CIELab and sRGB color values of *in vivo* normal and grasped porcine liver

Smita DE[1], Aylon DAGAN[1], Phil ROAN[2], Jacob ROSEN[2], Mika SINANAN[2], Maya GUPTA[2], Blake HANNAFORD[2]
[1]Dept. of Bioengineering, [2]Dept. of Electrical Eng., Univ. of Washington, Seattle, WA.

Abstract. Surgical simulators are excellent training tools for minimally invasive procedures but are currently lacking in realistic tissue rendering and tissue responses to manipulation. Accurate color representation of tissues may add realism to simulators and provide medically relevant information. The goal of this study was to determine feasible methods for measuring color of *in vivo* tissue, specifically liver, in a standardized color space. Several compressions were applied to *in vivo* porcine liver. Three methods were then used to determine the CIELab and/or sRGB colors of normal and damaged liver. Results suggest that there are significant differences between normal and damaged liver color.

1. Introduction

Minimally invasive surgical (MIS) techniques provide a number of patient benefits such as shorter hospital stays, decreased pain, and smaller scars. Surgical simulators have been developed to help surgeons train in MIS procedures and offer a number of advantages over traditional methods. Despite great potential, surgical simulators are still in a largely developmental stage [1]. Much effort is being devoted to improving the visual and haptic (force feedback) realism of simulators. Visual feedback is crucial as it provides 70% of our sensory input [2]. Therefore, it is important to accurately represent the effects of tissue manipulation in simulators such that trainees become accustomed to what occurs *in vivo*. Many current simulators tend to use approximate representations of organs and only illustrate consequences of gross errors (i.e. cutting a blood vessel) such that rough handling of tissues that may cause less severe injury may not be apparent to the trainee.

Color is a significant aspect of visual input and can provide medically relevant information. It has been used in other fields such as dermatology and dentistry to describe tissue pathology and aesthetics [3]. Monitors typically use device-dependent RGB, though many newer monitors utilize sRGB [4], a standardized color space. CIELab is also a standardized color space that is designed to be perceptually linear so that Euclidean distance in CIELab space is linearly related to human judgments of color differences. CIELab colors are described by ‘L’ for lightness, ‘a’ for the green to magenta spectrum, and ‘b’ for the blue to yellow spectrum.

Our goal was to develop a methodology that will allow for recording of accurate colors within an *in vivo* surgical field using a standard color space to allow for reproducibility. Such data could be used to improve the realism of tissue representation in simulators. We aimed to measure potential color differences between normal tissue

Medicine Meets Virtual Reality 15, Long Beach CA, February, 2007
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and grasper-manipulated tissue, as basic manipulation with graspers can cause tissue damage [5]. Our methodology included three techniques that were tested on *in vivo* porcine liver: CIELab estimation based on digital image, direct measurement with a spectrophotometer, and subjective visual validation. Several pilot experiments were done to determine an appropriate methodology. The results of one animal experiment using the revised methodology are reported here.

2. Methods

Adult female pigs were placed under full anesthesia and a laparotomy was performed. A motorized endoscopic grasper was used to apply compression stresses within the previously determined range typical of MIS to the edge of the liver [6]. Three methods to assess the color changes were performed within five minutes of stress application.

Digital Image Estimation: Based on pilot studies, a printed color chart was created with 48 colors that encompassed the expected color range of unstressed (normal) and stressed liver. Endoscopic lighting was used to illuminate the tissues from five inches away to mimic a laparoscopic setting. The color chart was photographed next to the injured tissues using a Canon PowerShot A80**.** Images from the experiments can be found on brl.ee.washington.edu/~sde/. CIELab values of the color chart patches were measured using a Spectrolino spectrophotometer. Average RGB values of the color chart patches and grasped and normal liver were measured in the digital images. The device-dependent RGB color values were transformed to device-independent CIELab color values using a regularized local linear regression trained on the known (RGB, CIELab) color pairs for the color chart patches [7].

Direct Spectrophotometry: The spectrophotometer probe was wrapped in clear plastic wrap to protect it from surgical site fluids and directly placed on normal and damaged tissues to measure their CIELab values. This method was only used in pilot studies so no results are presented here.

Subjective Validation: CIELab values measured in the pilot studies were transformed to the sRGB color space. Colors within the range of the measured values were displayed on an sRGB monitor. Three experts chose the best match between colors displayed on the screen and colors of the tissues under endoscopic lighting.

3. Results

Preliminary results of the digital image estimated CIELab values are given in Table 1. Student t-tests for ‘L,’ ‘a,’ and ‘b’ showed significant differences between normal and grasped tissues ($p < 0.05$). The table also contains corresponding sRGB values to the estimated mean CIELab values.

Table 1: CIELab (mean ± standard deviation) and sRGB (mean) values from Digital Image Estimation

	L ± S.D.	a ± S.D.	b ± S.D.	R	G	B
Normal	35.6 ± 0.78	40.5 ± 1.89	13.9 ± 0.98	140	53	75
Stressed	15.1 ± 0.33	-2.52 ± 0.42	10.6 ± 0.37	36	39	29

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Ranges of sRGB parameters of monitor colors identified by experts during the *in vivo* experiments are shown in Table 2.

Table 2: sRGB ranges from Subjective Validation.

	R	G	B
Normal	93-120	47-56	62-80
Stressed	96-120	44-56	55-70

4. Discussion

Three methods were tested for measurement of tissue colors *in vivo*. Pilot studies allowed for technique refinement and insight into which methods are most appropriate.

Digital image estimation was the most technical and user independent method, and similar estimation methods are standard in color management for printers. However, the estimations were only as accurate as the color chart allowed since the colors of interest should ideally be encompassed within the range of the color patches in the color chart. In addition, a continuing challenge is resolving differences in illuminants since the illumination of the spectrophotometer is not identical to the endoscopic light. Direct spectrophotometry was the simplest of the methods but had potential problems. Pressure from placing the probe on the tissue caused visible blanching of the tissue during measurement. Also, the *in vivo* setting may cause light from the probe to scatter rather than reflect back from the tissue leading to less saturated colors. This method will not be used further in this project. Subjective validation was the most relevant technique as the purpose of this study is for colors on simulator monitors to closely match what trainees will see in real surgeries. Other than subjectivity, a difficulty with this method was its dependence on what colors were shown on the monitor. Choices could be updated routinely based on subsequent experiments in order to obtain a narrower, more accurate range of sRGB values.

We have developed a methodology for accurate measurement of organ surface color with respect to the human observer. Preliminary results indicate that digital image estimation was sensitive enough to distinguish differences between normal tissue and damaged tissue, and subjective validation was appropriate based on our end goal. When transformed, the measured CIELab colors for normal tissue match closely with the sRGB range from the subjective validation. These two described approaches will be used to measure organ colors with statistically significant sample sizes.

5. References

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