computer methods and programs in biomedicine 113 (2014) 153–161

journal homepage: www.intl.elsevierhealth.com/journals/cmpb

Personalized identification of abdominal wall hernia meshes on computed tomography

Tuan D. Pham[a,*], *Dinh T.P. Le*[b], *Jinwei Xu*[c], *Duc T. Nguyen*[d], *Robert G. Martindale*[b], *Clifford W. Deveney*[b]

[a] *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*
[b] *Division of General Surgery, Oregon Health and Science University, Portland, OR 97239-3098, USA*
[c] *School of Engineering and Information Technology, The University of New South Wales, Canberra, ACT 2600, Australia*
[d] *Multidisciplinary Parallel-Vector Computing Center, Department of Civil and Environmental Engineering, Old Dominion University, Norfolk, VA 23529-0241, USA*

ARTICLE INFO

Article history:
Received 5 June 2012
Received in revised form
5 September 2013
Accepted 23 September 2013

Keywords:
Abdominal wall hernia mesh
Computed tomography
Pattern classification
Geostatistical entropy
Co-occurrence matrix
Information fusion

ABSTRACT

An abdominal wall hernia is a protrusion of the intestine through an opening or area of weakness in the abdominal wall. Correct pre-operative identification of abdominal wall hernia meshes could help surgeons adjust the surgical plan to meet the expected difficulty and morbidity of operating through or removing the previous mesh. First, we present herein for the first time the application of image analysis for automated identification of hernia meshes. Second, we discuss the novel development of a new entropy-based image texture feature using geostatistics and indicator kriging. Third, we seek to enhance the hernia mesh identification by combining the new texture feature with the gray-level co-occurrence matrix feature of the image. The two features can characterize complementary information of anatomic details of the abdominal hernia wall and its mesh on computed tomography. Experimental results have demonstrated the effectiveness of the proposed study. The new computational tool has potential for personalized mesh identification which can assist surgeons in the diagnosis and repair of complex abdominal wall hernias.

1. Introduction

It has been estimated that 250,000 ventral hernia repairs are being done in the USA yearly. It was reported that the world mortality statistics of ventral hernia ranks first in the USA and eighth in Japan (www.nationmaster.com/graph/mor_ven_her-mortality-ventral-hernia). Of these hernias at least 80% are being done with a large variety of synthetic or biologic mesh material made from a variety of synthetic materials and biologic origins. Hernia recurrence occurs in 20–40% of these patients [1]. Needless to say when performing repairs on recurrent hernias it is essential to know as many details as possible about the previous abdominal wall procedures especially in those patients with previously placed synthetic mesh. The synthetic meshes incorporate into the tissues at varying degrees and can be associated with varying degree of adhesions to bowel and other intra-abdominal organs. These quantities and severity of adhesions can be from minimal to severe often requiring a bowel resection or resection of

* Corresponding author. Tel.: +81 242 37 2568.
E-mail address: tdpham@u-aizu.ac.jp (T.D. Pham).
0169-2607/$ – see front matter
http://dx.doi.org/10.1016/j.cmpb.2013.09.019

wide segments of the abdominal wall. The identification of specific abdominal wall meshes used in previous repairs is a challenging task and can have significant impact on surgical morbidity and even mortality. There has been a tremendous effort to improve hernia treatments and repair including the investigation of effective surgical meshes and their implanting by means of laparoscopic surgery, also called minimally invasive surgery, or open incision [2–5]. However, surgical hernia repair is still a difficult task and there exists no single gold standard operation procedure for the repair of hernias [6,2].

As with any other surgical procedure there is a risk of recurrence [7,8] that is proportionally related to the comorbidities such as diabetes, obesity, hypertension, COPD (chronic obstructive pulmonary disease) as well as the concomitant procedures such as laparotomy, bowel resection, ostomy takedown or enterocutaneous fistulas. Patients with colostomies, ileostomies, or ureteral conduits are at even greater risk of herniation estimated at 50%. The incidence of hernia recurrence is significantly increased if the patient has a prior history of open abdominal wound, surgical site infection, smoking history as well as a prior history of surgical mesh insertions (http://www.herniahelpclinic.com/abut_hernia.htm).

Computed tomography (CT), which is a powerful nondestructive evaluation technique for producing 2-D and 3-D cross-sectional images of an object from flat X-ray images, has been widely used for medical diagnoses and treatment [9,10]. CT is also an integral technique for identifying a large variety of intra-abdominal pathology as well as abdominal wall structural defects [11,12]. Synthetic meshes in the abdominal wall often present with infectious complications postoperatively resulting in a dramatic increase in morbidity in attempts at removing the infected mesh or managing the infections. Many patients seek management of their recurrent hernias or post-operative complications at different clinics and emergency departments rather than where the hernia repairs were originally performed [13]. Most patients are unaware of the type of meshes used in their prior repairs. Further current CT scans do not provide the surgical team with the type of the existing mesh or the extent of the mesh incorporation (its density is the same as that of the fascia). This remains one of the most challenging tasks of hernia mesh identification.

It has been agreed that while small hernias can be repaired with most mesh types, but identifying an effective mesh for larger hernias is a difficult task [2]. However, many surgeons are refrained from selecting an appropriate mesh type of hernia repairs because of economical reasons which demand the least cost in the operation theater stocked with available meshes [13]. However, the consensus of medical opinion suggests that the mesh for hernia repair needs to have particular attributes and characteristics [2]. Appropriate selection of a good mesh for hernia repair is important because a poor choice will result in a significant foreign body reaction with *pathologic fibrosis* [2]. Because of the biological degradations that cause hernias such as *collagen defects*, the problem of abdominal wall hernia mesh identification can be regarded to be associated with abdominal wall tissues, which are subject to the fuzzy description of texture. Therefore, an appropriate methodology for identifying hernia meshes associated with abdominal wall tissues would resort to some effective texture extraction algorithms so that meaningful results can be obtained. In fact, texture has been recognized as useful discriminating information in many areas of medical image analysis [14,15] such as classification of patterns of normal and ulcerous regions in capsule endoscopy images [16], detection of lesions and differentiation between pathological and healthy tissues [15], vascular trees [17], and quantitative analysis of magnetic resonance images [18,19].

In the development of tools for automated diagnosis, texture has been recognized as a useful feature for characterizing complex information on medical images, such as texture analysis of cervical cell nuclei [20]; texture characterization of soft tissues of the liver, and gray matter, white matter, and cerebro-spinal fluid of the brain [21]; and texture analysis of prostate cancer region [22]. Texture in grayscale images, which is an important property existing in many types of data, refers to the variation of the image intensity in local regions [23].

Techniques for image texture extraction are vast in literature. Major approaches for texture description are structural, spectral and statistical methods [24,25], among which statistical methods are widely used [26]. Structural methods try to describe the texture of an image by applying a transform to the whole image, by which its structure can be quantified. Such transform-based measurements are Fourier transform, Laplace transform, and wavelets [27]. Regarding the statistical methodology for texture description, the co-occurrence matrix [28] still remains the most famous method because its good performance continues to be found in many applications until now [23], with particular application to medical image database retrieval, processing and analysis [29–32]. Based on the principle of geostatistics, the semi-variogram function, which can capture the spatial covariance of an image [33], has been reported to be useful for texture analysis and complementary to the co-occurrence matrix image texture extraction [34]. The geostatistical parameters for texture classification of images have been reported in various applications [26,35–37]. It is therefore further explored in this paper so that the texture information provided by the two complementary statistical methods can be combined to improve the texture description.

We present in this paper for the first time a novel application of image processing for automated identification of hernia meshes, and the original development of an entropy-based geostatistical feature, which can effectively capture the anatomic characteristics of the abdominal wall and its hernia mesh. A novel technical contribution of the paper is the development of the geostatistical entropy that is based on the concept of the kriging indicator and used as a new image texture descriptor. In addition, we make use of the complementary properties of this new texture feature and the texture feature based on the gray-level co-occurrence matrix to formulate a fusion model for characterizing the subtle image appearance of hernia mesh types on individual abdominal wall hernias on computed tomography. The proposed approach is expected to be useful for assisting physicians and surgeons in personalized diagnosis and clinical management of abdominal wall hernias.