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TECHNICAL NOTE

A novel biomagnetic approach to study caecocolonic motility in humans

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Abstract *Motility patterns play a major role in human colonic functions; however, its physiological significance is poorly understood. Several studies have been introducing the Alternating Current Biosusceptometry (ACB) as a valuable tool in gastroenterology and pharmaceutical research. Using gold standard techniques, great effort has been made to validate ACB as a method for measuring gastrointestinal motility in humans and animals. The aim of this study was to evaluate caecocolonic motility and its response to a meal in healthy volunteers. The results showed a dominant frequency of 3.17 ± 0.13 cycles per minute (mean ± SD) that remained unchanged even after a standardized meal (P > 0.01). The colonic response to a meal was recorded as a considerable increase in amplitude, reflected by motility index (P < 0.01) and was observed for all the volunteers. The caecocolonic motility could be assessed by the ACB providing new insights into physiological patterns of motility. Moreover, the method is non-invasive, radiation-free, cost-effective and independent of bowel preparation.*

Keywords *Alternating Current Biosusceptometry, biomagnetism, colonic motility, feeding response.*

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INTRODUCTION

Biomagnetic methods are a relatively new non-invasive approach in clinical, physiological and pharmaceutical research. Magnetic fields in the gastrointestinal (GI) tract originate from smooth muscle electrical activity[1] or are a result of ingestion of magnetic material.[2]

Alternating Current Biosusceptometry (ACB) is an attractive tool to evaluate GI motility and employs induction coils for recording the magnetic flux variation obtained from the response of small amounts of ferrite ingested. This material has a high magnetic susceptibility that produces a strong response when an alternating magnetic field is applied.[3] A multisensor ACB was recently developed to image and characterize the performance of magnetic markers in humans.[4–7] Moreover, ACB showed accuracy in analysing orocaecal transit[8,9] and gastric activity in humans and dogs.[10,11]

Idiopathic constipation, functional diarrhoea and irritable bowel syndrome are highly prevalent disorders characterized by disturbed colonic motility.[12–14] Recently, colonic motility is poorly understood due mainly to the limitations of the available methods for this kind of analysis. Multisensor ACB system was proposed to investigate the motor patterns of colonic motility in humans.

In current clinical practice, radio-opaque markers and radionuclide scintigraphy assess colonic transit[15–18] and demand ionizing radiation. Colonic motor function is evaluated by manometry, but requires bowel preparation and presents difficulty in accessing the ascending colon.[19,20] A fluxgate magnetometer can also be employed to record colonic motility by exploring the field remaining after a magnetization of particles,[21] although it has short-time recordings, strongly dependent on relaxation of the magnetic particles.

As an alternative to conventional methods, the aim of this study was to employ the multisensor ACB as a non-invasive, harmless and cost-effective method to evaluate caecocolonic motility and its response to a meal.

MATERIAL AND METHODS

Fundamentals of AC Biosusceptometry

The AC Biosusceptometer consists of two pairs of coils separated by a fixed distance (baseline), where each pair is composed of an excitation coil (external) and a detection coil (internal), in a first-order gradiometric configuration working as a double magnetic flux transformer with an air nucleus (Fig. 1). The pair (excitation/detection), located more distant from the magnetic material (ferrite), acts as reference.[5]

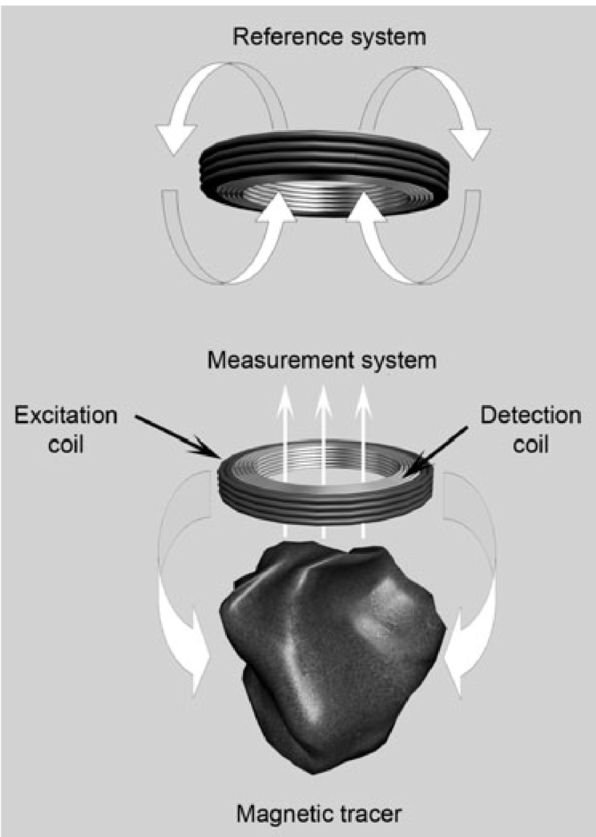

Figure 1 Illustration of the working principle of the AC Biosusceptometer. The proximity of a magnetic tracer to the measurement system causes imbalance in the magnetic flux. The response recorded depends on the strong variation of the signal obtained through the distance between the sensor and the material.

The amplitude of the magnetic signal increases with decreasing distance between the system and the ferrite within the organ. Thus, the magnetic flux recorded varies according to organ contraction activity, thus rendering the ACB system very sensitive to movements of the colonic wall.[11]

The multisensor ACB was developed with one pair of excitation coils ($\phi = 11$ cm) and seven pairs of detection coils ($\phi = 3.5$ cm), coaxially arranged. This biomagnetic system is mounted in an adjustable vertical support that allows the acquisition of magnetic signals continuously on the abdominal surface through lock-in amplifiers (Stanford Research Systems). The signals are digitized by an A/D board of 16 bits (PCI-MIO-16XE-10, National Instruments Inc., Austin, TX, USA) and stored in the computer for further analysis.[4–7]

In our previous studies for validation of the technique, magnetic data showed good agreement compared with standard methods.[9,10] Gastric activity contraction in dogs[11] and colonic motility in rabbits (unpublished data) were recorded simultaneously using manometry and ACB. Fig. 2 shows the correlation between magnetic and manometric signals characterizing the colonic activity in three anaesthetized rabbits under physiological conditions and after administration of cholinesterase inhibitors (prostigmine). The similarity in frequency of colonic activity (0.02 Hz) can be observed in the plots of the Fast Fourier Transform (FFT).

Study protocol

Ten healthy volunteers (aged 20–40 years, with body mass index of 20.5 ± 0.9 kg m^{-2}) participated in the study. None had alterations in the physical examination or reported GI diseases. Written informed consent of participation in the study was obtained according to the Declaration of Helsinki and with the approval of local Ethics Committee.

All the volunteers received a test meal composed of 90 g of yogurt (50 kcal; 7.0 g carbohydrate, 3.0 g protein and 0.5 g fat) mixed with 4.0 g of ferrite 12 h prior to biomagnetic measurements. At 10 AM, after an overnight fast, the multisensor ACB system was positioned in the region around McBurney's point (Fig. 3) with the subject in an upright position and the control measurement was acquired during 20 min.

After that, the volunteers ingested a standardized meal (bread, cheese and ham and 200 mL of a milkshake) with energy content of 820 kcal. The ingestion occurred in approximately 5 min, and the response measurement was recorded for at least 20 min.

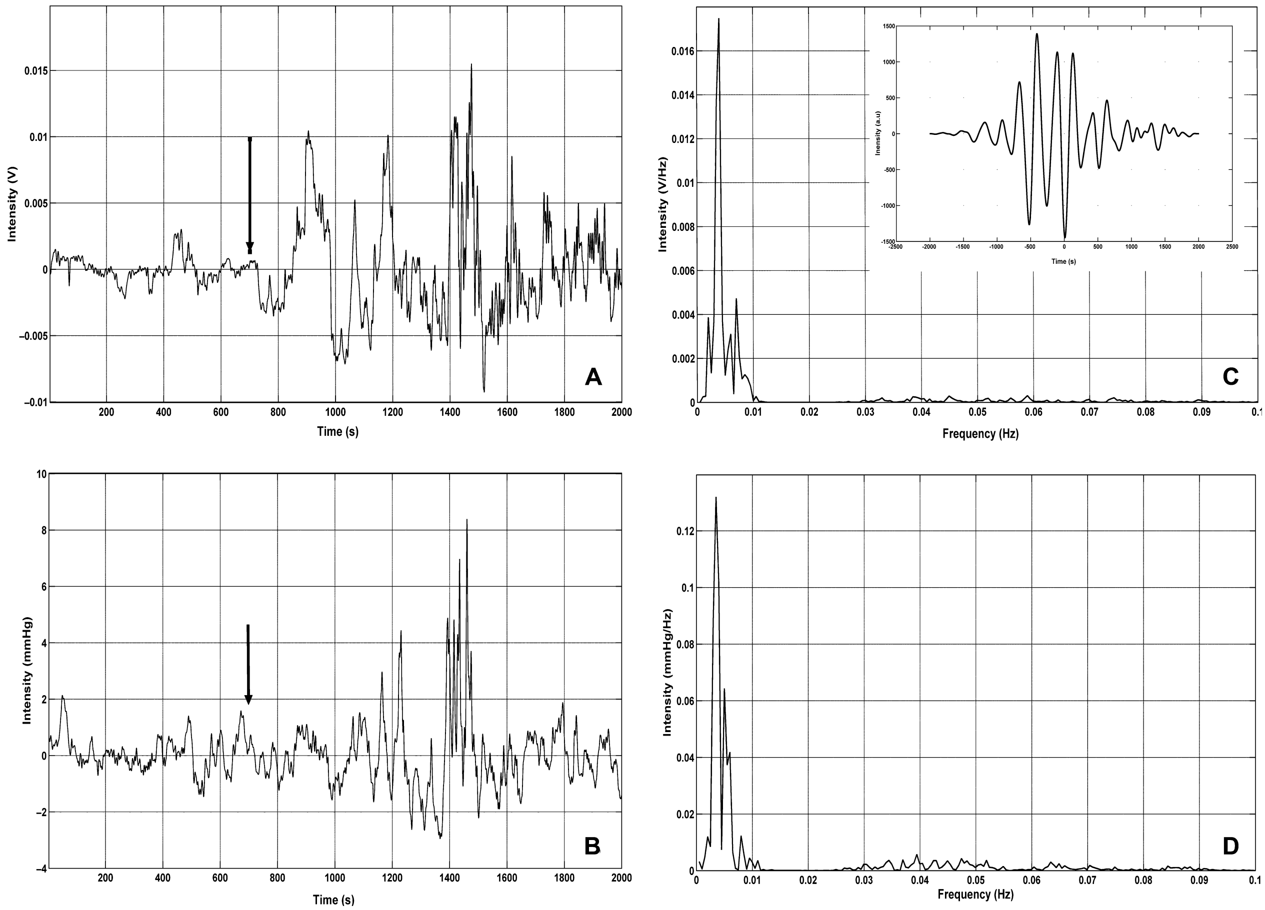

Figure 2 The tracings show colonic activity contraction in rabbits recorded by Alternating Current Biosusceptometry (A) and manometry (B). The arrows indicate the prostigmine administration with enhancement of amplitude. Spectral analysis shows a low frequency of contraction in magnetic (C) and manometric (D) signals. The inset illustrates the correlation between techniques.

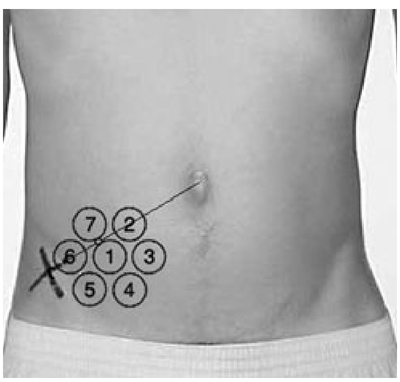

Figure 3 Multisensor Alternating Current Biosusceptometry system positioned on the abdominal surface around McBurney's point based on the external anatomical references.

Data analysis

Magnetic signals were sampled at 10 Hz/channel, stored in ASCII and analysed in MATLAB (Mathworks, Inc., Natick, MA, USA). The signals were filtered with cut-off frequency ranging from 0.01 to 0.2 Hz. Motility index (MI) was calculated before and after the standardized meal ingestion. Results are given as mean ± SD. Statistically significant differences were calculated using parametric tests (ANOVA, $P < 0.01$).

RESULTS

The dominant frequency of contractions recorded was 3.17 ± 0.13 and 3.15 ± 0.11 cycles per minute (cpm) in the fasting and fed states, respectively. No significant changes were observed in the fasting or in the postprandial frequency patterns ($P > 0.01$).

In six fasting volunteers, the magnetic tracings exhibited cyclic amplitude oscillations superimposed on the dominant frequency lasting 3.5 ± 1.0 min (Fig. 4A). In the other four volunteers only dominant frequency was observed. An example of a frequency

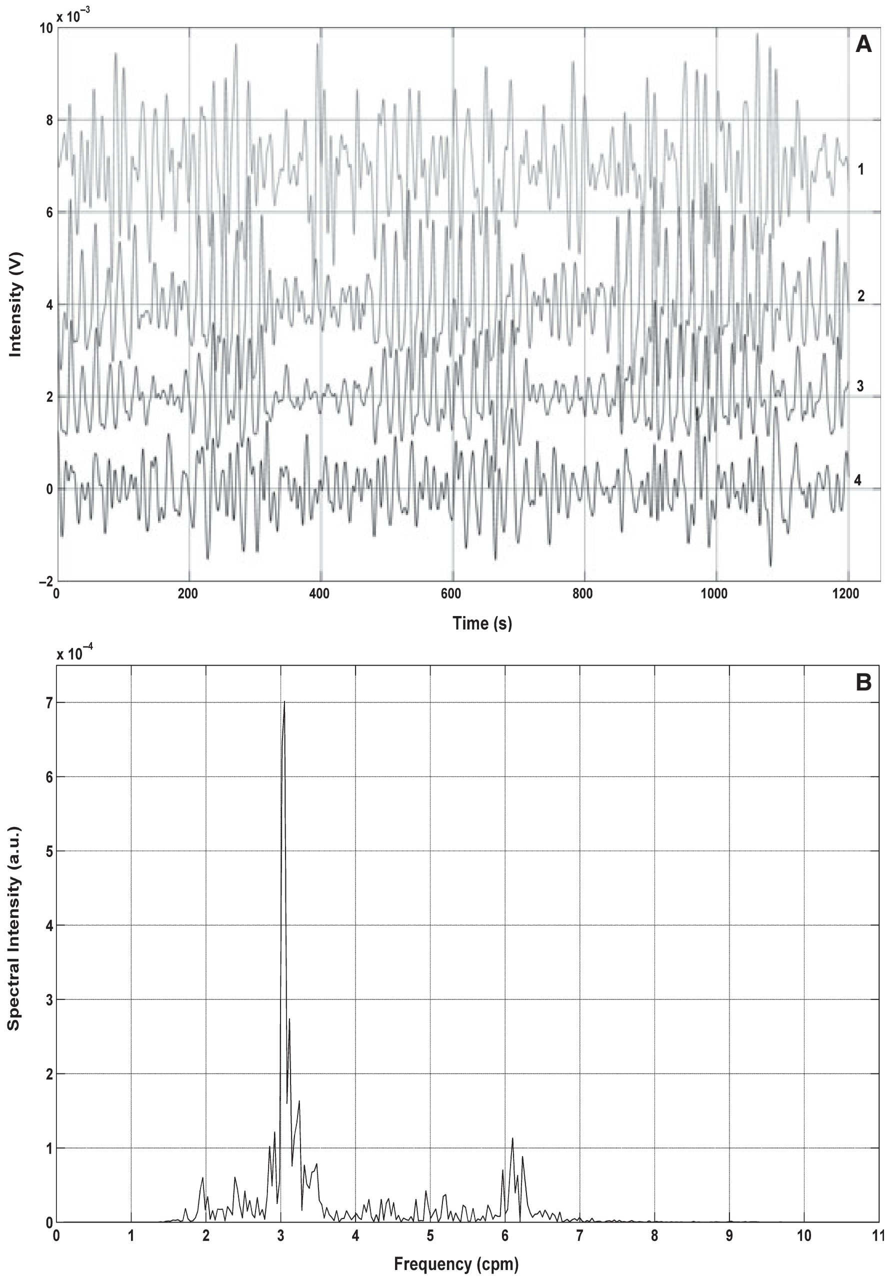

Figure 4 (A) Example of magnetic tracings for a fasting volunteer showing cyclic amplitude oscillations superimposed on the dominant frequency. (B) In Fast Fourier Transform (FFT) obtained from upper tracings (sensor 2) a single peak at 3 cpm was clearly observed.

spectrum using the FFT shows a single peak at 3 cpm (Fig. 4B).

Fig. 5 shows the magnetic data obtained before (Fig. 5A) and after (Fig. 5B) meal ingestion. Caecocolonic motor response to a meal was characterized by an enhancement of signal amplitude and was registered for all volunteers (Fig. 5B). Motility index values calculated before meal ingestion were 0.49 ± 0.35 and increased significantly after the meal reaching 1.04 ± 0.57 ($P < 0.01$).

DISCUSSION AND PERSPECTIVES

Human colonic motor activity is complex and poorly understood due to anatomic and physiological difficulties. Current methods employed have some technical

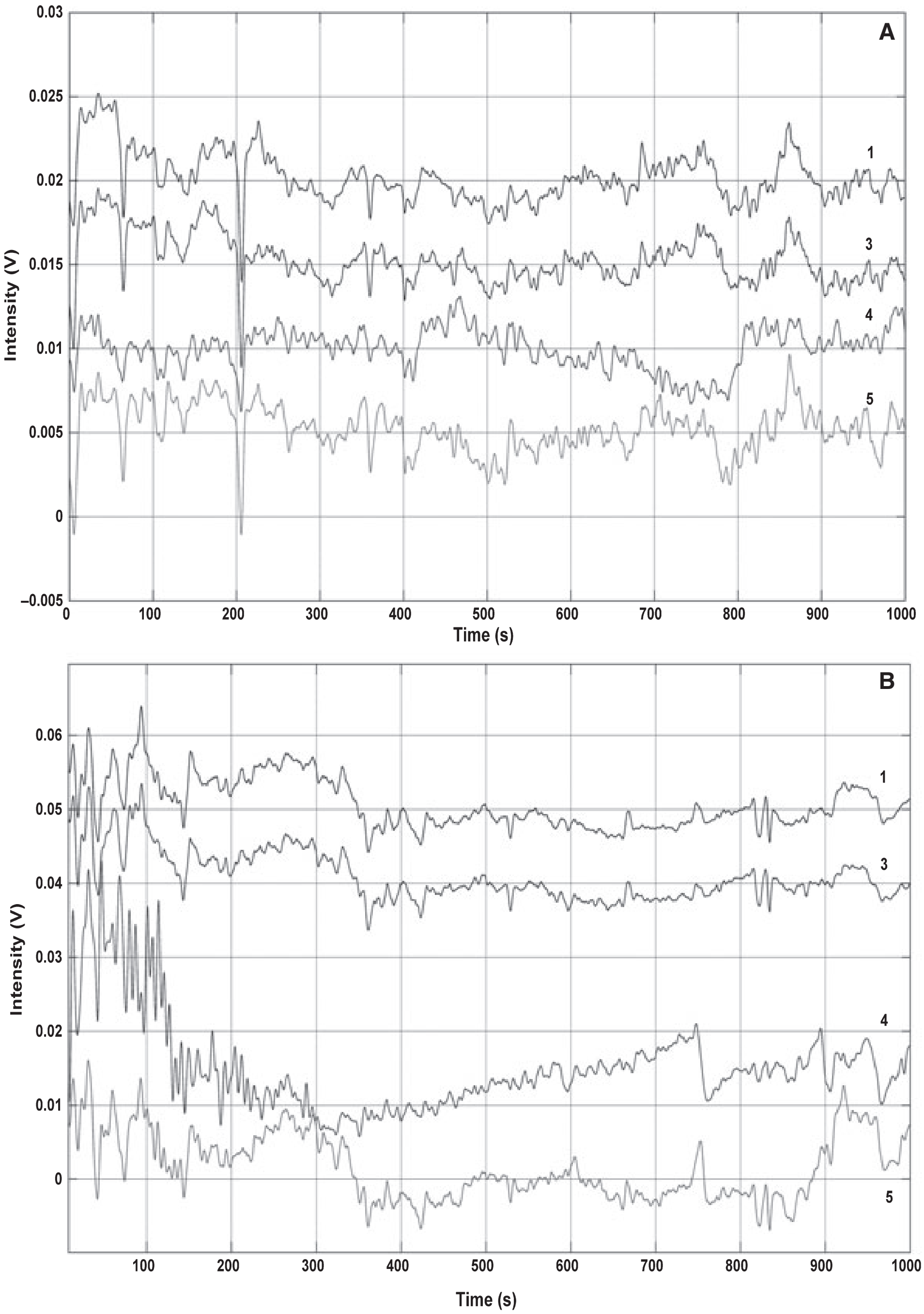

Figure 5 Magnetic tracings before (A) and immediately after (B) a standardized meal ingestion. Increase in signal amplitude characterized the caecocolonic motor response.

limitations, providing a controversial classification for the same event.[22,23] The improvement of these systems and the development of non-invasive techniques could contribute towards a better diagnosis of bowel disorders.

Previous studies validated the ACB for the investigation of colonic motor activity. In anaesthetized rabbits, colonic motility was simultaneously evaluated by ACB and manometry as a gold standard technique (Fig. 2). The data showed excellent correlation with increase in the signal amplitude observed after drug administration for both techniques.

However, in order to apply the ACB as a research tool it must be validated in healthy volunteers. Thus, GI transit and colonic motility in humans were evaluated after ingestion of a magnetic marker.[6] In this context, the ACB feasibly recorded caecocolonic motility under physiological conditions characterizing frequency of contractions and the response induced by a standardized meal.

In these studies, the recorded dominant frequency of contractions was around 3 cpm in all volunteers and there were no differences between the two prandial states (Fig. 4). On the other hand, the response to a meal was quantified by MI and characterized by significant amplitude increase in the magnetic tracings (Fig. 5).

Other methods used to study colonic motility have disadvantages-like radiation exposure and invasive intubation that may disturb normal physiology.[16,18,20] In this context, it is interesting to note that the ACB provides a non-invasive, low-cost and radiation-free technique to evaluate colonic motility accurately.

Further studies will be performed in order to characterize and compare the effects of different meal compositions on the caecocolonic motor response in healthy subjects and in patients with recognized colonic disorders. In conclusion, these results have significant implications for the use of ACB as an attractive research tool and in clinical practice.

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