

Current concepts and future directions in computer-aided diagnosis for CT colonography

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Abstract

This review summarizes recent progress in computer-aided detection for CT colonography.

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1. Introduction

Beginning in approximately 1997, we began an investigation of automated diagnosis for CT bronchography (“virtual bronchoscopy”) [1-3]. In our study published in 1998, we found that 100% of airway lesions 5mm in size or larger could be detected using a shape-based detection algorithm [4]. The specificity was 80%. This technology transferred readily to CT colonography, and in association with colleagues at Stanford University, we published a feasibility study showing that colonic polyps could be detected in a phantom model [5]. More recently, we published the first study of computer-aided polyp detection for CT colonography to appear in a peer-reviewed journal, in association with colleagues at Mayo Clinic [6]. These early results showed the feasibility of CT colonography computer-aided diagnosis. In addition, they suggested that computer-aided diagnosis might become an important part of the radiologist’s assessment of CT colonography studies. In this review article, I present a brief overview of the current status of CT colonography computer-aided diagnosis.

2. Rationale for computer-aided diagnosis

The rationale for computer-aided diagnosis or detection (CAD) is to reduce both perceptual error and interpretation times. It has been shown that perceptual error reduces the sensitivity of CT colonography by 14% for polyps 1 cm in size or larger [7]. Given the multitude of images in a CTC study, the causes of perceptual error are not mysterious. Depending upon the reconstruction interval, there can be 1,200 images or more to interpret. For example, images in the prone and supine position must be interpreted. Some investigators examine the colon antegrade and retrograde and in lung and soft tissue windows. When needed for problem solving, three dimensional virtual endoscopic views

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may also be used. Interpretation times ranging from 10 – 60 minutes per study have been reported in the literature. Many reported studies used consensus readings of two radiologists, further lengthening interpretation time. Consensus readings are usually impractical in most busy clinical radiology departments.

3. Principles of CAD

The purpose of CAD is to locate possible polyps automatically and either annotate the images or present a list of image locations. The radiologist reviews the output of the CAD and makes the final diagnosis.

The main functions of the CAD software are to identify features that characterize polyps and classify sites of detection as polyps or false positive diagnoses [8]. A suitable CAD system has high sensitivity for detection of clinically significant polyps (those over a size threshold, e.g. 0.5 or 1.0 cm) and a low number of false positive detections. All current CTC CAD systems produce on average at least one false positive detection per CTC examination.

Two useful features for CAD are surface shape and CT attenuation. Surface shape is an intuitive feature to identify polyps, and is an essential feature in the definition of a polyp. Colonic polyps protrude inward from the wall of the colon toward the air-filled lumen of the colon and are characteristically rounded in contour. In contrast, haustral folds tend to be circumferential and ridge-shaped.

CT attenuation has also been shown to be useful for CAD, particularly for distinguishing polyps from false positive diagnoses. False positive diagnoses tend to have low CT attenuation and polyps tend to have soft tissue attenuation. Residual stool may mimic a polyp but stool can sometimes be distinguished by the presence of tiny gas bubbles within it.

There are many ways to mathematically describe surface shape. A mathematical algorithm for computing shape is necessary since the computer must be instructed how to recognize such shapes. While there are a number of different methods for quantifying shape, we have found curvature to be an excellent shape descriptor [4]. The principle behind curvature assessment is that each point on the surface of the colon can be described as having one of six elemental shapes: elliptical pit, elliptical peak, hyperbolic, cylindrical valley, cylindrical ridge and plane. Elliptical peak shapes are like the top of an ice cream cone. Elliptical pit shapes are like the inside of a hollow ball. Hyperbolic shapes are like a saddle. Cylindrical valley and ridge shapes are like the inside and outside of a pipe, respectively. Plane shapes are flat.

Polyps tend to have elliptical peak shape [5]. Haustral folds tend to have cylindrical curvature. Normal colon between haustral folds tends to have plane, cylindrical, or elliptical pit curvature. We have found that approximately 91% of the colonic surface can be safely excluded from further analysis using this shape classification system [5]. The remaining 9% of the colonic surface contains polyps and other structures,

some of which the radiologist needs to review. Further processing can reduce the area of interest to only 0.4% of the colonic surface. In a study of ten simulated 1 cm polyps inserted into a CT colonography study of an adult patient we found that all 10 polyps could be detected using the shape based algorithm. When further processing was applied to reduce false positives, 8 of the polyps could be located without any false positive diagnoses.

Once potential polyps are detected by CAD, they must be shown to the radiologist who makes the final diagnosis. There are a number of ways to do this. We have found it useful to label sites directly on CT colonography images to show the radiologist where the tentative polyp detections may be found [9]. These labels can be turned on or off so that they do not obscure the original images. To save time, the radiologist can jump directly to the labeled images. To evaluate the potential time efficiency of CAD, we applied CAD to a CT colonography study consisting of 161 images. The CAD software placed 7 CAD detections on 22 of the 161 images. Some of the CAD detections spanned more than one image. The total interpretation time was only two minutes to locate a colonoscopically proven 1.5 cm polyp in the rectosigmoid colon. This result suggests that CAD may be able to sharply reduce interpretation times.

4. Current status of CTC CAD

CT colonography computer-aided detection is in a preliminary stage of development. It is in early clinical trials at several academic centers. In this section, I summarize the published results of these trials. Particular attention is paid to whether statistical analyses are performed (such as cross-validation) that correct the overestimate of CAD performance on data from which it has been developed and optimized.

Our first clinical trial, performed in collaboration with colleagues at Mayo Clinic, was a study of 20 high risk subjects with known polyps [6]. There were 28 polyps 1 cm or larger, 26 of which could be found in retrospect. The sensitivity of the CAD algorithm was 64%, using a classification scheme that minimized the false positive detections to on average 6 false positive detections per colon. Note that these results were obtained using supine CTC only. The sensitivity would be higher if prone CTC was added although the number of false positive detections would also be higher. The sensitivity could be improved at the expense of an increase in false positive detections. When only polyps in well distended colonic segments were considered, the sensitivity increased to 71%. In this study, CT attenuation was used to reduce the number of false positive detections by 39% (to 3.5 false positive detections per colon). Processing took about 2 minutes on a common desktop computer.

The University of Chicago group assessed curvature in a thin layer that included the colonic wall [10-12]. They analyzed “directional gradient concentration” and applied linear and quadratic discriminant analyses. They used a “leave-one-out” analysis to validate their results. In a study of 14 patients having 15 polyps less than or equal to 1 cm and 6 polyps greater than 1 cm, they found 100% sensitivity per patient. Their average

false positive rate was 2.0 per patient. At a false positive rate of 2.0 per patient, their sensitivity for polyps was 90% (19 of 21).

Stanford University researchers have used a shape analysis of the colonic wall based upon the Canny edge detector and Hough transform operator [13, 14]. In a study of 14 polyps greater than 8.5 mm in 9 patients, they found a sensitivity of 92.9% and 7.9 false positives per colon. In a refinement of their algorithm, they developed a random orthogonal shape selection (ROSS) technique based on statistical pattern recognition [15]. In this method, randomly selected volumes in coronal, sagittal, and axial orientations are taken through potential polyps and then analyzed using statistical pattern recognition. The ROSS method included additional shape signatures which identified elliptical and linear shapes. The researchers utilized ten-fold cross validation and found that the ROSS method reduced false positives by 62%. However, this technique was time consuming, requiring hours of processing per subject. This group has also published preliminary results of an optical flow technique to reduce false positive detections [16].

Wake Forest University researchers published a shape and wall thickness analysis for CTC CAD in a conference proceeding article [17]. They found 11 of 15 polyps measuring 0.5 to 4.0 cm in 10 patients (sensitivity 73%) with an average of 49 false positives per patient. Researchers from Leuven in a conference proceedings article used a shape analysis based on convexity and sphericity [18]. They found all 10 polyps 1 cm or larger in 18 patients. There were 8 false positives per CT colonography scan.

5. Challenges ahead

CT colonography computer-aided detection research is in an early stage but already is producing exciting results. There are many challenges ahead and one anticipates new and useful results in the near future [19]. The two most exciting research challenges are determination of useful features and improvement in classification strategies. The key to this research is to identify features that describe polyps so they cluster together and away from false positives in feature-space.

Another challenge is how to properly match polyps on conventional colonoscopy and on CT colonography. Typically, conventional colonoscopy identifies polyps to within a colonic segment and even then considerable errors in location can occur. Such errors can impair CAD research.

Additional challenges are the trade-off between sensitivity and specificity and the limited amount of available data to train and test CAD. While initial results often report high sensitivity and few false positives, when presented with new data CAD will typically have lower sensitivity with more false positives. This fact highlights the need for suitable training databases that researchers can use to validate the robustness of their CAD algorithms.

Polyp camouflage is another important problem. Polyp camouflage includes residual fluid, stool, and bulbous haustral folds, and can mimic or hide true polyps. CAD

needs to see through camouflage that hides polyps and distinguish camouflage that mimics polyps. Stool subtraction techniques may play a role here.

Another challenge is to use the supine and prone CTC images together to find polyps and reduce false positives. For example, if a polyp is found in the same location on both supine and prone CTC, the confidence is high that this represents a true polyp. CAD may need to recognize such concordances.

Cancer detection, while feasible with CAD, may be a less important use for CAD. It has been shown in a number of studies that CTC without CAD already has 100% sensitivity for detecting colon cancers [20].

Other challenges include how to deal with artifacts, poor colonic distention, image noise, and low image resolution. A most important challenge will be how to show the impact of CAD in an actual clinical interpretive setting. Studies will need to be done showing that CAD improves clinical sensitivity without an undue burden in terms of reduced specificity or an increase in interpretation time.

6. Conclusion

Preliminary results in CT colonography CAD are encouraging. There is evidence that high sensitivity and a low number of false positive detections per examination are possible in the foreseeable future. However, these early results need to be confirmed on larger image databases. The application of CAD to clinical practice is also sure to provide interesting results that will propel further research.

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