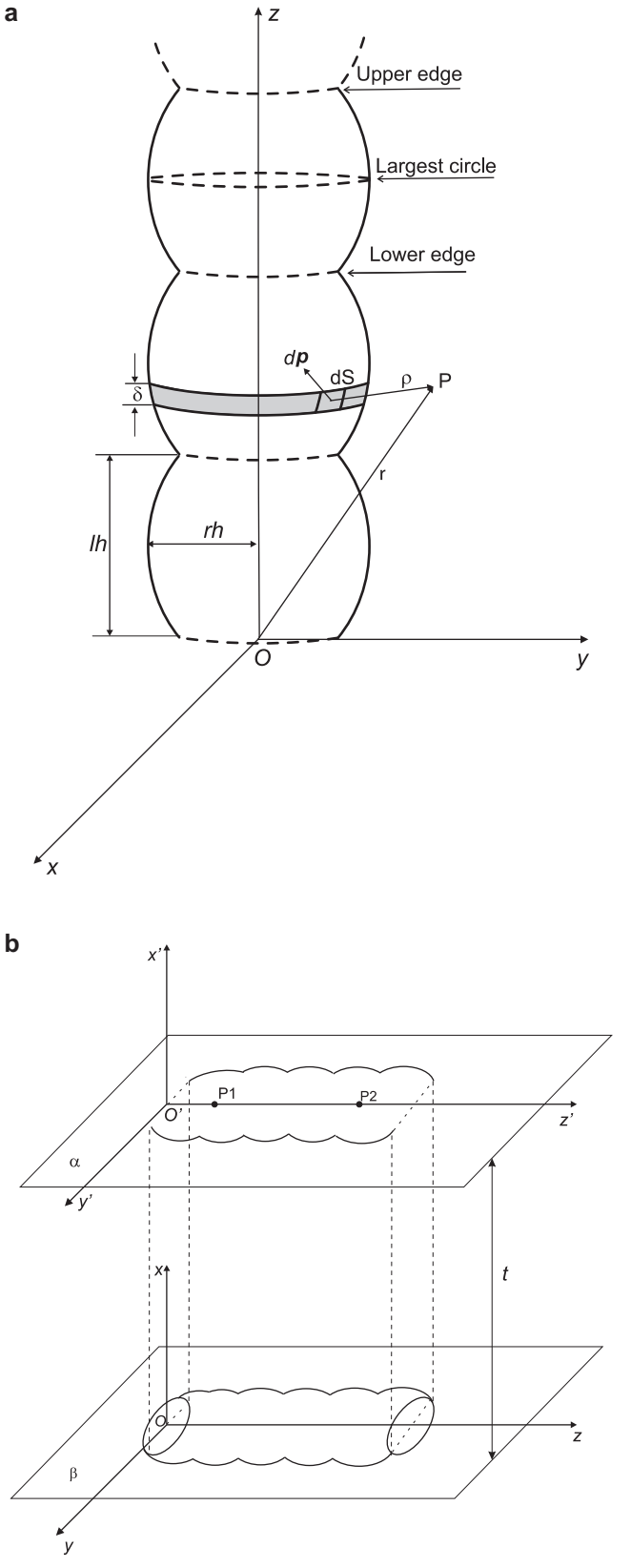

Fig. 1. (a) Schematic representation of the colon. The geometrical arrangement of the vectors $\boldsymbol{r}$, $\boldsymbol{R}$, $\boldsymbol{\rho}$, and $d\boldsymbol{p}$; the size of the ellipsoid length lh; the size of the radius of the largest circle of the ellipsoid rh; the size of the annular band δ; and the size of the infinitesimal area segment dS are highlighted. (b) Schematic representation of the colon on the abdominal surface. The projection of the colon axis and the points P1 and P2 where the electrodes were positioned are shown.

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