A Feasibility Study on Laxative-Free Bowel Preparation for Virtual Colonoscopy

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ABSTRACT

Objective: To investigate the feasibility of laxative-free bowel preparation to relieve the patient stress in colon cleansing for virtual colonoscopy. **Materials and Methods**: Three different bowel-preparation protocols were investigated by 60 study cases from 35 healthy male volunteers. All the protocols utilize low-residue diet for two days and differ in diet for the third day – the day just prior to image acquisition in the fourth day morning. Protocol Diet-1 utilizes fluid or liquid diet in the third day, Diet-2 utilizes a food kit, and Diet-3 remains the low-residue diet. Oral contrast of barium sulfate (2.1%, 250 ml) was added respectively to the dinner in the second day and the three meals in the third day. Two doses of MD-Gastroview (60 ml) were ingested each in the evening of the third day and in the morning before image acquisition. Images were acquired by a single-slice detector spiral CT (computed tomography) scanner with 5 mm collimation, 1 mm reconstruction, 1.5-2.0:1.0 pitch, 100-150 mA, and 120 kVp after the colons were inflated by CO_2. The contrasted colonic residue materials were electronically removed from the CT images by specialized computer-segmentation algorithms. **Results**: By assumptions that the healthy young volunteers have no polyp and the image resolution is approximately 4 mm, a successful electronic cleansing is defined as "no more than five false positives and no removal of a colon fold part greater than 4 mm" for each study case. The successful rate is 100% for protocol Diet-1, 77% for Diet-2 and 57% for Diet-3. **Conclusion**: A laxative-free bowel preparation is feasible for virtual colonoscopy.

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

1. INTRODUCTION

Virtual colonoscopy (VC) has evolved rapidly since its concept was presented in public [1-6] and shown comparable performance to the clinically available optical colonoscopy (OC) for polyp detection [7-10]. It has several advantages over OC, such as safer, lower cost, less invasive, and full colon examination. Furthermore, VC has the potential to utilize a less stressful bowel preparation than OC for improved patient compliance towards a screening modality [11, 12]. This potential could be realized by oral contrast for colonic material tagging and by digital subtraction of the tagged material image voxels from the acquired CT (computed tomography) abdominal scans, without physically washing out the colonic materials as for OC [13-17]. However, the partial volume effect due to the limited resolution of imaging devices and the non-uniform tagging of colonic materials would cause significant artifacts in the subtracted colon lumen image, and consequently it is infeasible to accurately render a three-dimensional (3D) endoscopic image of the virtual model of the colon lumen for interior flythrough. Furthermore, it creates a great number of false positives, especially when a technique for computer aided detection of polyps is utilized. Sophisticated image segmentation

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algorithms, which consider the feature of the tagged colonic materials and the partial volume effect, are needed to achieve a successful electronic colon cleansing [18-28].

This work describes a feasibility study on laxative-free bowel preparation for CT-based VC utilizing both oral contrast and image segmentation algorithm for electronic colon cleansing [18-28].

2. METHODS

A total of 35 healthy male volunteers were recruited under an informed consent approved by the Institutional Review Board (female was not considered due to the X-ray radiation exposure within the abdomen). None of the volunteers have personal or family history of colon cancer or polyps, or any GI symptoms. Their age distribution is given by Table 1.

Table 1:   Volunteer age distribution

Age Group	Number of Subjects	Average Age
[18 to 30]	22	23.0
[31 to 50]	13	42.5

Three different bowel-preparation protocols were investigated, see Table 2 and Figure 1. We define "Day-3" as the day that is three days prior to the CT scan, "Day-2" as the day that is two days prior to the CT scan, "Day-1" as the day prior to the CT scan, and "Day-0" or "Day-scan" as the day of the CT scan. All the three protocols cover four days – "Day-3" through "Day-0". In protocol Diet-3, each volunteer selected his favorable low-residue food from a nutritional meal list, see Appendix, for three days and drank water in the morning of Day-0. In protocol Diet-2, each volunteer followed the nutritional food for Day-3 and Day-2 and took a meal kit (E-Z-EM Inc., Westbury, NY) for Day-1. In protocol Diet-1, each volunteer followed the nutritional food for Day-3 and Day-2 and took only fluid or liquid food for Day-1.

Table 2:   Three different bowel preparation protocols

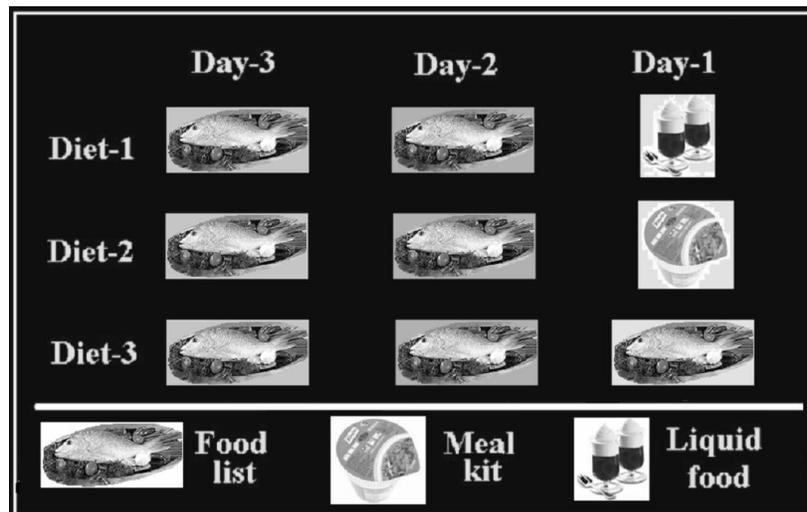|	Day-3	Day-2	Day-1	Day-0/CT-Scan
Diet-1	Nutritional food list	Nutritional food list	Fluid or liquid food	water in AM
Diet-2	Nutritional food list	Nutritional food list	E-Z-EM meal kit	water in AM
Diet-3	Nutritional food list	Nutritional food list	Nutritional food list	water in AM

Figure 1: All the three bowel-preparation protocols utilize low-residue diet for two days (i.e., Day-3 and Day-2) and differ in the third day (i.e., Day-1) before CT scan in the morning of the fourth day. Diet-1 protocol uses fluid or liquid food, Diet-2 utilizes a meal kit, and Diet-3 remains the low-residue diet in the third day.

Two kinds of oral contrast agents were utilized to tag the colonic materials. One is barium sulfate (2.1%, 250 ml, E-Z-EM Inc). The other is MD-Gastroview (diatrizoate meglumine and diatrizoate sodium solution, 60 ml, Mallinckrodt Inc., St. Louis, MO). The oral contrast agents were taken at the schedule as shown in Figure 2. There was no oral laxative or suppositories.
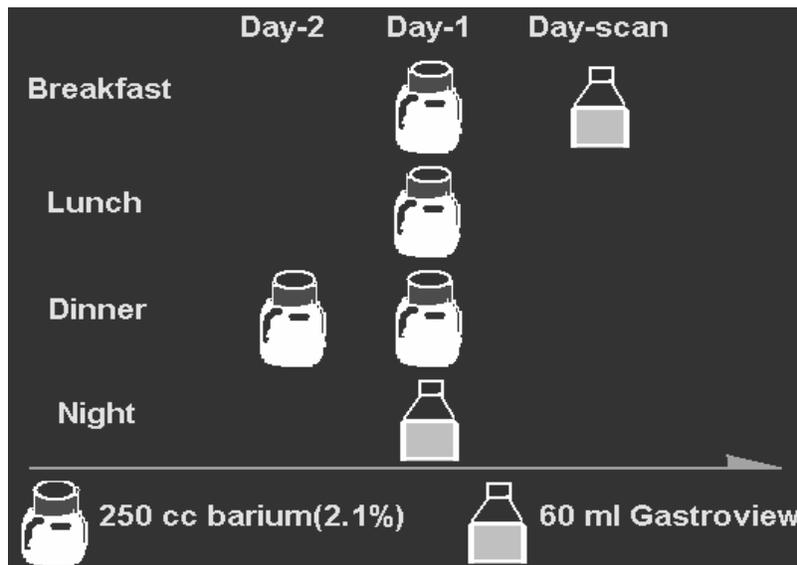

Figure 2: Four doses of barium sulfate (2.1%, 250 ml) were added each to the dinner in Day-2 and the three meals in Day-1, respectively. Two doses of MD-Gastroview (60 ml) were ingested each in the evening of Day-1 and in the morning before CT scan, respectively.

Twenty-one volunteers took two different diet protocols for two CT scans respectively, at more than a week apart, resulting in forty-two study cases. Two volunteers took three different diet protocols for three CT scans respectively, also at more than a week apart, resulting in six study cases. The other twelve volunteers took only one diet protocol. There were a total of 60 study cases, in which there were 20 Diet-1 cases, 26 Diet-2 cases and 14 Diet-3 cases, see Table 3 below.

Table 3: Sixty study cases from 35 volunteers

	Diet-1	Diet-2	Diet-3
Number of Cases	20	26	14

Prior to acquiring CT images, the colons were inflated with CO_2 (2 to 3 liters) without applying Glucagon or any other medication. A single-slice detector-band 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 about a half GB dataset. The dataset was transferred to the research lab in DICOM format via high-speed fiber-optic networking in less than three minutes and processed by the previously reported image segmentation algorithms for electronic cleansing of the contrasted colonic materials in the CT abdominal images [19-28].

The image-data processing includes the following steps. The first step was to remove the FOV background outside the body. The second step was to label the image elements into air, soft tissues and bone/contrasted colonic materials by

an automated self-adaptive vector quantization classification algorithm [23] and mixture-based segmentation method [25]. 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 [26] 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 colon wall and contrasted materials was inverted in the last step to mimic the partial volume effect of air and colon wall for this layer. For quantitative analysis on the mucosa layer between the air and the colon wall for detection purpose, we classified each image element inside the layer into partial volumes, reflecting the percentages of tissues in that image element. The entire processing took less than 15 minutes on a currently available PC Pentium III platform. Technical details for modeling the partial-volume effect and the non-uniform tagging of colonic materials are given in references [19, 22, 25].

After the electronic cleansing of the colon lumen, a 3D virtual model of the colon was built with sophisticated potential fields inside to facilitate user navigating through the model [3, 20, 29-31]. The colon model was reviewed by utilizing the V3D Colon-Module System of Viatronix Inc. (Stony Brook, NY). 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. At any suspected location, interactive tools, such as size measurement, zooming at any orientation, translucent view of the internal texture beyond the surface (or electronic biopsy) and the like, are available. The review results by both the 3D navigation and the 2D slice views with the interactive tools were scored based on the assumptions that there are no polyps in the healthy volunteers' colons and their colon walls and folds are relatively smooth. Furthermore, the image resolution is limited at approximately 4 mm for the employed CT image acquisition protocol. Therefore, this 4 mm size was defined as the threshold for quantitative error measures. If a non-smooth area or spot on the colon wall or fold was found while flying through the supine and prone colon models, the reviewer checked the 2D slice views to rule out an electronic cleansing error. However, if a portion of thick colon wall or fold (larger than 4 mm size) was indeed removed, the electronic cleansing or the study case was considered as a failure. Any remaining colonic material of size greater 4 mm on the colon wall was assumed as a false positive. If more than five false positives were observed in a study case, this study case was considered a failure. The number of false positives was limited to five because of the following observations. The best performance of current computer aided detection methods has not been better than this threshold [32-34]. The average number of suspected areas that a radiologist inspects during navigation through a study case is larger than this threshold.

In addition to the visualization evaluation above by both the 3D endoscopic navigation and the 2D slice views on the three different bowel-preparation protocols, the statistical significant difference among these bowel preparation protocols were quantitatively studied by a likelihood-ratio test for both paired (from the same volunteer) and unpaired (from different volunteers) datasets. From the 60 study cases, 13 datasets were selected from Diet-1 and Diet-2 protocols, respectively, and 10 datasets were selected from Diet-2 and Diet-3 protocols, respectively.

3. EXPERIMENTS

By the visualization evaluation, all the 20 study cases of Diet-1 protocol were rated as success (i.e., 100%), 20 out of 26 study cases of Diet-2 protocol were scored as success (i.e., 77%), and 8 out of 14 cases of Diet-3 were rated as success (i.e., 57%). The overall success rate is 80%, see Table 4. An example of successful electronic colon cleansing is shown in Figure 3.

Table 4: Scores of three different BP protocols

	Number of Case	Success		Failure	
Diet-1	20	20	100%	0	0%
Diet-2	26	20	77%	6	23%
Diet-3	14	8	57%	6	43%
Total	60	48	80%	12	20%

The six failed cases in Diet-2 protocol and six failed cases in Diet-3 protocol were due to either removal of a portion of a colon fold, i.e., true colon wall, greater than 4 mm or presence of more than five false positives. These electronic cleansing failures may be due to either bowel preparation variation or image artifacts. An example of removal of a portion of a colon fold is shown in Figure 4 and presence of false positive cases is shown in Figure 5. An image artifact example is shown in Figure 6.

By the likelihood-ratio test on the paired and unpaired datasets of the three different bowel-preparation protocols with a 0.05 significance level, it concludes that protocol Diet-2 is not significantly different from protocol Diet-3. However, protocol Diet-1 is significantly different from protocol Diet-2 or Diet-3.
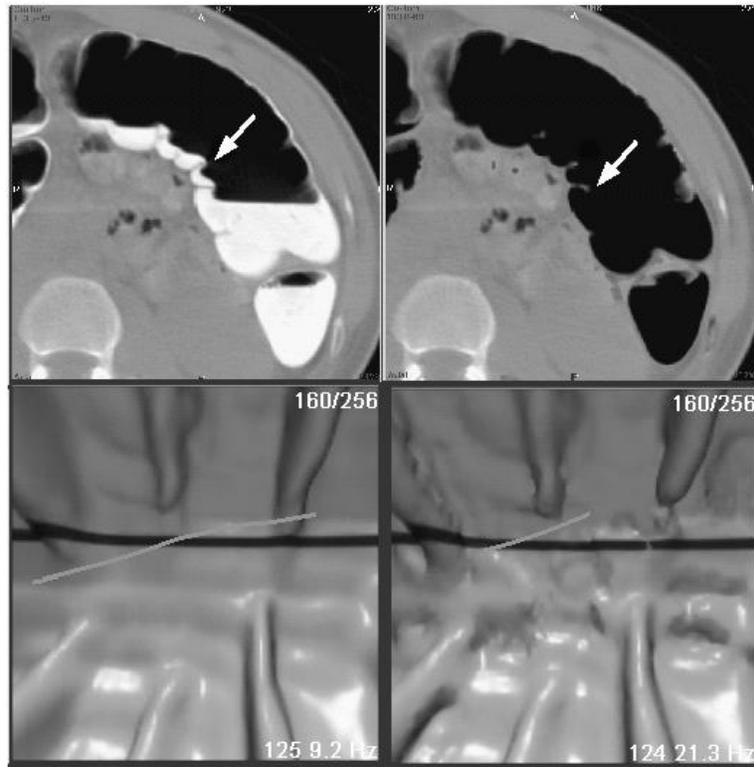

Figure 3: Non-uniformly tagged colonic materials and attached stool on the colon wall were successfully removed by protocol Diet-2. Top two images are the 2D slice views before (left) and after (right) the electronic cleansing. Bottom two pictures are the 3D endoscopic views on an area (indicated by the arrow in the slice image) before (right) and after (left) the electronic cleansing.

Figure 4: A portion of colon fold of approximately 5 mm size was removed because of the partial volume effect between the fold and the contrasted colonic materials in protocol Diet-3. The left two images are the 2D slice views before (left) and after (middle) the electronic cleansing, and the right one is the 3D endoscopic view (indicated by the arrow in the slice image).
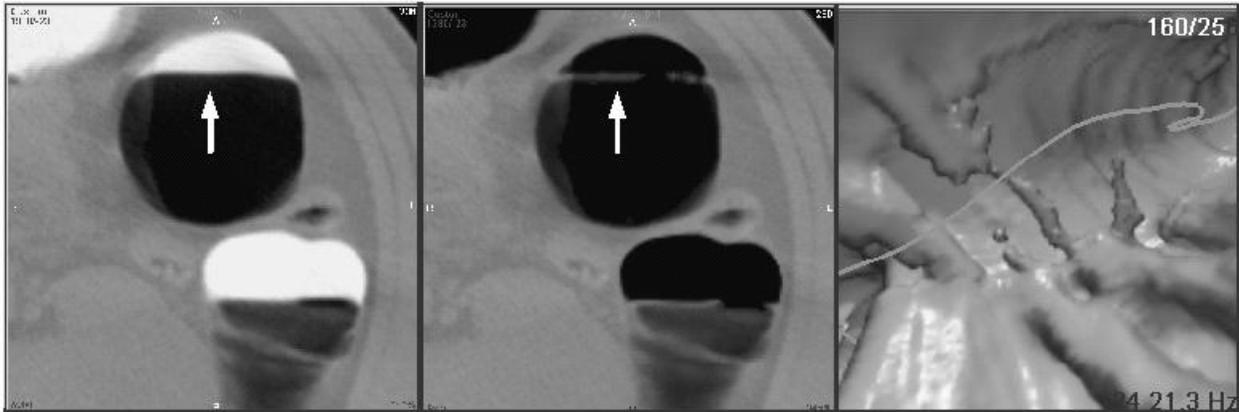

Figure 5: Residual colonic materials survived the electronic cleansing in protocol Diet-2 because of the partial volume effect among the contrasted materials, the colon wall and the air. The left two images are the 2D slice views before (left) and after (middle) the electronic cleansing, and the right one is the 3D endoscopic view (indicated by the arrow in the slice image).

Figure 6: A false positive case was created due to the image artifacts of patient motion in protocol Diet-1. The left two images are the 2D slice views before (left) and after (middle) the electronic cleansing. The right one is the 3D endoscopic view (indicated by the arrow in the slice image).

4. CONCLUSION

Based on a limited number of volunteer studies, a laxative-free bowel preparation was shown feasible for virtual colonoscopy. One of the investigated three bowel-preparation protocols showed significant difference from other two and rendered 100% adequate electronic colon cleansing by the current image processing strategy and the thresholds of resolution and acceptable number of false positives. Further improvement of the image processing strategy is needed to relax the food restriction in the protocols. Texture analysis on the tagged colonic materials is needed to differentiate the false positives from polyps [35-37]. The partial volume effect due to the enhanced image density of colonic materials could be reduced by alternative oral contrasts, which will decrease, rather than increase, the image density of the colonic materials towards that of the air in the lumen.

Acknowledgement

Appendix: Suggested and avoided low-residue diet list.

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.
Fruits	Most canned or cooked fruits, applesauce and ripe banana.	Dried fruits, all berries, most raw fruit, except banana.
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.
Vegetables	Cooked fresh, frozen, or canned carrots, beets, asparagus tips, French style string beans and pureed squash, spinach.	All others including raw and deep-fried vegetables, broccoli, cauliflower cabbage, spinach, sauerkraut, winter peas, corn, and any other vegetables with seed.
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.

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