ABSTRACT

Computer-aided detection (CAD) for CT colonography has been under development for about eleven years. It is now sufficiently accurate that clinically significant polyps 1 cm and larger can be reliably detected with 90% sensitivity. The research focus is now shifting to reducing the number of false positive detections, clinical validation and integrating CAD into clinical practice and applying CAD to the setting of fecal tagging and laxative-free bowel preparations. This is a dynamic research field which requires the use of state-of-the-art image processing and machine learning techniques.

Index Terms—colorectal cancer, polyps, shape, curvature

1. INTRODUCTION

Colorectal cancer is the second leading cause of cancer death in the Western world. Colorectal cancer can be prevented by the removal of precancerous polyps, small growths that arise in the wall of the colon. To remove polyps, they must first be detected. Optical colonoscopy is an invasive test that can both detect and remove polyps. Over the last 15 years, researchers have been developing a new minimally invasive technique that uses CT scanning to find polyps[1]. This test, known as CT colonography (CTC) or virtual colonoscopy, has been shown in clinical trials to be highly effective for screening patients for polyps [2, 3].

In the early days of CTC research, it was quickly recognized that finding polyps in the complex convoluted structure of the colon was a "needle in a haystack" problem - time-consuming and subject to perceptual error [4]. Automated methods of polyp detection could help alleviate this problem by reducing false-negative diagnoses due to polyps overlooked by radiologists.

One early computer-aided detection (CAD) system for the colon was based on a prototype system for finding abnormal growths in the air passages of the lungs on virtual bronchoscopy [5, 6]. These and other early results showed the feasibility of CTC CAD and suggested that CAD might become an important part of the radiologist’s assessment of CTC examinations. In this article, I present a brief overview of the current status of CT colonography computer-aided detection.

2. OVERVIEW OF CTC CAD

The purpose of computer-aided detection (CAD) is to locate possible polyps automatically and annotate the images or present a list of image locations. The radiologist reviews the output of the CAD and makes the final diagnosis.

A typical CAD system consists of components that locate the colon and colonic wall, calculate features along the wall relevant for identifying polyps and classify the features to distinguish normal wall from polyps. The most fundamental of these components is the calculation of shape features. Shape is an intuitive feature to identify polyps, as by definition a polyp is a distortion in the inner surface of the colonic wall. Colonic polyps protrude inward from the wall of the colon into the lumen of the colon and are characteristically rounded in contour. In contrast, haustral folds, normal colonic structures, tend to be circumferential and ridge-shaped. While there are a number of different methods for quantifying shape mathematically, we have found curvature to be an excellent shape descriptor that is highly effective at identifying polyps [5, 7].

3. TECHNICAL ADVANCES IN CTC CAD

There have been many different approaches to developing the technical components of CAD systems [8]. These approaches can be roughly grouped into colon segmentation, feature extraction and classification. Examples of these various approaches are summarized in this section.

Colon segmentation methods for CAD include region growing [6], knowledge guided segmentation [9], a combined fuzzy segmentation / level sets approach [10], maximum a posteriori expectation-maximization [11] and a colon wall evolution algorithm that uses level sets to
enhance polyps [12]. CT attenuation correction for pseudoenhancement due to beam hardening/scatter can be employed [13-15]. Methods to detect polyps in the presence of tagged fluid or fecal matter have been developed [16-20].

Feature extraction involves the computation of multiple features, the most important of which relate to shape of the inner colonic wall. Features can be computed from surface curvature [5, 6, 21], volumetric curvature [9], CT attenuation [6], directional gradient concentration [9], polyp segmentation using deformable contours [22], random orthogonal shape selection [23], optical flow [24, 25], surface normal overlap [26], wavelets [27] and topographic height map [28]. Other examples include a shape analysis based on convexity and sphericity [29], a shape and wall thickness analysis [30], a “General Shape” method with fit of an ellipsoidal model to polyp candidates [31] and smoothed shape operators [32].

Classifier methods include rule-based [6], linear and quadratic discriminant [9] and neural network and committee classifiers [33-36]. Optimal thresholds for classifiers may be determined using the Pareto front [37]. The large number of features can be reduced by a nonlinear dimensionality reduction method based on diffusion map and locally linear embedding [38].

False positive reduction can be accomplished through automated recognition of common causes of false positives such as the ileocecal valve, stool, the enema tube tip and bulbous haustral folds [33, 39-42] and by registration of supine and prone CAD detections [43-45].

4. RECENT CAD TRIALS

Recent research has focused on validating CAD on large proven data sets. The validations have been performed in standalone (nonclinical) trials and in observer performance trials in which radiologists use CAD in a clinical environment. The literature on CAD trials is growing rapidly and its discussion is beyond the scope of this review. The reader is referred to the forthcoming review in Ref. [46].

In a large standalone trial [47], a CAD system was trained on 394 patients’ CTC datasets and tested on 792 datasets. For the test set, per-polyp and per-patient sensitivities for CAD were both 89.3% (25 of 28 polyps) for detecting retrospectively identifiable adenomatous polyps at least 1 cm in size. The false-positive rate was 2.1 false polyps per patient. The CAD system detected one cancer originally missed by the colonoscopists. The per-patient sensitivities of CAD were not significantly different from those of optical colonoscopy for polyps 8 mm or larger.

In clinical use, CAD may be operated in the first, concurrent or second-reader modes. In first reader mode, the physician only looks at the CAD marks and does not perform a full evaluation of the image data set. In concurrent reader mode, the CAD marks are visible during the physician’s review of the entire image data set. In second reader mode, the CAD marks are not visible until after the physician has inspected the entire data set without CAD. Studies of the advantages and disadvantages of these three reading modes are still ongoing.

In observer performance trials, CAD has been found to improve the speed of image interpretation, find polyps missed by expert readers, decrease interobserver variability and increase sensitivity for reader detection of polyps [46].

5. THE FUTURE OF CTC CAD

CT colonography CAD research is in an intermediate stage of development. There is good evidence that CAD has high sensitivity and a low number of false positive detections for detecting clinically significant polyps. CAD is in clinical use abroad and nearing clinical use in the U.S.

New applications of CAD include its use in the settings of reduced-laxative and laxative-free bowel preparations that may be more patient-friendly. CAD research will be expedited by the accessibility of public databases of CTC case material (https://imaging.nci.nih.gov/ncia; http://www.acrin.org).

The major clinical challenge will be to evaluate the impact of CAD in an actual clinical interpretive setting[48]. Studies will need to show that CAD improves clinical sensitivity without placing an undue burden through reduced specificity or increased interpretation time. The application of CAD to clinical practice is sure to motivate further technical research.

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7. REFERENCES


