

PENTAX i-SCAN™ Functionality, Application, and Technical Analysis



TECHNICAL WHITEPAPER

i-SCAN is a digital, post-processing image enhancement technology that provides the user an enhanced view of the texture of the mucosal surface and blood vessels.



i-SCAN: Technical Description

Introduction

Endoscopy is a widely used diagnostic tool to detect disease in the gastrointestinal (GI) tract. Using flexible fiberoptic endoscopes to visualize the GI tract was pioneered by Basil Hirschowitz in 1957. In the 1990s, the advent of video endoscopy using charge coupled devices (CCD) replaced fiberoptic technology and revolutionized the field of gastrointestinal endoscopy. Responding to the need for earlier detection of digestive malignancies, CCD technology allowed for the development of current high resolution endoscopes with 800,000 to over 1,000,000 pixels, which makes more mucosal details visible.

Alongside the advancement of high resolution endoscopes, endoscopic adjunctive techniques and technologies have been developed. These techniques and technologies are focused on helping the endoscopist better visualize what is in the endoscopic field through complementing and enhancing high definition white light endoscopy (HDWLE). One of most widely studied of these techniques is chromoendoscopy, the application of dyes or contrast stains directly to mucosa.^{1,2} Dye-based and spray chromoendoscopy is effective in identifying and delineating GI lesions, but is also time consuming and cumbersome.^{1,2} To overcome this inconvenience during routine clinical practice, several innovative, high-technology alternative approaches have been introduced, such as Olympus NBI®, Fujinon FICE™, and most recently PENTAX i-SCAN™. The purpose of this paper is to:

- 1) describe i-SCAN and its functionality
- 2) briefly introduce the clinical applications of i-SCAN
- 3) provide technical analysis in support of the functionality of the technology

Overview:

What is i-SCAN?

i-SCAN is a dynamic, software-based, image enhancement technology that provides the user an enhanced view of the texture of the mucosal surface and blood vessels. i-SCAN has three default settings: i-SCAN 1, i-SCAN 2, and i-SCAN 3, all of which can be simply accessed with the touch of a button. Switching between HDWLE and the three i-SCAN settings can be initialized on a real-time basis, without any lag, thus enabling efficient endoscopic observation.

How does i-SCAN Work?

i-SCAN functions by performing per pixel modifications of the white light image. i-SCAN 1, comprised of surface enhancement (SE) and contrast enhancement (CE), provides the user with a view that sharpens surface vessels and enhances surface texture of the mucosa. i-SCAN 2, comprised of SE, CE and tone enhancement mode c (TEc), provides the user with an image that increases the contrast between the mucosa and blood vessel. This increased contrast leads to improved visibility of blood vessels while also providing the same enhancements to the mucosal surface texture achieved in i-SCAN 1. i-SCAN 3 (SE, CE and tone enhancement mode g (TEg)) provides the user with increased visibility of blood vessels, including in dimly illuminated far-field regions, while also providing the same enhancement to the mucosal surface texture achieved in i-SCAN 1. Table 1 includes examples of i-SCAN modes and enhancement functionality.

i-SCAN Settings

i-SCAN combines a variety of parameters to produce the effect of each i-SCAN mode. Among these are the following: brightness of light (off, -5 to +5), red (off, -5 to +5), blue (off, -5 to +5), light measuring mode (ave, peak) enhancement (off, low, med, high), surface enhancement (off, +1 to +6), contrast enhancement (off, +1 to +6), tone enhancement settings (off, c, g, r, e, b, d), and noise reduction (off, low, med, high). The GI default settings used in the Americas for i-SCAN 1, 2, and 3 are provided below in Table 2. Detailed descriptions of SE, CE, and TE are provided in the addendum.

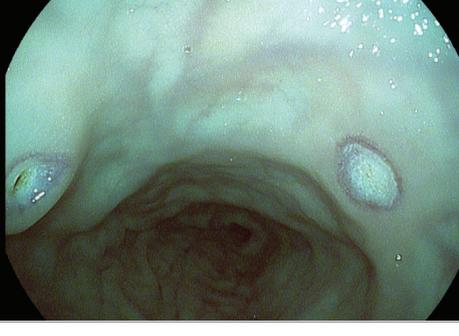
MODE	ENHANCEMENT	IMAGE	FUNCTIONALITY
i-SCAN Modes Off (HDWLE)	SE (off), CE (off), TE (off)		High definition white light endoscopy image
i-SCAN 1	SE, CE		Sharpens surface vessels and enhances surface texture of mucosa
i-SCAN 2	SE, CE, TEc		Increases contrast between mucosa and blood vessels, enhances surface texture of mucosa
i-SCAN 3	SE, CE, TEg		Increases contrast between mucosa and blood vessel including dimly illuminated far-field regions, enhances surface texture of mucosa

TABLE 1. i-SCAN modes and enhancement functionality.

SETTINGS	i-SCAN 1	i-SCAN 2	i-SCAN 3
Brightness	0	2	1
Red	-1	0	0
Blue	0	0	0
Light Measuring Mode	Ave	Ave	Ave
ENH	Low (+2)	Low (+2)	Low (+2)
Surface Enhancement	Med (+5)	Med (+5)	Med (+5)
Contrast Enhancement	Low (+2)	Low (+2)	Low (+2)
Tone Enhancement	Off	c	g
Noise Reduction	Off	Med	Med

TABLE 2. i-SCAN default settings.

To provide further flexibility, the user has the option to step away from the default settings and change the volumetric options of the settings for customizability.

i-SCAN Modes

i-SCAN 1 provides the user with a sharper view of the HDWLE image and enhances areas of the mucosa that are depressed or elevated. As depicted in Figure 1, this mode sharpens surface vessels and enhances surface texture while maintaining an image that is as bright as a conventional white light image. Vessels also retain a natural red coloration. Analyses supporting the technical functionality of i-SCAN 1 are provided in the addendum.



FIGURE 1. Comparison of HDWLE and i-SCAN images, Left Top & Bottom: HDWLE image. Right Top & Bottom: i-SCAN 1 engaged.

i-SCAN 2 utilizes the same levels of CE and SE as i-SCAN 1, resulting in the sharpening surface vessels and enhancing surface texture. In addition to these enhancements, i-SCAN 2 improves contrast of blood vessels and the mucosa (Figure 2) through engagement of tone enhancement mode c. Vessels retain a natural, red coloration when i-SCAN 2 is engaged. Analyses supporting the technical functionality of i-SCAN 2 are provided in the addendum.

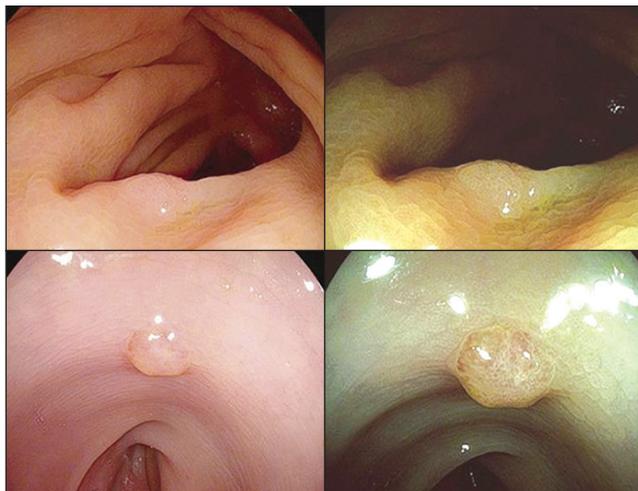


FIGURE 2. Top Left & Right: Hyperplastic diminutive polyp HDWLE and i-SCAN 2. Bottom Left & Right: Diminutive adenoma HDWLE and i-SCAN 2.³

In similar fashion to i-SCAN 2, i-SCAN 3 utilizes the same levels of CE and SE as i-SCAN 1, resulting in the sharpening of surface vessels and enhancement of surface texture. In addition to these enhancements, i-SCAN 3 improves contrast of blood vessels and mucosa through engagement of TEg. The primary difference between i-SCAN 2 and 3 is one of brightness due to the different tone curves employed. Engaging i-SCAN 2 improves contrast in vessels, but it may reduce the brightness of already low intensity regions of the image. i-SCAN 3 maintains visibility into dimly illuminated far-field regions such as the depths of tubular cavities and large lumens. It achieves this by balancing tonal alterations and image brightness to avoid excessive darkening of regions with low brightness. As seen in the images in Figure 3, i-SCAN 3 generates a contrast enhanced image, while maintaining uniform brightness. As is the case for all i-SCAN modes, vessels maintain a natural red coloration when i-SCAN 3 is engaged. Analyses supporting the technical functionality of i-SCAN 3 are provided in the addendum.

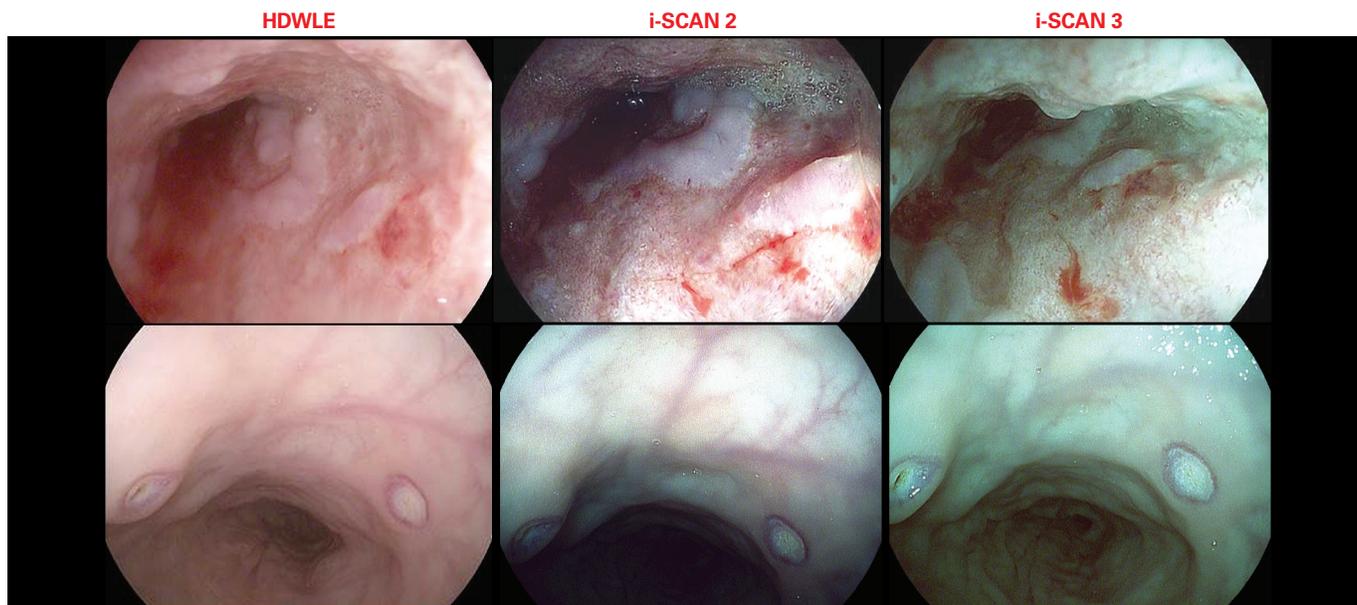


FIGURE 3. Image enhancements achieved by i-SCAN 2 and i-SCAN 3.

i-SCAN is a dynamic, software based, image enhancement technology that provides the user an enhanced view of HDWLE endoscopic images. i-SCAN has three default settings, i-SCAN 1, i-SCAN 2, and i-SCAN 3, all of which can be simply accessed with the touch of a button. Switching between HDWLE and the three i-SCAN settings can be initialized on a real-time basis, without any lag, thus enabling efficient endoscopic observation. Through engaging the i-SCAN modes, the user is able to see more mucosal and vascular details as compared to the white light image.

Since i-SCAN is a relatively new technology in the GI field, the clinical literature on i-SCAN is limited to-date. There is a growing body of results indicating that i-SCAN has a useful place among advanced endoscopic technologies. Most recently, Neumann et al. described a learning curve effect for prediction of hyperplastic and adenomatous colorectal lesions, and they concluded that diagnostic accuracy rapidly increased over a short period of time among endoscopists who had never used i-SCAN.⁴ Hong et al. conducted a randomized study in which i-SCAN 2 improved the histological prediction of hyperplastic and adenomatous colorectal lesions over HDWLE.⁵ Another study by Lee et al. presented results on i-SCAN vs. the more widely studied NBI for the prediction of diminutive colonic polyp pathology and found that both technologies had statistically significant higher sensitivity and accuracy compared to HDWLE. In addition, no significant differences were evident between NBI and i-SCAN (sensitivity, 88.8% vs. 94.6%; specificity, 86.8% vs. 86.4%; accuracy, 87.8% vs. 90.7%, respectively; $p < .05$).³ Another recent study investigated i-SCAN's role in evaluating duodenal villous patterns.⁷

In the esophagus, i-SCAN has been reported to improve identification of reflux-associated mucosal breaks.⁶ A recent study by Hoffman et al. studied the diagnostic yield for detecting Barrett's esophagus using targeted biopsies with i-SCAN or acetic acid compared to the diagnostic yield of a protocol of random biopsies.⁸ The results from this randomized controlled trial showed the diagnostic yield for specialized columnar epithelium was significantly higher with targeted biopsies and i-SCAN (66% vs 21%; $P = .009$) or acetic acid (57% vs 26%; $P = .012$) than with the random biopsy protocol.

These initial studies set the stage for continued research and further establishment of the clinical utility of i-SCAN technology. This dynamic technology allows for an enhanced view of the texture of the mucosal surface and blood vessels through the touch of a button, produces bright images, maintains red as a predominate vessel color and allows for contrasted observation of larger areas in the distant view. This promising technology may have a role in a wide array of clinical scenarios throughout the entire gastrointestinal tract.

Bibliography

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*Users should follow the Manufacturer's Instruction for Use.

TECHNICAL INFORMATION ON i-SCAN

Definitions of Contrast, Surface and Tone Enhancements

Contrast Enhancement (CE)

The CE function identifies locally dark pixels and further darkens them to improve contrast and enhance surface areas with micro-unevenness (texture). CE adjusts the luminous contrast between a central target pixel and the surrounding pixel area. The CE algorithm is applied to each pixel in the video signal. A target pixel appears as locally dark (lower luminous component value) if neighboring pixels along three directions are lighter (higher luminous value). If the target pixel is locally dark along any of the three directions, its blue tone component is enhanced slightly. If the luminance component value for the target pixel is either the same or greater than the value of the surrounding pixels, its color tone remains unchanged.

Surface Enhancement (SE)

The SE function enhances detailed patterns and micro-unevenness (texture) of surface structures by adjusting luminous contrast between the center pixel of an area containing 25 pixels 5 x 5 and those pixels in the surrounding area. The SE algorithm is applied to each pixel in the video signal. The difference between the target pixel's luminance and the average luminance of surrounding pixels in the 5 x 5 pixel grid determines an enhancement variable by which the target pixel's luminance is subsequently adjusted. This variable is positive if the target pixel is brighter than those surrounding it and is negative if the

opposite is true. When the target pixel luminance value is greater than the average luminance of the surrounding pixels, the target pixel is more brightly displayed. When the target pixel luminance value is lower than the average luminance of the surrounding pixels, it is identified as an edge pixel and is more darkly displayed.

Tone Enhancement (TE)

The color of the mucosal tissue is strongly related to hemoglobin, which has high absorption characteristics for blue and green light components and low absorption characteristics for the red light component. In a standard, white light image, the contrast between mucosa and blood vessels is low.

Tone enhancement was designed in such a way that several digital filters with different brightness and contrast levels are available to the user as volumetric options. Each of the six TE digital filters available on the PENTAX Medical processor represent a distinct tone curve of Red (R), Green (G), and Blue (B) channels. Tone curves specify an input-output relationship for all pixel values of one color channel in the image and result in both brightness and contrast of an image being controlled. TE modes apply tone curves that improve contrast in the G and B channels while reducing brightness in the R channel. Since blood vessels absorb light in the 400-450nm and 520-580nm wavebands, they will naturally exhibit more contrast in the G and B channels. Selectively increasing contrast in these two channels, while suppressing the R channel further improves vessel contrast. The default TE settings, (TEc) and (TEg), which are found in i-SCAN 2 and i-SCAN 3, result in the largest suppression of brightness in the red light channel.

TECHNICAL ANALYSES - i-SCAN 1, i-SCAN 2 & i-SCAN 3

i-SCAN 1

The enhancements made to mucosal surface structures and textures are supported by a fast Fourier transform analysis of i-SCAN 1 and HDWLE images (Figure 1). Visibility of textures on mucosal surfaces depends on the strength of mid-spatial frequency components in the image, and increases in mid-spatial frequency amplitudes correlate with more visible textures. Prior to engaging i-SCAN 1, a steady falloff of spatial frequency intensity can be observed in the fast Fourier transform (FFT) plot presented in Figure 1. After i-SCAN 1 was engaged, there was an increase of approximately 200% in mid-spatial frequency content (Figure 2). This increase can be easily visualized by the pronouncement of surface textures in the i-SCAN 1 image.

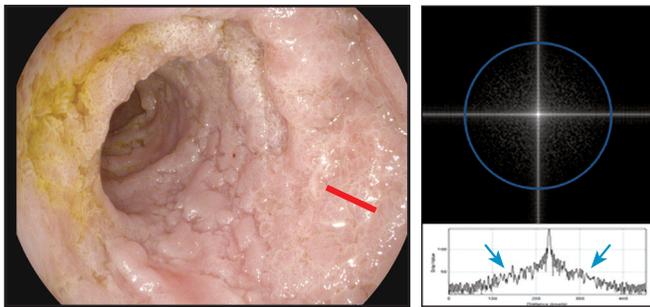


FIGURE 1. Spatial Frequency – HDWLE Left: HDWLE image of the duodenum with highlighted region of interest. Top Right: 2-D FFT of ROI with 99% energy (DC excluded) encircled in blue. Bottom Right: Line trace through FFT showing luminous contrast.

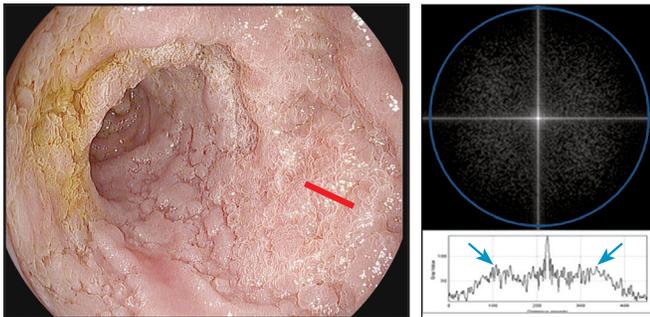


FIGURE 2. Spatial Frequency – i-SCAN 1 Left: i-SCAN 1 image of the duodenum with highlighted region of interest. Top Right: 2-D FFT of ROI with 99% energy (DC excluded) encircled in blue. Bottom Right: Line trace through FFT showing luminous contrast.

i-SCAN 2

The following analysis compares improvements in vessel luminous contrast achieved with the engagement of i-SCAN 2 as compared to the respective white light image. In this analysis, the average pixel luminance over a vessel and average pixel luminance of the neighboring mucosa was measured to derive vessel contrast of HDWLE and i-SCAN images. Pixel luminance is a weighted sum of R, G and B channel pixel values. The results show an improvement in contrast ranging from 147% to over 300% between the blood vessels and mucosa in the i-SCAN 2 image as compared to HDWLE.

% Contrast

	FIGURE 3 LEFT	FIGURE 3 RIGHT
HDWLE	1.2%	3.4%
i-SCAN 2	5.1%	8.3%
Improvement	337%	147%

TABLE 1. Vessel contrast improvements of i-SCAN 2 over HDWLE are measured for images shown in Fig. 3

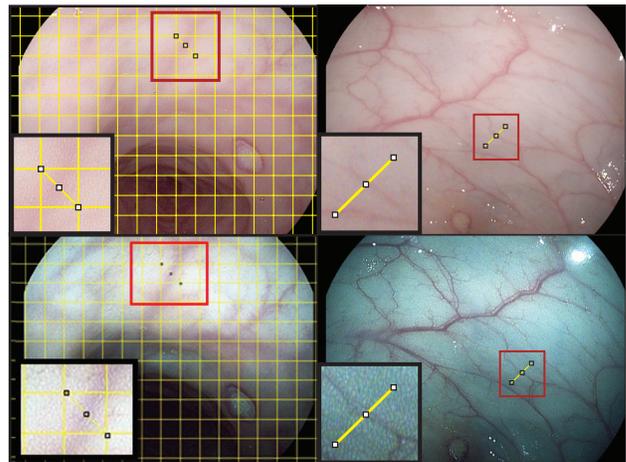


FIGURE 3. HDWLE and enhanced images of a demarcated region in a porcine colon with expanded ROI. Top Left and Right: HDWLE. Bottom Left and Right: i-SCAN 2.

i-SCAN 3

The analysis below compares i-SCAN settings in images taken of the duodenum and the colon. In both cases, i-SCAN 3 achieves greater visibility of dimly illuminated far-field regions than i-SCAN 2, while also improving vessel contrast over i-SCAN 1 and HDWLE. Histograms and descriptive statistics of pixel luminance are found in Figures 4 and 5, and Table 2 below. Changes in mean and standard deviation between i-SCAN 1 and HDWLE are less than 5% in both datasets. i-SCAN 2 and 3 images exhibit comparably lower mean pixel values in both datasets. However, pixel luminance standard deviation differs substantially between i-SCAN 2 and 3. Since i-SCAN 3 exhibits a smaller increase in pixel standard deviation, more pixels with higher luminance values remain in the image than in i-SCAN 2. This produced an image with greater visibility of features in a dimly illuminated far-field region, which will allow for a contrasted view of larger luminal diameter areas.

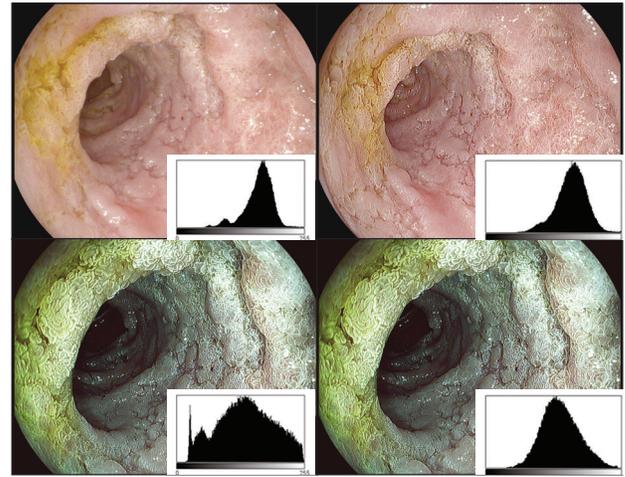


FIGURE 4. Normalized luminance histogram analysis of HDWLE and enhanced images of duodenum. Top Left: HDWLE. Top Right: i-SCAN 1. Bottom Left: i-SCAN 2. Bottom Right: i-SCAN 3.

Pixel Luminance Data

		MEAN	STD
DUODENUM (Figure 4)	HDWLE	163.8	28.5
	i-SCAN 2	161.1	28.9
	i-SCAN 2	136.8	56.8
	i-SCAN 2	140.6	35.2
COLON (Figure 5)	HDWLE	149.8	53.3
	i-SCAN 2	143.1	54.4
	i-SCAN 2	119.4	78
	i-SCAN 2	116.9	57.8

TABLE 2. Pixel luminance statistics for images in Figures 4 and 5 of the duodenum and colon respectively. Despite comparable reductions in mean pixel luminance, i-SCAN 3 exhibits a smaller increase in standard deviation resulting in more pixels with higher luminance values.

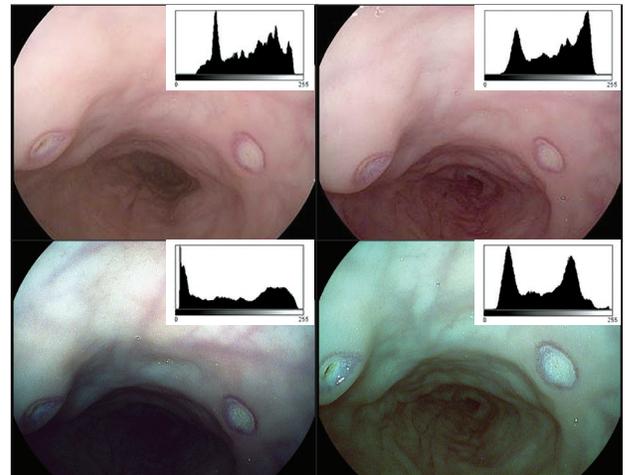


FIGURE 5. Normalized luminance histogram analysis of HDWLE and enhanced images of porcine colon. Top Left: HDWLE. Top Right: i-SCAN 1. Bottom Left: i-SCAN 2. Bottom Right: i-SCAN 3.

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