Computers in Biology and Medicine 96 (2018) 203–213

Contents lists available at ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/compbiomed

A survey on Barrett's esophagus analysis using machine learning

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A R T I C L E I N F O

Keywords:
Barrett's esophagus
Machine learning
Adenocarcinoma
Image processing
Pattern recognition
Computer-aided diagnosis

A B S T R A C T

This work presents a systematic review concerning recent studies and technologies of machine learning for Barrett's esophagus (BE) diagnosis and treatment. The use of artificial intelligence is a brand new and promising way to evaluate such disease. We compile some works published at some well-established databases, such as Science Direct, IEEEXplore, PubMed, Plos One, Multidisciplinary Digital Publishing Institute (MDPI), Association for Computing Machinery (ACM), Springer, and Hindawi Publishing Corporation. Each selected work has been analyzed to present its objective, methodology, and results. The BE progression to dysplasia or adenocarcinoma shows a complex pattern to be detected during endoscopic surveillance. Therefore, it is valuable to assist its diagnosis and automatic identification using computer analysis. The evaluation of the BE dysplasia can be performed through manual or automated segmentation through machine learning techniques. Finally, in this survey, we reviewed recent studies focused on the automatic detection of the neoplastic region for classification purposes using machine learning methods.

1. Introduction

The adenocarcinoma appearance in Barrett's esophagus (BE) diagnosed patients has increased significantly in western populations. This is mainly explained by obesity, a known risk factor [1–3]. As such, the expectation of this disease to rise in the next years must be considered. The bad prognosis for patients suffering from esophageal adenocarcinoma is related to its late diagnosis. However, when detected at the early stages, the dysplastic tissue can be treated with very successful rates of handling the disease, such as 5% of morbidity and 0% of mortality. Additionally, 93% of patients featured a complete remission of the disease after 10 years treatment [2,4,5]. Developments in interventional therapies, such as endoscopic resection and ablation techniques (radiofrequency ablation, cryoablation) are promising methods for the management of BE, with the potential of reducing the cancer risk in dysplasia diagnosed patients. However, there are limitations of the currently accepted methods for monitoring and evaluating the disease state of BE patients, with the benefit from early diagnosis and additional tools to improve the detection of dysplasia [6–8].

Several endoscopic technologies for image enhancement, such as chromoendoscopy, electronic image enhancement, optical coherence tomography, and confocal laser endomicroscopy have been developed for BE evaluation, enabling endoscopists to conduct a more accurate assessment of the dysplasia with an *in vivo* characterization of esophageal histology [9]. This ability could result in improvements concerning the detection of BE (screening), detection of dysplasia based on BE surveillance, characterizing abnormalities within BE (selecting lesions and delineating margins during endoscopic therapy), and detection of recurrent neoplasia in patients who have received endoscopic treatment (post-treatment surveillance) [9].

BE is often misdiagnosed during endoscopy because of: (1) inability to differentiate columnar mucosa of the proximal stomach (cardia) from metaplastic epithelium in the distal esophagus; or (2) lack of goblet cells in biopsies obtained from columnar lined epithelium in the esophagus. Since dysplasia/BE areas are sometimes not readily perceived with standard white-light endoscopy, the Seattle biopsy protocol is usually recommended, where biopsies are taken for every 1 cm of the BE's mucosa. However, this protocol may be susceptible to sampling errors

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https://doi.org/10.1016/j.compbiomed.2018.03.014
Received 19 December 2017; Received in revised form 22 March 2018; Accepted 22 March 2018

because only a small part of the entire BE mucosa is usually considered for sampling purposes, especially in patients with extensive disease area [9]. Besides, the biopsy protocol can be costly and time-consuming, and thus prone to errors. Consequently, the risk of missed dysplasia or cancer diagnosis rises significantly [10]. Other studies have also considered the classification of different esophagus' lesion types based on color and texture information of the injured tissue area as well [11].

Machine learning techniques have benefited from significant improvements in image analysis and artificial intelligence fields. However, related to the automated analysis of BE, we observed one recent work only that attempted to compile relevant articles [12]. This work is a very brief survey to discuss advances in BE Computer-aided diagnosis (CAD) systems in three endoscopy modalities used for esophageal examination: (i) white light endoscopy (WLE), (ii) high-definition white light endoscopy (HD-WLE), and (iii) narrow band imaging (NBI). Focusing on detection methods lately developed for BE detection, the survey is composed of eight papers about automatic detection and evaluation of the BE, compared by its endoscopy modality, number of images and evaluated classifiers applied to the problem, validation method and results. The authors state the challenges for this detection and mention some directions for future research.

Our work aims at reviewing and investigating the feasibility and usage of machine learning techniques in the context of BE evaluation, dysplasia description, and treatment, thus providing more details to the previous brief survey. Next sections present the methodology used to evaluate the compiled articles, as well as some medical background related to the disease.

2. Theoretical background

2.1. Barrett's esophagus

The replacement of squamous cells by columnar cells in the esophagus' mucosa is known as BE. This process is recognized as a complication of gastroesophageal reflux disease, and in some critical stage, it can progress and evolve into esophageal cancer. Fig. 1 illustrates the human esophagus region [2,4,13].

Squamous cells (similar cells to skin or mouth ones) compose the mucosa of the normal esophagus. The normal color of the squamous mucosal surface looks like whitish-pink, while the gastric mucosa goes sharply from salmon-pink to red [2,4]. A demarcation line called squamocolumnar junction or "Z-line" defines the normal esophagogastric junction (Fig. 2), where the squamous mucosa of the esophagus and the columnar mucosa of the stomach meet [13]. BE's mucosa may extend upward in a continuous pattern, making the entire circumference of the distal esophagus covered by columnar mucosa. A difference is stablished among patients with more than 3 cm of BE ("long-segment BE") and those who feature the so-called "short-segment BE", with refers to BE that figures less than 3 cm, as depicted in Fig. 3.

2.2. Machine learning

Machine learning techniques have been paramount in the last decades mainly due to their capability in handling problems non-linearly by nature. Given a dataset composed of samples, the traditional pipeline used for so many years considers partitioning the data into training and testing sets. The former is used to learn the model (i.e., statistics of the data) meanwhile the testing set is used to assess the efficiency of the method.

Depending on the amount of knowledge we have about the training set, machine learning techniques can be categorized into three main groups: (i) supervised, (ii) semi-supervised, and (iii) unsupervised approaches. Supervised techniques usually achieve the best results since they make use of an entirely labeled training set, thus having more information to cope with. Semi-supervised learning approaches make use of both labeled and unlabeled data since only a fraction of the training data is labeled. Different approaches such as active learning-based or reinforcement learning can be referred to as well. In a nutshell, these approaches employ the user knowledge into the learning process, which can thus refine the results and correct possible errors.

Unsupervised learning or clustering stands for the group of techniques that have no information about the training data, which means they must group the data using some heuristic that can get together (i.e., same cluster) samples that share some information. To evaluate such techniques, we usually make use of measures that take into account the compactness and separability of clusters in the feature space, i.e., it is highly desirable to have well-separated and compact clusters at the end

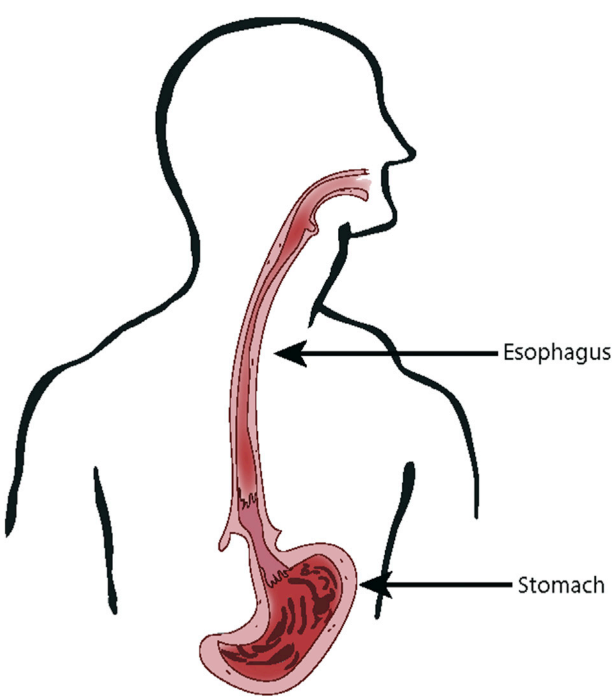

Fig. 1. Esophagus' location in the human body.

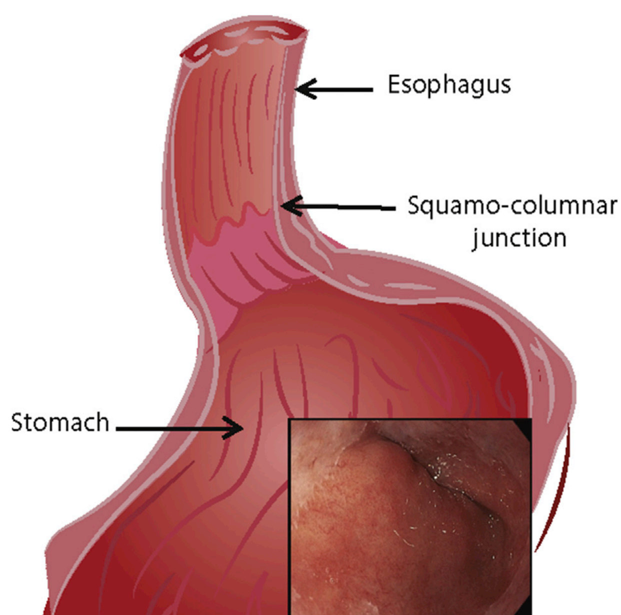

Fig. 2. Squamo-columnar junction and its respective esophagus endoscopic image.