Quantitative analysis of peristaltic and segmental motilities in the rat GI tract with dynamic MRI and spatio-temporal maps

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Introduction. Gut motility plays an intrinsic role in mixing, transport and absorption of nutrients, particularly in the jejunum region of small intestine. Conventional methods of quantifying segmental and peristaltic motion in animal models are highly invasive, involving the external isolation of segments of the gastrointestinal (GI) tract either from dead or anesthetized animals. MRI has been used in humans for diagnosing early signs of Crohn's disease, quantifying peristaltic frequencies with and without drugs and acquiring functional information such as water flux and water content in the small intestine [1-5]. Few MRI studies have been carried out to study the small intestine of animal models, and none with quantitative analysis of segmental and peristaltic motions. The objective of the present study was to use MRI to analyze quantitatively motions in the jejunum of anesthetized rats non-invasively and compare results with previous invasive measurement techniques.

Materials and Methods. Dynamic images of the GI tract were acquired with a similar MRI protocol to that described in our previous studies [6]. Rats (n=6) were anesthetized using isoflurane anaesthesia, and given an oral gavage of Gd contrast agent. Data were acquired at a rate of six frames per second, registered to remove breathing artifacts, and segmented by 2D space + time image segmentation software developed in house. The medial axis was computed to derive $D(x,t)$ which represents the diameter along the medial axis (x) of every image in time (t) and produce iso-contour spatio-temporal plots of $D(x,t)$. Spatio-temporal maps of occlusion vs. space time can be derived by computing the values of minimum (D_{min}) and maximum (D_{max}) diameters at each point along x and scaling by a factor $(D(x, t)-D_{min})/(D_{max}-D_{min})$: this results in the minimum diameter appearing dark and maximum diameter appearing bright. A one dimensional signal which described the variation of the diameter as a function of time was obtained from a fixed location in x by computing the average diameter of the gut in the regions of constriction, and the characteristic frequency (F) of the constriction was computed using Fourier transformation.

Results and Discussion. Spatio-temporal maps acquired at different times during the experiment show clear distinctions between peristalsis and segmental motilities (Figure 1). Peristaltic motion is represented by a periodic train of propagating waves, with a single dominant frequency at 0.45 ± 0.01 Hz, and the propagating waves appear as dark diagonal streaks. Various physiological parameters can be derived from the spatio-temporal maps and are shown in Table 1. Results using an *in-vitro* Trendelburg method have reported that the frequency of peristalsis in the jejunum region of rat small intestine was 0.43-0.47 Hz [7-12], in good agreement with the in-vivo results presented here. The speed of propagation (4.34 ± 1.03 mm/s) of peristalsis wave as measured here by MRI lie within the range (2-5 mm/s) reported previously [13, 14] using invasive techniques. In contrast to peristalsis, segmental motility was characterized by a static standing wave pattern, with two frequency components at 0.28 ± 0.02 Hz and 0.45 ± 0.07 Hz: the stationary constrictions appear as dark vertical bands in the spatio-temporal map (Figure 1). The frequency peak at 0.28 ± 0.02 Hz was found to be dominant in all the animals and all the physiological parameters were derived using this frequency. Gwynne *et al.,* [15, 16] have shown that segmental contractions can be produced in *in-vitro* guinea pig models by infusion of fatty and amino acids. The MRI data shown in Table 1 gives a frequency in the jejunum which lies at the upper end of that reported by Gwynne *et al.,* (9.6 ± 6.0 cycles min^{-1}) but care should be taken in comparing the results from different animals under very different measuring conditions. From the data shown in Table 1, physiological parameters such as dominant segmental and peristaltic frequencies, average distance (4.56 ± 1.21 mm) between segmental constrictions which are not dependent on the location of the MRI slice were found to be statistically identical between animals at $p<0.05$. In all of the experiments, segmental motion was found to occur much more often than peristalsis, confirming the inhibitory role of isoflurane anaesthesia [17]. In three data sets, considerable periods of complete inactivity were recorded, lasting between 220 and 400 seconds.

Conclusion. This study represents the first quantitative analysis of motion of the GI tract *in-vivo* in animal models using MRI. In contrast to invasive procedures, MRI does not require extensive tissue preparation, and captures a much truer physiological state of the gut. Quantitative analysis of the data showed that both peristalsis and segmental motions are present in anesthetized animals, and could be readily identified by propagating and stationary type constrictions, respectively. Segmental motility was characterized by two dominant frequencies and peristaltic motility by a single dominant frequency. Results showed good agreement with parameters derived from previous invasive measurements.

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Table 1: Physiological parameters derived from spatio-temporal maps of peristalsis and segmental motion in n = 6 different rats. * represents significant inter-animal differences at p=0.05 level.

Parameters	Peristalsis (Mean ± SD)	Segmental (Mean ± SD)
Frequency (Hz)	0.45 ± 0.01	0.28 ± 0.02
Period (seconds)	2.18 ± 0.02	3.6 ± 0.25
Wavelength (mm)	9.4 ± 0.78	9.08 ± 2.74*
Maximum diameter (mm)	5.42 ± 0.53	4.6 ± 1.35*
Minimum diameter	1.45 ± 0.52	2.28 ± 0.8*
Amplitude (mm)	1.98 ± 0.33	1.16 ± 0.38*
Speed of collapse (mm/s)	0.91 ± 0.15	0.33 ± 0.1*
Propagation velocity (mm/s)	4.34 ± 0.35	N/A
Average distance between constrictions (mm)	N/A	4.56 ± 1.21
Inactive Period of the gut (s)	220 to 440	

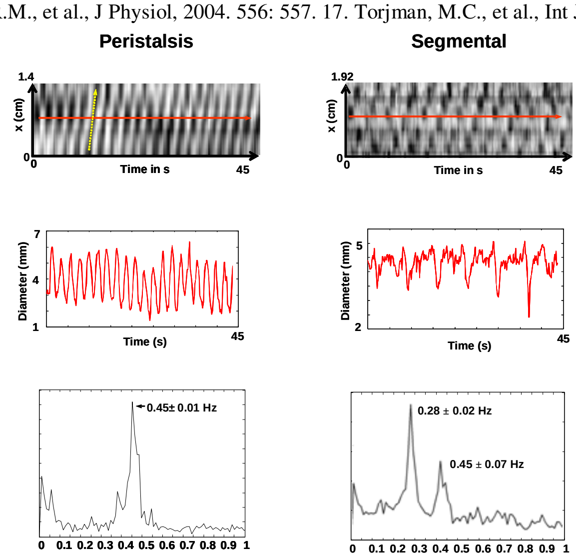

Figure 1: (top left) Spatio-temporal map of peristaltic motility, in which a single constriction travels along the length of the gut, represented by dark diagonal streaks. (mid left) A plot of diameter vs. time is derived from a fixed constricting location in x (solid red line) and its average frequency analysis resulted in a single frequency (bottom left). In contrast the spatio-temporal map of segmental motility (top right) shows stationary constrictions approximately at a fixed location (standing wave pattern) and is represented by short dark vertical bands. The average frequency analysis of the segmental motility resulted in two dominant peaks (bottom right).