Application of Iterative Reconstruction on CT Colonography for Low Dose Scanning

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1. Introduction

Pickhardt et al. (2003) reported a colon cancer screening method based on CT colonography (CTC) that targets asymptomatic patients, producing very good results with a 93.8% detection sensitivity and 96% specificity for polyps 1 cm or larger⁵. Furthermore, evaluation of colorectal screening using CTC was conducted in a multi-centered study in ACRIN (American College of Radiology Imaging Network) in the USA, and widespread use of CTC in the USA and Europe is rapidly increasing⁶. On the other hand, dissemination of CTC is progressing slowly in Japan. However, this trend is changing tremendously as a result of revision of the medical treatment fees in 2012, which added 600 insurance points to CTC examinations using MDCT of more than 16ch with an automatic carbon dioxide injector⁷. Through the use of the latest workstations, CTC has attained excellent image quality, and problems related to residue and residual liquids can be solved by methods such as fecal tagging and electronic cleansing⁴⁵. With CTC screening, it is necessary to quickly detect pathological abnormalities without sacrificing efficiency. We have therefore developed a filter for analyzing the image and shape of the lumen that can accurately display the properties of the intestinal tract⁶. Furthermore, low radiation exposure is essential for screening which examines healthy people of all ages, so we examined the application of an iterative reconstruction method to produce high image quality with low dose scanning in CTC. This paper presents an overview of this method including with phantom and clinical samples.

2. Panoramic imaging and shape analysis filter

Representative CTC image display methods consist of two-dimensional imaging including MPR (multi-planar reconstruction), virtual endoscopy imaging, and three-dimensional imaging such as air-enema CT and intestinal...
tract expansion imaging. Reading of overly large number of axial images less than 1 mm slice causes large physical and psychological burdens to the observer. The automatic flythrough method for virtual endoscopy imaging generates blind spots at the back of the folds, making additional observation necessary for areas that are not directly detected by the observer, resulting in a certain amount of time required to observe supine and prone positions. Intestinal tract expansion imaging shows the whole inner surface of the colon as if it were cut open like an isolated preparation, providing a still image of the entire colon from the anus opening to the ileocecal area without any blind spots. There are two different methods of showing the dissection images. One is the image showing the intestinal tract at the same width, and the other is the image keeping the original shape and width of intestinal tract. The panoramic image we developed is equivalent to the latter. The advantage of panoramic imaging is its ability to easily recognize intestinal tract narrowing, making it possible to instantly identify sites with extension defects due to inflammation or narrowing of colon lumen due to presence of advanced cancer (Figure 1, Figure 2). The disadvantage is that it does not expand the diameter of the intestine, resulting in poor visualization of lesions located at sites that are not extended well and thus can be a cause of oversight.

In order to quickly and accurately detect lesions during CTC screening, a computer support system (CAD: computed assisted detection) has been developed. In Japan, however, no CAD system for CTC has been approved for use so far. A shape analysis filter is a filter that distinguishes normal regions such as colon folds from raised or protruded regions by different colors, thus bestowing a similar functionality as CAD. As the detection of polyps 1cm or larger is indispensable for colon cancer screening, this filter’s functionality makes it possible to display protruding regions in panoramic images without blind spots so that the required observation time can be reduced. For highlighting color in protruded area, unique colors are assigned based on Shaped Index values calculated in each points. Shaped Index is a color map that continuously assigns a number between 0 and 1 based on changes of the shape of the surface. Protruding regions that have spherical shapes (polyps) are colored in red. In addition to polyps, the shape analysis filter can detect not only polyps but also advanced cancers as it identifies irregular protrusions caused by cancer as an abnormality (Figure 2). The condition for high-accuracy CAD is high specificity, high sensitivity, and low false negative ratio. In case of shape analysis filter, it detects less than 20 protruding regions

Figure 1: Panoramic imaging of colon diverticulitis and early colorectal cancer
a: Extension defect at the descending colon from the sigmoid colon compared to other parts of the intestinal tract caused by chronic diverticulitis (area indicated by arrow)
b: An enlarged image of the circled area in Figure a. showing continuous early colorectal cancer (black arrow) from the colon fold. White arrow: clip.
c: virtual endoscopic image of the part shown in Figure b. Black arrows: early colorectal cancers.

Figure 2: Detection of advanced cancer via the shape analysis filter
The narrowing of the internal abdominal cavity caused by advanced cancer in the ascending colon is shown with color by the shape analysis filter (white arrow). The part of the sigmoid colon with an extension defect is also shown with color due of its abnormal shape, but is not caused by a lesion. The other small colored parts are also not caused by lesions; most parts of the colon are normal.
on average in one case, however it is sufficient level for the use in daily clinical practice.

3. Reduction of CTC radiation exposure

In CTC, scanning is performed in 2 positions, supine and prone. In order to lower radiation exposure, it is desirable to use half the normal dose in either position. In Japan, it is not uncommon to perform enemas as a second step for fecal occult blood-positive patients. Comparison of the diagnostic performance of CTC and enema have been reported that CTC has a greater ability to detect polyps and cancer but still has problems in the level of radiation exposure. Two-position scanning in CTC with normal radiation dose results in higher radiation exposure than enema examination. Performing the same scanning with up to a 50 mAs dose resulted in lower radiation exposure than enema examination, so low dose scanning has been recommended. It has also been reported that a 10 mAs dose is sufficient to detect polyps that are 6 mm or larger. However, because not only the intestinal lumen but also extra-intestinal lesions need to be evaluated in CTC, image noise increased under insufficient low-dose scanning interfere the diagnosis. Recently, iterative reconstruction methods have been successfully applied in low-dose CT scanning and the use of 1/4-1/2 of the normal dose on CTC applying the method has been reported by each company.

4. Intelli IP (Advanced)

Hitachi Medical Corporation developed Intelli IP; Noise reduction through application of iterative reconstruction. With this method, more than 40% noise reduction compared to the current method is expected. Intelli IP (Advanced) removes noise components in the projection space through iterative reconstruction algorithm based on highly accurate statistical models, and then controls image quality based on statistical and anatomical information in the image space. Clinical benefits of applying this method include low radiation exposure, suppression of artifacts and improvement of image quality when using a high-frequency weighted filter.

5. Application of Intelli IP (Advanced) for CTC

First, we examined the optimal dose for radiation dose reduction in imaging phantom followed by examination in clinical cases. Inside the phantom, we created multiple doughnut-shaped protrusions with different sizes and heights, similar to those of protrusions seen in early colorectal cancer (Figure 3). Scanning protocols are shown in Table 1. Three-dimensional virtual endoscopic and panoramic images and two-dimensional images were created, and detection capacity was then evaluated. As shown in Figure 4a (virtual endoscopic image), -noise in wall increased with dose reduction. At 10 mAs, localizing diagnosis is possible but qualitative diagnosis of protrusions with less than 0.5 mm height was difficult. A front-view virtual endoscopic image of a protrusion with 5 mm diameter is shown in Figure 3.

![Figure 3: Schematic diagram of phantom](image3)

![Figure 4a: Virtual endoscopic image of an entire protrusion](image4a)

<table>
<thead>
<tr>
<th>Model</th>
<th>64-column CT SCENARIA (Advanced) made by Hitachi Medical Corporation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube voltage</td>
<td>120kV</td>
</tr>
<tr>
<td>Tube current</td>
<td>10 to 600mA</td>
</tr>
<tr>
<td>Reconstruction interval</td>
<td>0.625mm</td>
</tr>
<tr>
<td>Reconstruction slice thickness</td>
<td>0.625mm</td>
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<tr>
<td>Reconstruction FOV</td>
<td>100mm</td>
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<tr>
<td>Scan time</td>
<td>0.5s/rot</td>
</tr>
<tr>
<td>Beam pitch</td>
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</tr>
</tbody>
</table>

Table 1: Equipment model and scanning conditions
lateral diameter (Figure 4b) showed problems arising not only from the noise in wall, but also from the unclear doughnut-shape of the protrusion, unless the dose was increased to 25 mAs or more. The overall picture of the panoramic image (Figure 4c) also shows protrusions less than 1 mm in height and 5 mm in lateral diameter (the shapes of three protrusions at the upper-right side of each image, shown by arrows), are unclear at 20 mAs or lower.

With the axial view of protrusions with a height of 1 mm height and 5 mm lateral diameter, localizing diagnosis was also difficult, with an increase of noise in wall at 25 mAs or less (Figure 4d). Degradation of image quality due to low-dose scan was more substantial with two-dimensional imaging than with three-dimensional imaging, so we attempted to reduce the image noise for protrusions with a height of 1 mm and 5 mm lateral diameter, which are representative of flat-type early colorectal cancer, scanned using 50 mAs dose (a dose that is considered appropriate; 1/5 of the normal dose) using Intelli IP (Advanced). Noise reduction was observed in virtual endoscopic images with Intelli IP (Advanced) level 3-6 (Figure 5a). Noise reduction at level 7 was too strong, causing blurring in the entire area of protrusions. -Levels 4-6 are considered optimal for the reduction of noise in wall to improve axial images (Figure 5b). From the results of the phantom experiment, we conclude that it is possible to reduce the radiation dose to SD=45 (10 mAs) for the detection of polyps and SD=20 (50 mAs) for the screening of colonic disorders, respectively. Effects of Intelli IP (Advanced) were more substantial for two-
 dimensional images compared to three-dimensional images. Using Intelli IP (Advanced) levels 4-6, it was possible to reduce the noise of images taken with low dose (SD=11-14) to a level similar to that seen with normal dose in addition to improving image uniformity.

For clinical cases, we performed normal-dose scanning at one position and low-dose scanning at other positions and analyzed the improvement of image quality using Intelli IP (Advanced). Although the virtual endoscopic image of cancer progression in the ascending colon showed, as with the phantom experiment, a reduction in low dosage-induced image quality degradation (Figure 6a), use of Intelli IP (Advanced) set at levels 4-6 allowed a further reduction in noise from the intestinal mucosal surface compared to the level seen when using the filtered-back projection (FBP) method (Figure 6a). In two-dimensional images from the same clinical case, noise from the outer intestinal wall was also reduced by using Intelli IP (Advanced) set at levels 4-6 (Figure 6b). Because detection of extraintestinal findings is also important in CTC, image degradation caused by low-dose has become a problem. Increased noise resulting from low dose was also observed in the detection of kidney cysts, just as with the detection of atypical cysts. However, using Intelli IP (Advanced) set at levels 4-6 allowed visualization of the internal part of the cyst at the same level of clarity as with normal cysts (Figure 7). For clinical cases, we have shown that a reduction in dose to 1/4-1/2 of the normal dose is possible through the use of Intelli IP (Advanced), and that the effects are more substantial with two-dimensional images, with the optimal level for Intelli IP (Advanced) considered as 5-6.

![Figure 6a: Changes in the detectability of advanced cancer by Intelli IP (Advanced) (virtual endoscopy images)](image1)

![Figure 6b: Changes in the detectability of advanced cancer by Intelli IP (Advanced) (coronal image)](image2)

![Figure 7: Changes in the detectability of a renal cyst by Intelli IP (Advanced) (axial image)](image3)

6. Future remarks on Intelli IP (Advanced) for CTC

While the expansion of the use of CTC for colorectal cancer screening, demand from surgeons for conducting Virtual CT Laparoscopy prior to laparoscopic surgery is increasing in Japan. Virtual CT Laparoscopy is an imaging procedure that uses contrast medium and create three-dimensional composite images that are produced based on important vascular anatomy structures. This procedure clarifies the relationship between the artery, portal vein, vein, ureter and a tumor. Because it is necessary to perform scanning more than 4 times, radiation exposure is problematic. Furthermore, a good contrast effect with the blood vessels cannot be achieved by an excessively low dose imaging. Therefore, attempts to enhance contrast by low kV scanning and applying iterative reconstruction method to reduce image noise have been made. With this method, low-dose and low-kV scanning can be achieved and it is expected that the amount of the contrast medium can be reduced by scanning at low kV. In the future, we expect the low-noise CTC that applying iterative reconstruction method such as Intelli IP (Advanced) will become widely used; therefore, studies on optimal radiography techniques considering contrast enhancement method will be necessary.
7. Summary

In this paper, we have reviewed the application of the iterative reconstruction method, Intelli IP (Advanced), in CTC to obtain high image quality and evaluated the obtained image quality. By using Intelli IP (Advanced), it was possible to reduce the dose to 1/4-1/2 of normal dose, which will be useful in colorectal cancer screening. From this study, it is expected that the use of CTC examination will become more common in Japan.

*1 Intelli IP and *2 SCENARIA are registered trademarks of Hitachi Medical Corporation.

References

6) Tetsuo Nakazawa et al.: New functions of CT Colonoscopy – Features of Shape Analysis Filter –, MEDIX, 57: 30-33, 2012.