A Pilot Study on Less-Stressful Bowel Preparation for Virtual Colonoscopy Screening with Follow-up Biopsy by Optical Colonoscopy

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ABSTRACT

Objective: To investigate a less stressful bowel preparation for polyp screening by virtual colonoscopy (VC) with follow-up biopsy on the positive findings by optical colonoscopy (OC). **Materials and Methods**: Fifty-eight volunteers of age older than 40 -- receiving low-residue diet and laxatives of magnesium citrate, bisacodyl tablets and suppository -- were divided into three groups. In Group I, 16 volunteers took three 40cc oral doses of MD-Gastroview with the three meals respectively, the day prior to VC procedure. In Group II, 18 volunteers ingested barium sulfate suspension (2% w/v, 250 cc/dose) at bedtime and in the next day morning of VC. In Group III, 24 volunteers received 60 cc of MD-Gastroview at bedtime and in the next day morning of VC. Following colon inflation with CO_2, computer tomography (CT) abdominal images were acquired by a standard single-slice detector-band VC protocol, i.e., 5 mm collimation, 1 mm reconstruction, 1.5-2.0:1.0 pitch, 120 kVp and 100-150 mA. The CT density of the tagged residual fluid was measured. An image segmentation algorithm was applied to remove electronically the residue fluid. **Results**: The average fluid density was 97 HU for Group I, 221 HU for Group II2, and 599 HU for Group III. These three groups' density means are significantly different ($p < 0.001$ one-way ANOVA). After the electronic cleansing, the % of cleansed fluid regions was 5.5%, 16.5% and 93.1% ($p<0.0001$ Chi square) for these groups respectively. **Conclusion**: A less-stressful bowel preparation with low residue diet and MD-Gastroview oral contrast is feasible for VC screening with follow-up biopsy on the positive findings by OC.

Keywords: CT-based virtual colonoscopy, optical colonoscopy, less-stressful bowel preparation, oral contrast, image segmentation, electronic colon cleansing, colonic polyp screening.

1. INTRODUCTION

Virtual colonoscopy (VC) has evolved rapidly since its concept appeared in public [1-6] and shown comparable performance to the clinically available optical colonoscopy (OC) in detecting polyps of greater than 5 mm size [7-10]. It has several advantages over OC, such as safer, lower cost, less invasive, and full colon examination [11]. These advantages make VC more suitable than OC to be a screening modality by the following facts: (a) in asymptomatic population of age over 50, polyps of size greater than 8 mm occur less than 10 percent [12, 13]; and (b) the percentage of patient compliance is less than 20% for the currently recommended OC procedure [14, 15]. A more suitable screening would increase the compliance rate and reduce the number of costly OC procedures without polyp findings. However, the lack of biopsy capability of VC screening requires subsequent OC procedure to remove the found polyps, although the number of biopsy is small (less than 10% of the screened subjects). To facilitate both VC screening and

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immediate follow-up OC biopsy, an adequate bowel preparation for both VC and OC is needed. Modification of the conventional OC bowel preparation for VC has been frequently seen in the literature [16-21].

This work describes a pilot study on a less-stressful bowel preparation for both VC and OC utilizing both oral contrast and image segmentation algorithms for electronic cleansing of the tagged residue colonic fluid or material for VC [17-29], while most colonic materials are pushed out by minimal laxatives. The residue fluid can be sucked out and small residue stool can be pushed away from the colon wall during OC procedure.

2. METHODS

A total of 58 volunteers of age older than 40 was recruited under a written consent approved by the IRB of the State University of New York at Stony Brook. Among them, 13 are females. All the volunteers have no personal or family history of colon cancer or polyps and do not have any GI symptom.

All the volunteers followed a one-day low-residue diet, as suggested by Appendix, prior to CT (computed tomography) scan. No food or liquid in the morning before the CT procedure. Laxatives of magnesium citrate and bisacodyl tablets and suppository were taken as follows:

1. Magnesium Citrate Effervescent laxative mixed with cold water was taken at dinner time in the day prior to the CT procedure.
2. Four Bisacodyl tablets (5 mg) were taken two hours after magnesium citrate laxative.
3. One Bisacodyl suppository (10 mg) was taken in the next day morning of the CT procedure.

The 58 volunteers were divided into three groups to test three different oral contrast protocols, respectively, as follows:

1. In Group I, 16 volunteers took three 40 cc oral doses of MD-Gastroview (diatrizoate meglumine and diatrizoate sodium solution, 120 cc/bottle, Mallinckrodt Inc., St. Louis, MO) with three meals, respectively, in the day prior to the CT scan.
2. In Group II, 18 volunteers ingested two bottles of CT Colonography Tracer (barium sulfate suspension, 2% w/v, 250 cc/dose, E-Z-EM Inc., Westbury, Long Island, NY) each at bedtime and in the morning at least two hours prior to the CT scan.
3. In Group III, 24 volunteers ingested two 60 cc doses of MD-Gastroview each at bedtime and in the morning at least two hours prior to the CT scan.

Following colon inflation with CO_2 (2 to 3 liters) without applying Glucagon or any other medication, a single-slice detector high-speed spiral CT (GE/CTI) scanner was used (GE Medical System, Milwaukee, IL). The data acquisition protocol was 5 mm collimation, 1.5-2.0:1.0 pitch range (depending on the body size for a single breath-holding scanning period of 35 to 45 seconds), 35-40 cm field-of-view (FOV) size, 100-150 mA, 120 kVp, and 1 mm reconstruction. Both supine and prone positions were scanned for each study case. Each case contains 700 to 900 slice images of 512×512 array size with 16 bits for each image element density, resulting in a half GB dataset. The dataset was transferred to our research lab in DICOM format via fiber-optical high-speed networking (in less than three minutes). By the laxatives, most colonic materials were pushed out, except for some residue fluid (and sometime residue stool), which has an enhanced image density by the oral contrast. The enhanced residue fluid can be sucked out and the small residue stool can be pushed away from the colon wall during OC procedure. For VC study, the enhanced fluid and/or stool must be removed electronically from the CT images. This virtual removal is called electronic cleansing [24], consisting of two steps of (1) oral contrast and (2) computerized image segmentation [23].

The DICOM image dataset was processed by a region-growing and threshold strategy [25] to extract the portion of colon lumen which was filled with air. A corresponding virtual colon model was constructed by the use of a three-dimensional (3D) visualization program (V3D Colon-Module System, Viatronix Inc., Stony Brook, NY). The CT densities of the enhanced fluid were then measured at eight segments of the colon model, as shown by Figure 1 below, before the fluid was electronically removed. The number of locations with fluid before and after electronic cleansing was determined. The electronic cleansing procedure is described below.

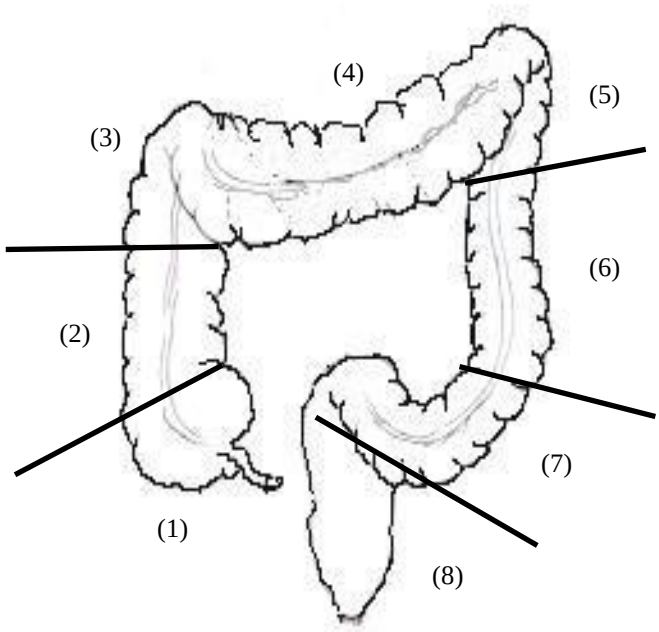

Figure 1: The entire colon was divided into eight segments for a quantitative analysis. (1) cecum; (2) ascending; (3) hepatic flexure; (4) transverse; (5) splenic flexure; (6) descending; (7) sigmoid; and (8) rectum).

Our electronic cleansing procedure includes following steps. The first step was to remove the FOV background outside the body. The second step was to label the image voxels into air, soft tissues and bone/contrasted colonic materials by our automated self-adaptive vector quantization classification algorithm [26] and mixture-based segmentation method [28]. The partial volume layers between the air and the contrasted colonic materials and between the contrasted materials and the colon wall were detected by a segmentation-ray strategy [29] in the third step. The fourth step was to remove the contrasted materials and the layer between the air and the contrasted materials for a clean colon lumen. For visualization purpose, the layer between the colon wall and the contrasted materials was inverted in the last step. The entire processing took less than 15 minutes on a currently available PC Pentium III platform [30].

After the electronic cleansing, a 3D virtual model of the entire colon was built and reviewed by utilizing the V3D Colon-Module System of Viatronix Inc. The system provides both automatic 3D endoscopic navigation and axial, sagittal and corollary slice views. It also has the option to navigate simultaneously through both the colon models of the supine and prone scans. The review by both the 3D navigation and the slice views determined the number of locations with fluid before and after the electronic cleansing. A great effort was devoted, by both 3D and slice views, to ensure that there is no miss-reviewing of any abnormality (or polyp, if exits) being removed under the residue fluid. Since the residue fluid was tagged relatively uniform, removal of abnormality of greater than 4 mm size (corresponding to the partial volume effect and the spatial resolution of the CT protocol) is expected less likely. This was proved in this study.

3. EXPERIMENTS

An example from Group III of the above presented less-stressful bowel preparation is shown by Figure 2, Figure 3, and Figure 4 below. Most colonic materials were pushed out by the laxatives, except for some residue fluid, which was tagged nearly uniformly by the oral contrast (left of Figure 2). The tagged residue fluid was effectively removed by our electronic cleansing technology (middle of Figure 2). Our method for colon lumen extraction demonstrated its robustness before and after the electronic cleansing (right of Figure 2).

The CT density of the tagged residue fluid was measured by selecting a region of interest (ROI) in the fluid volume. One measurement was taken from each of the eight colon segments of Figure 1. The average fluid density from these measurements was 97 HU for Group I, 221 HU for Group II, and 599 HU for Group III (the CT density is approximately

50 HU for colon wall and -1000 for air). These three groups' density means are significantly different ($p < 0.001$ one-way ANOVA). In Group I, the three 40 cc doses of MD-Gastroview (a total of 120 cc) -- mixed with the three meals, respectively, in the day prior to CT scan -- provide a moderate enhancement of the fluid CT density. In Group II, the two 250 cc 2% w/v doses of barium sulfate suspension (a total of 500 cc) provide a significant CT density enhancement for the residue fluid with slightly less uniform tagging. The two 60 cc doses of MD-Gastroview (a total of 120 cc in a bottle) in Group III provide the maximal enhancement and uniform tagging. The number of fluid regions in all the eight segments is 91 for Group I, 79 for Group II, and 159 for Group III. One reason for a smaller number of fluid regions for Group I and Group II may be due to the partial volume effect, where the small fluid volumes with lower CT densities are invisible for the views.

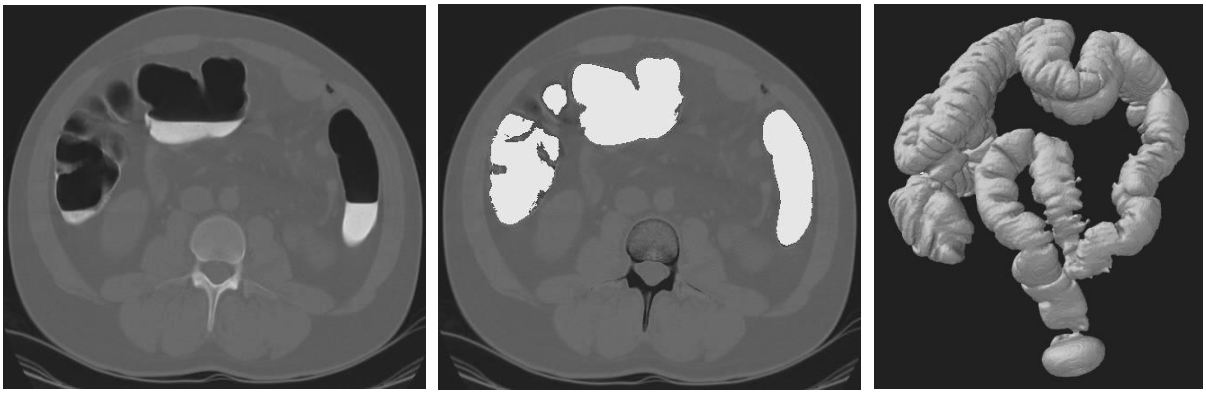

Figure 2: An example from Group III – Uniformly tagged colonic residue fluid (left); effective electronic cleansing of the tagged fluid (middle); and robust extraction of colon lumen for virtual colon model (after electronic cleansing, right).

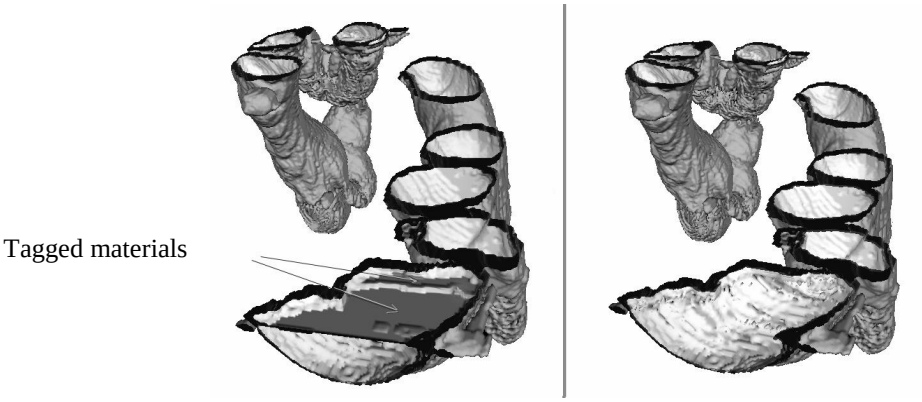

Figure 3: A 3D display of the tagged materials (both fluid and stool) before (left) and after (right) our electronic cleansing.

By our electronic cleansing algorithm, 5 fluid regions were removed for Group I, 13 were removed for Group II, and 148 were removed for Group III. The % of cleansed fluid regions was 5.5%, 16.5% and 93.1% ($p<0.0001$Chi square) for these three groups, respectively.

4. CONCLUSION

Based on a limited number of patients or elder volunteer studies, a less-stressful bowel preparation was shown feasible for polyp screening by virtual colonoscopy and immediately followed by optical colonoscopy for biopsy on positive findings. The low residue diet covers a relatively wider food range. The laxatives of magnesium citrate and

bisacodyl tablets and suppository are relatively more acceptable than the routinely used one for optical colonoscopy [16].

Two 60 cc doses of oral contrast (MD-Gastroview, 120 cc in a bottle), one is given in the evening prior to CT scan and the other in the morning at least two hours before CT scan, provided sufficient image density enhancement and uniform tagging of the colonic residue fluid.

Further investigation in image processing or segmentation strategy is needed to minimize the partial volume effect for improved performance of electronic cleansing of the tagged residue fluid and/or stool. This can be achieved by partial volume or mixture-based image segmentation [31].

A successful electronic cleansing of the colon lumen is essential for computer aided detection and diagnosis to achieve the goal of massive polyp screening [32, 33].

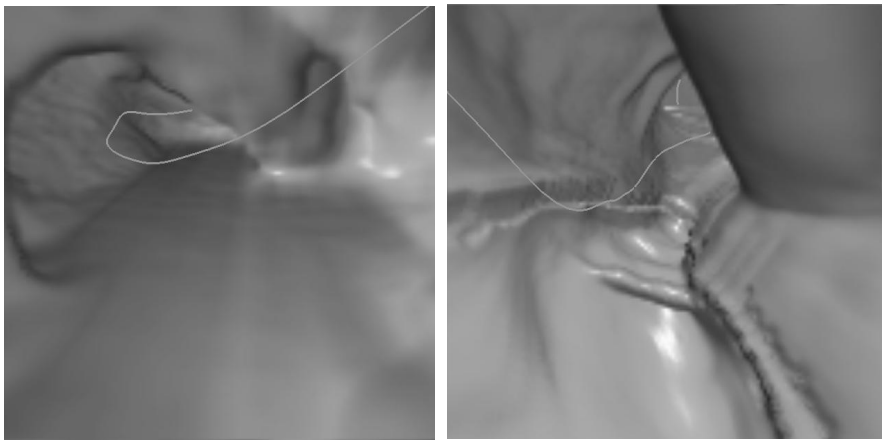

Figure 4: A 3D endoscopic view of colon lumen before (left) and after (right) tagged colonic residue fluid was removed by the electronic cleansing. On the left, residue fluid narrows a portion of colon lumen (bottom left) and prevents viewing of the colon wall there. On the right, colon fold and wall are seen after residue fluid is removed electronically (bottom left).

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Appendix: Suggested and avoid low residue diet list (red color shall be avoid)

FOOD GROUPS	FOOD ALLOWED	FOODS TO AVOID
Breads	White refined breads, rolls biscuits, muffins, crackers, pancakes and waffles.	Whole grain flower products of any type and baked goods made with bran, nuts, seeds, coconut, fruits, bagels, cornbread or graham crackers.
Cereals	Refined cooked cereals, including cream of wheat, and farina, puffed wheat, puffed rice and rice krispies.	Oatmeal, any whole grained cereal bran or granola and any containing nuts, seeds, coconut or dried fruit.
Desserts	Plain cakes and cookies, water ices (Marinos), plain low-fat yogurt, Jello, custard, grape or apple jelly, plain hard candy, marshmallows and lite ice cream without nuts or chocolate.	Any desserts made with whole grain flour, bran, seeds, coconut, dried fruit, yogurts with fruit skins or seeds or nuts, sherbets and popcorn. No chocolate.
Potato and Potato Substitute	Cooked white potato without the skin, white rice, white pasta and egg noodles.	All others, including whole-wheat pasta, noodles, vegetable pastas, and sweet potato.
Fats	Margarine, salad oil, lite salad dressings, lite mayonnaise, and plain gravy.	Butter, any fat containing whole grain flour, bran, seeds, nuts, Coconut, or dried fruit.
Meats and Meat Substitutes	Ground and well-cooked white meat chicken and turkey, with skin removed, Fish, shellfish, eggs, and low-fat cheese.	Red meat, BBQ or pickled meat, any made with whole grain ingredients, seeds or nuts, dried beans, peas, lentils, legumes, peanut butter and whole milk Cheese.
Soups	Bouillon, broth, low-fat cream made with allowed vegetables, noodles, rice, or refined white flour.	All others.
Beverages	Decaffeinated liquids of all kinds, Caffeinated beverages limited to 2-3 (10 oz.) cups per day, low- fat milk, and strained fruit juices.	Espresso, frappucino, cappuccino, whole milk, fruit/vegetable juices containing pulp, prune juice, and all alcoholic beverages.