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Semi-automatic Colonic Content Analysis for Diagnostic

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Abstract

The analysis of the morphology and content of the gut is necessary in order to understand metabolic and functional gut activity and for diagnostic purposes. Magnetic resonance imaging (MRI) has become an important modality technique since it is able to visualize soft tissues using no ionizing radiation, and hence removes the need for any contrast agents. In the last few years, MRI of gastrointestinal function has advanced substantially, although scarcely any publication has been devoted to the analysis of the colon content. This paper presents a semi-automatic segmentation tool for the quantitative assessment of the unprepared colon from MRI images. This application has allowed for the analysis of the colon content in various clinical experiments. The results of the assessment have contributed to a better understanding of the functionality of the colon under different diet conditions. The last experiment carried out by medical doctors showed a marked influence of diet on colonic content, accounting for about 30% of the volume variations.

Categories and Subject Descriptors (according to ACM CCS): I.3.8 [Computer Graphics]: Applications—

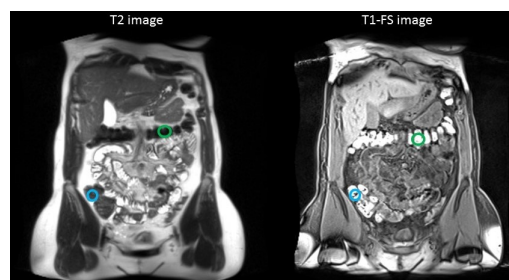
1. Introduction

Colonic content analysis is fundamental for the diagnose of several digestive dysfunctions as well as to better understand the colon behavior under different diet conditions [BMM*16]. Traditionally, Computer Tomography (CT) imaging has been the standard method for addressing this analysis [APA*09, MMPN*13]. Unfortunately, the radiation limits its application, and new, less aggressive techniques are desirable. Magnetic resonance imaging (MRI) has become an important technique since it is able to visualize soft tissues [CVC*95] using no ionizing radiation, and hence removes the need for any contrast agents. MRI acquisition techniques allow the modification of the signal emitted in order to acquire different tissues presented in the body. The MRI sequences commonly used for the analysis of the colonic content are T2-weighted (T2) and T1-weighted Fat-Sat (T1-FS). However, those techniques, by themselves, do not allow for a proper classification of the colonic content. In T2 images, the colon morphology is well-defined due to the presence of fat around the colon; but the intensity of the interior pixels does not identify the colonic content (for instance, black pixels could be gas or solid matter, see Figure 1). On the other hand, in T1-FS modality solid is well-defined but gas and fat are poorly contrasted, so the colon morphology can not be identified with high precision. In this paper we have addressed this issue by providing a

set of tools that facilitate the analysis of the colon. The techniques we have developed are:

- An interactive semi-automatic colon segmentation tool from T2 images.
- An automatic registration method that transfers the colon segmentation from T2 images to T1-FS images.
- An automatic classification method of the colonic content from T1-FS images in order to obtain the amount of solid content.

Figure 1: Differences between T1-FS and T2 MRI modalities for the same abdomen region. Black pixels in T2 (left) may correspond to gas (blue circle) or stool (green circle) in T1-FS (right).



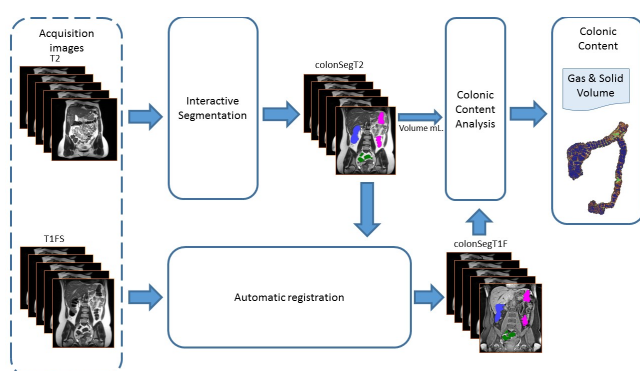
Pritchard *et al.* [PMG*14] obtained a 3D reconstruction of the colon by 2D manual segmentation using the Analyze9TM software. From the 3D reconstruction they calculate the volume of each region of the colon. As they said, the identification of the colon is a

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very time-consuming task, so its use is costly and thus not suitable for the clinical practice. Sandberg *et al.* [SNP*15], on the contrary, developed a semi-automatic segmentation method for the quantification of the colon content from a manual segmentation over the T2-weighted images. From the segmentation of the colon on T2-weighted images, the software obtains, automatically, the segmentation of the colon on LAVA-Flex images using a rigid registration process. After that, the segmentation of the faecal content within the colon is performed using a classification step. Our proposal has a similar workflow than that of Sandberg *et al.*. However, we use completely different techniques in each step.

2. Materials and Methods

Figure 2: Workflow of the system: colon content is achieved using T2 to identify the morphology and T1-FS to establish its content.



The architecture of the application is shown in Figure 2. To begin with, the patient is scanned twice, first in T1-FS modality, and later in T2. These two sequences form our input dataset. The application eases the segmentation process for the medical doctor, using the following steps: First, an anisotropic contrast enhancement filter is applied to the images to enhance the colon boundary without losing details in the interior. Then, the user manually places some seed points on each image. The expansion of these seed points depends on the grey-level mapping defined by the window-level setting of the images. This process may need some user intervention in regions where the colon contour is not well defined because of surrounding tissues having the same grey-level intensity. We carefully designed the interaction to reduce user effort (i.e., mouse displacements) and time consumed. The colon segmentation takes around 20 minutes to complete, which is between 4 and 6 times faster than with regular segmentation techniques.

Solid content is identified using T1-FS images. So that, in order to obtain a good baseline of the solid content that a human-eye is able to classify, we asked medical doctors to manually segment a set of different T1-FS image sequences. The comparison between the obtained results and the expected amount of solid content inside the colon based on the analysis of CT images revealed the uncertainty presented in MRI images. Medical doctors were able to identify $73.47 \pm 16.2\%$ of solid volume inside the colon with respect to the total colon volume; and Bendezú *et al* [BBB*16a] stated that the expected solid volume is 90% with respect to the total colon volume. These results led us to develop a more accurate method

for the computation of the colon content. Moreover, manual procedures cost from 1 to 2.5 hours for an experimented user.

We reduce this manual process by using the previously segmented T2 images. First, an automatic registration using the ANTs software package [ATS*11] registers the T2 images to the T1-FS set using a deformable transformation. Once the identification of the colon in T1-FS has been computed, and optionally interactively corrected, the system calculates automatically the solid content on it. This process consists of classifying the pixel intensities according to the percentage of solid content they represent. We established three categories: *Non-Solid* (0% solid), *Uncertain-Solid* (the percentage of solid is defined computationally) and *Solid* (100% solid). The classification of the intensities pixels is based on the k-means clustering algorithm. We use this algorithm to define the upper bounds of the three categories. Once the range of pixel intensities belonging to the *Uncertain-Solid* category has been established, the amount of solid that each pixel intensity represents is determined by using a piecewise linear function defined by the upper-bound values of the different clusterings used to determine the three categories.

3. Results

The evaluation of the system was carried out by different experiments that evaluate each step in an isolated way. First of all, the *inter-observer agreement* was evaluated by two observers. The reproducibility of the measurements was analyzed using Bland Altman plots which yielded similar results for the total colon. In order to evaluate the accuracy of the identification of the colon content, different experiments have been carried out. First of all, we compared the manual segmentation on T1-FS with respect to the automatic segmentation. Since the manual segmentation does not contain all of the solid content, we decided to compare the manual segmentation with just the *Solid* category. The results we obtained were very satisfactory in terms of the correspondence between them: $86.14 \pm 6.5\%$ of the volume of the manual segmentation belongs to the *Solid* category. Moreover, we designed other experiment in order to validate the accuracy achieved when computing the solid volume, by comparing it to the real faecal measured volume (image sequences before and after defecation were compared). The results were very satisfactory. In the *before* sequence, the total colon volume is 848.97 ± 148.43 mL., the solid volume is 769.64 ± 143.41 mL., and the amount of solid content is $90 \pm 4.47\%$ of the total volume. In the *after* sequence, the total colon volume is 690 ± 158.16 mL., the solid volume is 630.34 ± 146.84 mL., and the amount of solid content is $91.52 \pm 6.49\%$ of the total volume. Analysing the difference between the two acquisitions, the computed solid volume is 139.29 ± 106.48 mL. which agree with the real solid volume defecated (136.27 ± 78 mL.). The results obtained are accurate within the required precision by the medical doctors.

4. Conclusions and Future Work

This paper presents a semi-automatic segmentation tool for the quantitative assessment of the unprepared colon from MRI images. The application is currently being used by physicians in all experimental studies where MRI is required [BMM*16, BBB*16b].

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