# Extraction and processing of videocapsule data to detect and measure the presence of villous atrophy in celiac disease patients

Edward J. Ciaccio [a,*], Govind Bhagat [a,b], Suzanne K. Lewis [a], Peter H. Green [a]

[a] Celiac Disease Center, Department of Medicine, Columbia University Medical Center, New York, United States
[b] Department of Pathology and Cell Biology, Columbia University Medical Center, New York, United States

A B S T R A C T

Background: Videocapsule endoscopy is a relative new method to analyze the gastrointestinal tract for the presence of pathologic features. It is of relevance to detect villous atrophy in the small bowel, which is a defining symptom of celiac disease.
Method: In this tutorial, methods to extract and process videocapsule endoscopy data are elucidated. The algorithms, computer code, and paradigms to analyze image series are described in detail. The topics covered include extraction of data, analysis of texture, eigenanalysis, spectral analysis, three-dimensional projection, and estimation of motility. The basic paradigms to implement these processes are provided.
Results: Examples of successful quantitative analysis implementations for selected untreated celiac disease patients with villous atrophy versus control patients with normal villi were illustrated. Based on the implementations, it was evident that celiac patients tended to have a rougher small intestinal texture as compared with control patients. From three-dimensional projection, celiac patients exhibited larger surface protrusions emanating from the small intestinal mucosa, which may represent clumps of atrophied villi. The periodicity of small intestinal contractions tends to be slower when villous atrophy is present, and the estimated degree of motility is reduced as compared with control image series. Basis image construction suggested that fissuring and mottling of the mucosal surface is predominant in untreated celiac patients, and mostly absent in controls.
Conclusions: Implementation of computerized methods, as described in this tutorial, will likely be useful for the automated detection and measurement of villous atrophy, and to map its extent along the small intestine of celiac patients.

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## 1. Introduction

Celiac disease is a major health issue in many parts of the world, but it is unknown to many and often remains undiagnosed [1]. Yet, left untreated, the disease can cause many harmful effects, including damage to the nervous system and cancer [2]. The disease is caused by reactivity to gluten, a protein found in wheat, rye, and barley grains, and similar protein components [3]. There is only one effective treatment thus far developed – abstinence from consuming gluten and its components. Yet, most persons do not maintain the diet unless diagnosed as having the disease. Diagnosis of celiac disease is difficult owing to the presence of occult symptoms [4]. A defining manifestation is the presence of villous atrophy in the small intestine, which can be detected in biopsy specimens acquired during standard endoscopy using light microscopy. However, the presence of villous atrophy in the small intestinal mucosa is often patchy and subtle [5]. It is not so readily evident by visual observation based on the endoscopic imaging technology that is readily available at the present time. Thus, the need for a computerized means for detection of villous atrophy.

If villous atrophy could be detected based on computerized analysis of endoscopic images, it would go a long way toward improving success in diagnosing the disease in many more patients. Yet, with standard endoscopy, distal regions of the small intestine, in the jejunum and ileum, where villous atrophy is sometimes present, cannot be analyzed due to the limited locational ability of the technique. More recently, videocapsule endoscopy has been introduced to enable the observation of the entire small intestine for presence of pathologic features [6–8]. Videocapsule endoscopy consists of a small swallowable capsule with camera and light source that acquires high-resolution images from the small intestine at periodic intervals. The imaging data is transferred via radio link to a receiver console for subsequent analysis. Although the videocapsule images are currently acquired at a rate of approximately 2 frames per second and a resolution of

576 × 576 pixels, this temporal and spatial resolution is not wholly adequate to observationally determine the structure of the small intestinal villi and their status as being either normal or atrophied. If computerized methods could be implemented for quantitative analysis, it would be useful for improved efficacy to detect and measure the presence of villous atrophy all along the small intestinal tract [7]. Such information might possibly reduce the need for standard endoscopy and intestinal biopsy, thus decreasing invasiveness, and likely decreasing procedural cost as well.

In prior work, the extraction and quantification of videocapsule endoscopy data was studied for the analysis of untreated celiac patients with villous atrophy versus control patients with normal villi [7,9–13]. The purpose of this tutorial is to show methods of implementation in terms of the algorithms, flow of computer code, and paradigms for successful analysis. Herein, techniques that have been noted to be useful for detection of villous atrophy in celiac disease patients will be defined and described in detail, so that they can be readily implemented on any computer system for analysis of videocapsule data.

## 2. Method

In this section, the clinical methods, the videocapsule device specifications, the implementation of algorithms for videocapsule data analysis, and the presentation of relevant paradigms for computer code will be described and discussed. Implementation of the computer code provided enables the rapid analysis of data on PC-type computers.

### 2.1. Clinical methods

Retrospective use of videocapsule endoscopic data was approved by the Internal Review Board of Columbia University Medical Center. Adult patients that were referred for videocapsule analysis included both confirmed celiac disease patients and controls. Only in the celiac patients was villous atrophy present in the small intestinal mucosa. Based on a prior analysis of small intestinal biopsies obtained by standard endoscopy and imaged under light microscopy, the severity of villous atrophy in the celiac patients ranged from Marsh Score II–IIIc. Control patients with either obscure bleeding or suspected Crohn's disease were used for quantitative comparison. Both male and female patients were included for analysis.

### 2.2. Description of the videocapsule

The videocapsule device used for imaging was the Pillcam SB2 (Given Imaging, Ltd, Yoqneam, Israel). The plastic capsule size is 11 × 26 mm, the weight is 2.8 g, the videocamera field of view is 156°, and it acquires 2 images per second [14]. The battery life is 8 h, with an image resolution of 576 × 576 pixels. The capsule is disposable. It consists of an imaging device, a compact lens, a white light emitting diode which acts to illuminate the gastro-intestinal mucosa, and an internal battery. The entire wireless capsule system consists of a videocapsule endoscope, a sensing and recording system which is attached via a belt to the patient, and a computer console with proprietary software (RAPID v6.5, Given Imaging). After fast, the patient swallows the capsule with water, and can then undergo normal daily activity. Data transmission is via ultra-high frequency radio band telemetry. Once the data stream is downloaded, representative images and videoclips can be annotated and stored to PC hard drive or removable media. Contraindications for this procedure include known or suspected gastrointestinal obstruction, presence of a cardiac pacemaker or implantable cardioverter defibrillator, swallowing disorder, and
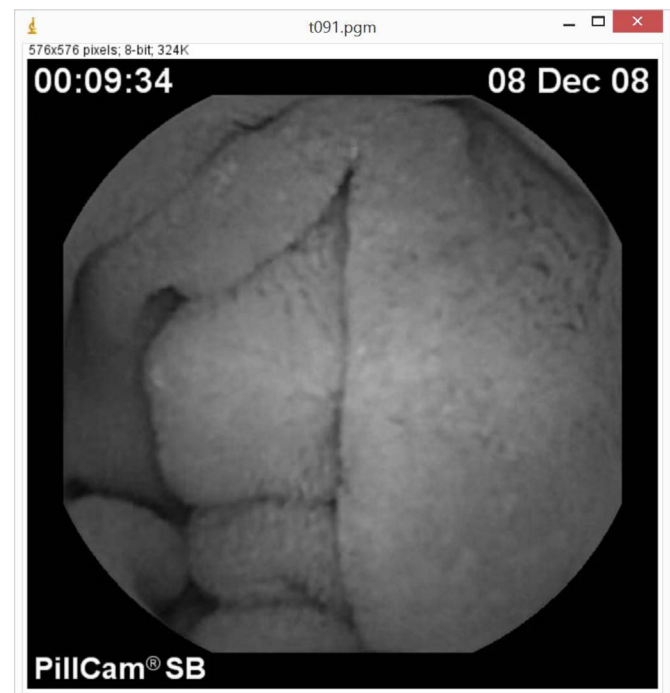

Fig. 1. Celiac disease endoscopic image used to show data format in the PGM file.

pregnancy of the female patient.

### 2.3. PGM image format specification

Once the imaging data is downloaded, although videocapsule images are initially stored as tricolor data, for simplicity, reduced storage requirement, and ease of use, the information is first transformed to grayscale level. The Portable Gray Map specification (PGM or pgm) is a straightforward method for encoding grayscale images that is used for this purpose. The format of PGM images is comprised of several components, which are described in detail in the Appendix, Part A. The graylevel is embedded in the file data for a total of 576 × 576 pixels, and therefore 576 × 576 grayscale values, i.e., 331,776 pixels in all. In Fig. 1, this data is displayed using the ImageJ program [15]. Depicted is an image of the small intestinal mucosa from a control patient. At the top left of the image, the ImageJ program displays the spatial resolution (576 × 576 pixels), grayscale level (8 bit or 256 levels), and the rounded total number of pixels contained in the image. Additional information that is embedded in the image is also shown – the date that the image was acquired, patient code, and imaging model (Pillcam SB). The borders are black by default in the Pillcam system. The image itself only consists of the portion within the black borders. ImageJ, as a program that can display PGM images, provides the information about the image resolution at top and displays with white borders.

### 2.4. Extraction of imaging data

To obtain PGM images for analysis, the computer program in the Appendix, Section B, can be used. The program plays a color mpeg videoclip, and then stores the individual frames as 256-level grayscale PGM images in ASCII. The reading of videoclips that are made in other formats, and the writing of the separate images to other formats or to a binary file, can be readily done by changing a few of the parameters. The play speed for the movie, 2 per second for the Given Imaging system application, can be altered via the last parameter in the movie function, and can be used to slow