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Enhanced Blood Vessels in Laparoscopy by Using Narrow-Band Imaging

Hamed Akbari, Yukio Kosugi
Tokyo Institute of Technology
G2-16, 4259 Nagatsuta, Midori-ku, Yokohama
226-8502, JAPAN
d05akbari & kosugi@pms.titech.ac.jp

Kazuyuki Kojima, Toshiaki Ohya,
Hideki Akamatsu, Naofumi Tanaka
Tokyo Medical and Dental University
1-5-45 Yushima, Bunkyoku, Tokyo 113, JAPAN
tanaka.oper@tmd.ac.jp

Abstract

In laparoscopic surgeries, because of lack of tactile sensation and 3D visual feedback, it is difficult to identify the position of blood vessels intraoperatively. An accidental injury to a blood vessel could result in change of laparoscopic procedures to open surgery. A noninvasive, reliable, and economical method to detect blood vessels during laparoscopic and endoscopic procedures would be very useful. In this study we have examined the usefulness of narrow-band imaging. The contrasts and color differences between the blood vessels and the adjacent tissues were measured using narrow-band imaging and conventional broadband imaging. Wilcoxon signed-rank test was used as a statistical test for evaluating the differences between the two groups. By using narrow-band illumination of 530-550 nm, the contrast of the blood vessels was greatly improved. The performance of this technique is evaluated for detection of the artery and vein in the laparoscopic surgery on a pig. The results demonstrated a statistically significant difference with narrow band images, which have a higher contrast and higher color difference than the conventional images. The result shows that in narrow band images, we have lesser color difference standard deviation. The contrast in narrow band images is about twice that of the conventional images.

1 Introduction

Unlike laparotomy where a large incision is required, laparoscopic surgery is done by making a few small incisions to insert a laparoscope and other devices. This slim scope takes images and sends them to a monitor so the surgeon can see the operation field. For technical accuracy in this minimally invasive surgery, surgeons rely almost entirely on 2D visual feedback. No endoscopic probe has the capability for 3D shape visualization. In the laparoscopic surgery, because of lack of tactile sensation and 3D visual feedback, it is difficult to identify a blood vessel position intraoperatively.

A noninvasive, reliable, and cost-effective method to detect blood vessels would be useful during laparoscopic and endoscopic procedures. An accidental injury to a blood vessel could result in change of laparoscopic procedures to open surgery and it is a major limitation for development of more complex laparoscopic procedures [1].

As of now, various methods have been designed for studying the vascular system based on different physical properties. But optical methods are mainly attractive for identifying vascular system in Laparoscopic Surgery because light delivery to and from tissue can be accomplished via fiber optics. Narrow-band imaging (NBI) is a new technique which is used in several fields of science. In this technique only a specific wavelength is used. Recently narrow-band imaging has been used in several research fields in medicine as well. Sano et al. conducted preliminary clinical tests of NBI during colonoscopy. They reported that imaging of the colonic mucosa with NBI provides enhanced pit pattern contrast compared with ordinary observation [2]. Narrow-band imaging was used by Yoshida T. et al. for assessing the intrapapillary capillary loop in esophageal mucosa of forty-one patients [3]. Nakayoshi T et. al. used this technique in 165 patients with depressed-type early gastric cancer lesions. And the lesions were carefully observed with magnification using the NBI system [4]. Gono et. al. has evaluated usefulness of NBI in Barrett's esophageal endoscopy and Colonoscopy [5]. K Shibuya, et. al. investigated the use of high magnification bronchovideoscopy combined with narrow band imaging for the detailed examination of angiogenic squamous dysplasia (ASD). This was carried out in relation to bronchial vascular patterns with abnormal mucosal fluorescence in heavy smokers at high risk for lung cancer [6]. As of now, narrow-band imaging has been used in several types of endoscopic procedures but this method has not been evaluated for laparoscopic surgery. In this paper, as a new technique to identify the distribution of blood vessels, narrow-band images have been used on laparoscopic images. The blue filter is designed to correspond to the peak absorption spectrum of hemoglobin to emphasize the image of capillary vessels on surface mucosa. And the green image shows blood vessels at a deeper level [7]. In this study the filter 530-550nm was selected and color difference and contrast quantitatively were compared between narrow-band images and conventional broadband images. Because our research is still in initial stages, for first step we have done it on a pig. The results showed that narrow-band images have significantly more color difference and contrast.

2 Materials and Methods

The color laparoscopic images which are under processing have three R, G, and B channels. The dynamic range of the pixel in each channel is 8-bit. The images were captured from an abdominal laparoscopy on a pig. The light source used in the surgery was Olympus CLV-U40 in two modes conventional imaging and by using narrow band filtering (530-550nm). The Olympus light source has a filter disk which allows for placement of a desired filter in the light path for special applications. These two types of images were compared in point of contrast and color difference between blood vessels and nearby tissues. In this study, the contrast was defined as the Weber ratio. (Eq. 1) Human visual luminance perception was used to calculate substitution for the luminance.

$$ctr = \left| g_v - g_t \right| / g_t \tag{1}$$

where g is the pixel value of the recorded image and subscripts v and t refer to the blood vessel and its nearby tissue, respectively. The locations of blood vessels were selected manually by a medical doctor. After the position of the blood vessel was defined, the position of its neighbor tissue was defined from an area where there is not any blood vessel. Four hundred such selections were selected for the NBI and conventional laparoscopic images. For comparing contrast values and color differences which were obtained in each group, statistical formula was used. The correlated-samples t -test suppose certain assumptions such as the source population from which these differences have been drawn can be supposed to have a normal distribution. In this study, we cannot reasonably suppose this constraint to be satisfied, so the t-test for correlated samples is not appropriate. The Wilcoxon signed-rank test or Mann-Whitney U test which is used in our study is a non-parametric alternative to the paired Student's t-test for the case of two related samples. For large samples U can calculated as follows:

$$U = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1 \tag{2}$$

where R_1 is summation of the ranks assigned to group whose sample size is n_1 and n_1 and n_2 are samples size which in our study are equal. We may determine the significance of an observed value of U by: [8]

$$Z = \frac{U - \frac{n_1 n_2}{2}}{\sqrt{\frac{(n_1)(n_2)(n_1+n_2+1)}{12}}} \tag{3}$$

The CIELab color space was used in this study. The CIE system allows the measurement of color according to characteristics of human vision. The CIE has defined a system which classifies color according to the human visual system (HVS). Using this system we can specify any color in terms of its CIE coordinates and hence be confident that a CIE defined color will match another with the same CIE definition. The CIE has measured the sensitivities of the three broad bands in the eye by matching spectral colors to specific mixtures of three colored lights. The spectral power distribution (SPD) of a color is matched with these sensitivity functions to produce the tri-stimulus values. These tri-stimulus values uniquely represent a color, however since the illuminant and lighting and viewing geometry will affect the measurements these are all carefully defined. The three CIE tri-stimulus values are the building blocks from which many color specifications are made. The advantage of such a color space is that it enables us to predict what a color will look like when viewed by a (typical) observer in a variety of conditions. A CIE specification will enable a color to be made to match another and can be used to predict visual differences between colors. The three parameters in the model represent the lightness of the color (L*, L*=0 yields black and L*=100 indicates white), its position between magenta and green (a*, negative values indicate green while positive values indicate magenta) and its position between yellow and blue (b*, negative values indicate blue and positive values indicate yellow).

The difference between two measured colors can be expressed using the CIE color difference formula [9].

$$dE = \sqrt{\left(L_v^* - L_t^*\right)^2 + \left(a_v^* - a_t^*\right)^2 + \left(b_v^* - b_t^*\right)^2} \tag{4}$$

where the subscripts v and t represent the L*a*b* values calculated from the pixel values sampled from vessels and the nearby tissue, respectively. CIEL*a*b* values were calculated by CIE XYZ tri-stimulus values. (Eq. 5)

$$L^* = 116\left(\frac{Y}{Y_w}\right)^{1/3} - 16$$

$$a^* = 500\left[\left(\frac{X}{X_w}\right)^{1/3} - \left(\frac{Y}{Y_w}\right)^{1/3}\right]$$

$$b^* = 200\left[\left(\frac{X}{X_w}\right)^{1/3} - \left(\frac{Z}{Z_w}\right)^{1/3}\right] \tag{5}$$

where X_w, Y_w, and Z_w are XYZ tri-stimulus values of white. This white is the color displayed on the monitor with pixel values (R, G, B) = (255,255,255). The nonlinear L*a*b* transformation takes into account the findings that perceptual difference between two colors is nonlinear and better predicted by the contrast difference between the two colors [10]. For any color produced by additively mixing three primaries, the relationship between the primaries' luminance and the color's CIE tri-stimulus would be calculated. XYZ tri-stimulus values are calculated from RGB pixel values by Eq. (6) [11]

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = C \times \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{6}$$

where C is the 3 by 3 matrix:

$$C = \begin{bmatrix} \frac{x_R}{y_R} & \frac{x_G}{y_G} & \frac{x_B}{y_B} \\ 1 & 1 & 1 \\ \frac{z_R}{y_R} & \frac{z_G}{y_G} & \frac{z_B}{y_B} \end{bmatrix} \tag{7}$$

where x_R, y_R, z_R are the chromaticities which coordinate of the red. x_G, y_G, z_G are the chromaticities which coordinate of the green. And x_B, y_B, z_B are the chromaticities which coordinate of the blue.

xy chromaticity have calculated by the primary color on the color monitor as follows. (Table-1)

Table 1. xy chromaticity of a primary color in the color monitor

	Red	Green	Blue
x	0.63	0.29	0.15
y	0.33	0.60	0.06

Then, the remaining tri-stimulus value, z, can he computed as follows:

$$\begin{aligned} z_R &= 1 - x_R - y_R \\ z_G &= 1 - x_G - y_G \\ z_B &= 1 - x_B - y_B \end{aligned} \quad (8)$$

In CIELab, function L^* is a good index for human visual luminance perception. The contrast of L^* was calculated by Eq. (9).

$$L^* contrast = \left| L_v^* - L_t^* \right| / L_t^* \quad (9)$$

The laparoscopic surgery was done on a pig. The images were captured from different parts of intestine and peritoneum. In each image the selected pixels are from superficial and deep blood vessels.

3 Experiments and Evaluation

The performance of this technique is evaluated for enhancement of the arteries, veins, and capillaries in laparoscopic surgery on a pig. The surgery was on the pig's abdomen. The blood vessels were selected from different parts of the intestine, peritoneum, and other tissues. The pixels were selected from superficial and deeper vessels which could be seen in the operation field. The images cover different shapes of vessel in laparoscopic procedures.

The vascular distribution and pixels selection were done by a medical doctor by hand. These maps are used as the reference maps in calculating the contrasts and the color differences by using filter and conventional images. The images which are used in this study were divided into two groups: narrow band images and conventional images. These two groups are captured from similar parts of organs and tissues in the laparoscopy. As the next step we defined the blood vessels. Different types of the vessels were selected in this step including arteries, veins, and capillaries with different deepness.

We selected the pixels of the blood vessels and adjacent tissue in a pair in narrow band images and the conventional images. Four hundred pair pixels were selected for each group of narrow band images and conventional. The contrast and color difference were calculated for each pair. To test our hypothesis that contrast and color difference are higher in narrow band images, statistical theories were used. The correlated- samples t -test suppose certain assumptions such as the source population from which these differences have been drawn can be supposed to have a normal distribution. In this study, we cannot reasonably suppose this constraint to be satisfied, so the t-test for correlated samples is not appropriate. The Wilcoxon signed-rank test or Mann-Whitney U test which is used in our study is a non-parametric alternative to the paired Student's t-test for the case of two related samples. The images produced by the narrow-band filter and conventional images are shown in Fig. 1 and Fig. 2.

The p value for two groups of contrasts in narrow band images and conventional images is 1.40×10^{-66}. The p value for two groups of the color differences in narrow band images and conventional images is 7.81×10^{-24}.

Figure 1. An image of conventional laparoscopy

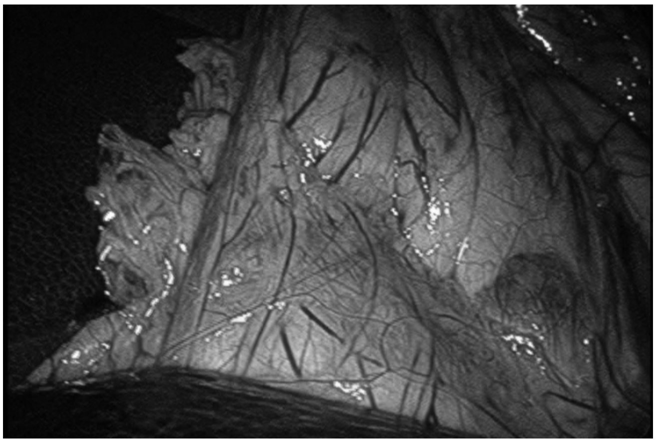

Figure 2. An image of NBI laparoscopy

In conventional images which are captured from conventional type of laparoscopic surgery, the contrast between the blood vessels and background tissues is 0.17 ± 0.06. The contrast between the blood vessels and the background tissues in the narrow band images is 0.35 ± 0.06. In conventional images which are captured from conventional type of laparoscopic surgery, the color difference between the blood vessels and background tissues is 25.95 ± 10.68. The color difference between the blood vessels and the background tissues in the narrow band images is 32.72 ± 6.60. (Table 2) The results also demonstrated a statistically significant difference with narrow band images, which have a higher contrast than the conventional images (p value <0.01). The results also show that color difference has a statistically significant difference in narrow band images and conventional images (p value <0.01). The result shows that not only color difference is higher in narrow band images but also in narrow band images, we have lesser standard deviation. The contrast in narrow band images is about twice of the contrast of the conventional images.

Table 2. p values of statistical analyses, contrasts, and color differences in two groups.

	Contrast	Color difference
Conventional	0.17 ± 0.06	25.95 ± 10.68
NBI*	0.35 ± 0.06	32.72 ± 6.60
P value	1.40×10^{-66}	7.81×10^{-24}

* Narrow Band Images

4 Conclusion

The open surgery has mainly replaced by the minimally invasive laparoscopic surgery. Proper detection and the localization of the blood vessels is of the utmost importance in laparoscopic surgery. An accidental injury to a blood vessel during laparoscopy could result in change the laparoscopy to open surgery. However, because of lack of tactile sensation and three dimensional visual feedback it is difficult for a novice or in anatomical variations. To facilitate blood vessels detection, especially for the novice, a newly developed NBI system was applied to conventional laparoscopic light source. The NBI system is a novel technology based on optimization of the spectrum features of the RGB filters to emphasize the blood vessels pattern. The present study demonstrates the advantages of the NBI system over the conventional imaging laparoscopic systems. Hurzeler used blue illumination to heighten the contrast of nodules, scars, and metaplasia in the bronchi. He used a blue filter with a broad bandwidth of about 250 nm. The results suggest that use of blue illumination will be useful for diagnosis in bronchoscopy[12]. Gono et al. has compared the narrow band imaging and board-band imaging in gastrointestinal endoscopy they found that $415nm \pm 30nm$ is appropriate for imaging the superficial blood vessels; $500nm \pm 30nm$ or $540nm \pm 20nm$ is appropriate for imaging little deep blood vessels; and $600nm \pm 20nm$ is appropriate for imaging the deeper blood vessels. In addition, they found that narrowing the bandwidth can improve the contrast of the vascular pattern. In our study, because we have considered the enhancement of the entire vascular pattern we have used *530-550 nm.* In this study we have numerically proved that narrow band imaging is a good method for enhancing the blood vessels during the laparoscopic surgery. And it can be useful in laparoscopic surgery because it is important in these procedures that surgeon is conscious to vessels and when surgeon notices that there may be a vessel in a special region, he or she can be more vigilant. Although in this study, surgery was done on a pig. For next steps it can be tested on the human and the other parts of the body.

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