Spatio-temporal maps of intestinal motor patterns

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Intestinal movements have been studied for well over a century with the first record of intraluminal pressure recorded by Legros and Onimus in 1869 using a rubber balloon in conscious animals. The birth of physiological traces, *i.e.* the recording of changes in any physiological parameter over time, is the hall mark of modern physiology and was due to the invention of the Kymograph by Carl Ludwig in the Department of Physiology in Leiptzig in 1847. The apparatus consisted in a smoked rotating drum and a writing lever that left a trace on the smoked surface. The lever could be connected to any moving tissue or organs thus recording changes of a particular parameter in time, as Legros and Onimus did.

This was the first time continuous changes in some phenomena could be plotted against time in a graphical way as a "physiological trace" replacing simple visual inspection or tabulations. As Helmholtz realized this would enable quantification of physiological phenomena and improve the reliability and ensure objectivity of the observations. Bayliss & Starling (1899) in their classic study developed the 'enterograph' to record motion of both intestinal muscle layers and recorded for the first time the mechanical changes of the muscle layers at one points during propulsion of a bolus by 'peristaltic movements'. Recording of force or movements of intestinal muscle in isolated preparations or *in vivo* progressed with the advent of the polygraph and more recently with computer based data acquisition systems. Recordings was limited to one or few points along the intestine and thus the full motions could not be recorded and quantified.

In parallel research into human motor activity relied mostly on intraluminal pressure recording (manometry). This method has been recently dramatically improved, by using multiple, close recording points along the intestine giving a much greater resolution of the spatio-temporal characteristic of intestinal pressures generated by the movements (Dinning *et al.*, 2010). The other fundamental line of recording physiological events was photography and cinematography, that ensured reliability of visual observations. Cannon was the first to record intestinal motility by X-rays at the turn of the 20th Century (Cannon 1896, 1902). However, despite of these methods of visual recording, researchers relied mostly on visual inspection to describe the patterns of motor activity (see Cannon, 1911). A few attempts to quantify changes in the geometry of the intestinal wall during movements were made manually.

While fluoroscopy has not been used for research in humans since realizing its danger, it has been successfully used in animals to describe motor patterns *in vivo* (see Ehrlein *et al.*, 1987) but quantification could only be done manually. The combination of video recording and computer software led a few laboratories in the late 90s to develop methods to record digitally movements of the intestine portraying changes in the geometry quantitatively along all points of an intestine segment (Hennig *et al.*, 1999). This was achieved by constructing spatio-temporal maps of the changes of diameter (Dmaps) or of longitudinal muscle (LMaps) in which the motor events are readily detected visually and any functional parameter quantifiable. This method has been used successfully to describe details of motor patterns in different species.

The combination of spatio-temporal mapping of diameters and intraluminal pressure was achieved and manually analysed only recently in isolated segments of rabbit intestine (Dinning *et al.*, 2011). We have developed further this combined method to extract mechanical states of the muscle that identify in the spatio-temporal maps active contractions and relaxations and distinguish whether motor activity is due to enteric neural circuits or to the spontaneous activity of the muscular apparatus. As these methods are applicable also to human intestine, they open the possibility to classify normal and abnormal patterns of motility based on mechanisms rather than pure description.

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