Identification of intestinal wall abnormalities and ischemia by modeling spatial uncertainty in computed tomography imaging findings

Taichiro Tsunoyama[a], Tuan D. Pham[b],*, Takashi Fujita[a], Tetsuya Sakamoto[a]

[a] *School of Medicine, Department of Emergency Medicine, Trauma and Resuscitation Center, Teikyo University, Tokyo 173-8606, Japan*
[b] *Aizu Research Cluster for Medical Engineering and Informatics, Research Center for Advanced Information Science and Technology, The University of Aizu, Aizu-Wakamatsu, Fukushima 965-8580, Japan*

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ABSTRACT

Intestinal abnormalities and ischemia are medical conditions in which inflammation and injury of the intestine are caused by inadequate blood supply. Acute ischemia of the small bowel can be life-threatening. Computed tomography (CT) is currently a gold standard for the diagnosis of acute intestinal ischemia in the emergency department. However, the assessment of the diagnostic performance of CT findings in the detection of intestinal abnormalities and ischemia has been a difficult task for both radiologists and surgeons. Little effort has been found in developing computerized systems for the automated identification of these types of complex gastrointestinal disorders. In this paper, a geostatistical mapping of spatial uncertainty in CT scans is introduced for medical image feature extraction, which can be effectively applied for diagnostic detection of intestinal abnormalities and ischemia from control patterns. Experimental results obtained from the analysis of clinical data suggest the usefulness of the proposed uncertainty mapping model.

1. Introduction

Intestinal abnormalities and ischemia are medical conditions of a restriction in blood supply to the bowel, blocking oxygen and glucose needed for cellular metabolism to keep tissues alive. There are many types of bowel disorders and such conditions are not only uncomfortable, but can also lead to further health complications when left untreated. Intestinal ischemia can either affect the small or large (colon) intestine, or even both. As a consequence, intestinal ischemia caused by the inadequate blood flow can result in pain and can permanently damage the intestine. Sudden loss of blood flow to the intestine can cause acute intestinal ischemia that is a medical emergency, life-threatening, and requires immediate surgery. Intestinal ischemia that develops over time (chronic) requires treatment because it can become acute, or lead to severe weight loss and malnutrition [1–3]. Typical symptoms of acute intestinal ischemia are sudden abdominal pain, forceful bowel movements, swollen abdomen, nausea or vomiting or both, and fever. Intestinal ischemia can be divided into two categories: colon ischemia (ischemic colitis) and acute

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* *Corresponding author.* Tel.: +81 242 37 2568.
E-mail addresses: taichirotsunoyama@yahoo.co.jp (T. Tsunoyama), tdpham@u-aizu.ac.jp (T.D. Pham), foujitausc@hotmail.com (T. Fujita), sakamoto.tetsuya@nifty.ne.jp (T. Sakamoto) .

mesenteric ischemia [3]. Colon ischemia occurs when blood supply to the colon is inadequate and this is the most common type of intestinal ischemia. Colon ischemia usually affects adults over the age of 60 years old, but may occur at any age. Acute mesenteric ischemia affects the small intestine. Acute mesenteric ischemia occurs abruptly and blood clot is its most common cause that can result from congestive heart failure, irregular heartbeats, or a heart attack [3].

Several different invasive methods are used to detect abnormalities of the small intestine. A tissue specimen can be obtained by using an endoscope (a flexible viewing tube), or by using a thin tube with a small cutting instrument at the end; while several similar types of capsules are used for tissue collection [4–6]. Abdominal CT scanning is the current gold standard for the non-invasive clinical assessment of intestinal abnormalities and ischemia in emergency care. This imaging method uses X-rays to obtain the visual information of the cross-sectional (axial) areas of the part of the body between the thorax and the pelvis. Given the increasing use of CT as a screening technique for patients because of the growing confidence in this imaging technology; in many cases, surgeons are confused with the differential diagnosis of small-bowel abnormalities and ischemia on CT scans [7]. In fact, medical experts not only find it difficult to visually detect abnormalities based on CT findings of the bowels, it is still a challenge for surgeons to evaluate the similarities and differences in the CT appearances between healthy subjects and patients in other complex disorders such as pulmonary disease, which needs the incorporation of computer methods to provide pattern-recognition approaches to enhance the interpretation of imaging findings [8–10]. In general, the radiological findings of mesenteric ischemia have different course in case of different etiology. In particular, bowel wall thinning is typical but difficult to recognize so diagnosis may be hard. The prompt recognition of each condition is essential to ensure a successful treatment [11]. Therefore, the reliable detection of intestinal abnormalities and ischemia on CT findings is important for surgical decision making.

Most computer-aided methods for the analysis of medical images involve segmentation, registration, and feature extraction. To be effective, these computer tools need to meet the clinical relevance as well as the methodological feasibility with respect to image processing, data analysis, and pattern recognition to solve real-world medical problems. For the study of medical imaging, there are various imaging modalities, such as PET, MRI, CT and X-ray, which can belong to either structural or functional imaging, depending on the type of information provided by the image. Given that radiologists are trained in producing medical images, these experts but do not always have the background in the relevant area of medicine to interpret the images with confidence [12]. As advanced diagnostic imaging is rapidly pervading into therapeutic medicine, so there is an urgent need for hospitals and medical institutions world-wide to have possibilities to perform examinations with the aide of computerized pattern recognition technology. Such a computer-aided tool should have the capacity to automatically identify normal anatomical and physiological appearances on an image and the variations of these appearances, which may be identified as indicators of pathology [13].

Medical images are intrinsically characterized with structures of spatial patterns with respect to the size, shape, and arrangement of their components. These sub-image structures are often visual features of surfaces, whose properties can be appropriately described by spatial statistics. For automated pattern classification of medical images, advanced methods for feature extraction are important because they help select concise and discriminative properties of raw-image objects while eliminate redundancy existing in a large amount of information contained in the image [14,15]. This feature extraction process is usually specific for a certain type of disease and is derived from the findings obtained by medical experts [16]. Based on the extracted features, classifiers or machine-learning algorithms can be trained with these samples to carry out the diagnostic identification of unknown objects in terms of specificity and sensitivity. This study is also concerned with the extraction of an effective feature of medical images, representing its texture. This is because the definition of texture mostly fits well into the description of appearances of medical images, which can be used to distinguish complex diseased from normal patterns. In fact, texture analysis is very helpful for the classification of different regions of interest in medical images. It is an increasingly on-going field of research which reports applications ranging from the extraction of anatomical structures and lesions to the recognition of pathological tissues from healthy ones in different organs [17–19].

Based on the motivation of developing an effective algorithm for the detection of intestinal abnormalities and ischemia, a new application of a geostatistical mapping of spatial uncertainty in images for automated pattern identification of the intestinal disorders is introduced herein. The rest of this paper is organized as follows. Section 2 presents the material and methods. Section 3 presents results together with discussions. Finally, Section 4 is the conclusion of the findings.

2. Materials and methods

2.1. CT scans and diagnostic features

CT scans were obtained from patients who had surgery because of the peritonitis with the suspicion of the bowel ischemia except for one control patient who was admitted in our unit for other reason. The patients were diagnosed by physical examination, blood tests and CT scans. Important physical findings of peritonitis were the muscular defense and rebound tenderness. The lactic acidosis elevation suggested the bowel ischemia in the blood test. If the renal function of the patient was normal, intravenous contrast (IV) was used to enhance the CT. The CT finding was read by the attending radiologist. The CT patterns of the black and gray attenuation in the intestine were indicators of bowel ischemia. After the diagnosis of peritonitis with bowel ischemia, the emergency surgery was carried out. If the bowel was necrotic (of dead body tissue), it was resected.

Eleven subjects were included in this study: eight patients of ischemia, one benign and two control subjects. Four ischemic patients had surgery. The ischemic bowels were