Analysis of Multi-Modal Optical Images of Skin-Lesions For Skin-Cancer Detection and Characterization

Atam P. Dhawan, Nizar Mullani and Sachin Patwardhan

Abstract—Optical imaging of skin-lesions for early detection and management of skin-cancers has been of significant interest in dermatology. Though there are optical imaging systems available today, such as the “Dermascope”, they largely utilize surface illumination for epiluminescence light microscopy (ELM) imaging. Limitations of surface reflectance based imaging systems have been realized in producing images with important vascular and depth dependent information. We have developed a novel optical imaging system, the Nevoscope, that uses transillumination as to provide images of skin-lesions showing sub-surface pigmentation as well as vascular architecture based blood volume information. This paper presents a Nevoscope transillumination method to acquire vascular architecture information, and compare its performance to epiluminescence imaging method for its ability to measure vascular information for characterization of skin-lesions.

I. INTRODUCTION

Skin cancer is the most common malignancy of mankind representing about one-half of all new detected cancers.

Approximately 1.2 million new cases of skin cancer are detected in the United States each year. Melanoma is the deadliest of the skin cancers, accounting for 75% of all skin cancer deaths. It is estimated that one in five Americans will develop at least one skin cancer and one in 75 Americans will develop at least one malignant melanoma. More precisely, over 90,000 new cases of melanoma are estimated to have been diagnosed in 2004 causing over 7500 deaths. However, if detected early and excised, the cure rate of malignant melanoma is very high [1].

It is clear that patients can benefit greatly if their skin cancers are diagnosed during the earliest stages of tumorigenesis. However, despite this knowledge the early diagnosis of skin cancer has remained a challenge for clinicians and researchers alike. In an effort to increase the diagnostic accuracy and sensitivity for detecting early skin cancers many researchers have begun to evaluate non-invasive optical imaging instruments such as the Dermascope or the DermLite [1].

The current method of examining a skin lesion is to use surface lighting and some form of magnification lens. Most of the information obtained about a nevus from surface lighting is from the reflected light from the skin/air boundary and the deeper pigmentation structure is often overcome by the surface reflection of the light. The diagnostic accuracy of visually detecting early melanoma by expert physicians is 58% and is lower for non-experts who

do not specialize in early melanoma detection [1]. This accuracy is improved for advanced melanomas, which exhibit large changes in pigmentation and color in the skin lesion. A better accuracy for detecting melanoma can be obtained through the use of the Epiluminescence Light Microscopy (ELM) imaging method, where the reflection of the surface light is reduced by either an oil-glass interface on the skin (Dermoscope or cross-polarization of the surface and reflected light to cancel the surface reflection (MoleMax, DermLite, Oil-immersion epiluminescence microscopy (OELM)). It has been used by Wolf et al [1] to improve the accuracy of detecting early melanomas. Of course, the sensitivity for detecting melanoma varies with respect to the stage of the melanoma.

The ELM method of imaging skin-lesions utilizes surface reflectance dominant illumination techniques to allow the visualization of subsurface structures and colors. These subsurface structures and colors in combination with their location and distribution (pattern) have been shown to improve a clinician’s ability to detect early melanoma and basal cell carcinoma.

The ELM imaging can be performed utilizing polarized or non-polarized light. Cross-Polarization method for ELM imaging uses linear polarizer in the incident light and a viewing lens to cancel the light that is reflected from the skin. Since most of the reflected light from the skin surface has for the most part the same polarization angle as the incident light, cross-polarization blocks most of the surface reflected light and only the light that is diffused below the skin surface is visualized. Several investigators have demonstrated that the cross-polarization method of imaging with the ABCD rule can provide a comparable diagnostic accuracy for the detection of melanoma. Although, different illumination techniques allow for the visualization of many common structures and colors they are not identical. The non-contact cross-polarized dermoscopy method may prevent compression of blood vessels thus allowing for better visualization of the vascular plexus.

Though the ELM imaging method provides important information about the surface pigmentation texture and color patterns clearly, it provides little blood volume and vascular information due to the limited depth of penetration. The vascular information provided by cross-polarized ELM imaging method appears to be coming only from the superficial structures and does not represent the blood volume from deeper vascular structures.

In this paper, we present a transillumination light microscopy (TLM) method of imaging skin-lesions as an additional mode of optical imaging techniques to capture the

blood volume information from subsurface superficial and deeper vascular structures of skin-lesions. The comparison of various ELM imaging modalities including non-contact polarized and oil-based non-polarized methods are described elsewhere [ref?]. In this paper, we selected a non-contact polarized ELM method for comparison with TLM imaging method since the use of glass plate puts pressure on the skin surface causing a distortion in the superficial vascular architecture and change in blood flow in the respective sub-volume of the lesion. We compare non-contact polarized ELM with TLM imaging methods to demonstrate that TLM imaging method provides better vascular information from the subsurface lesion architecture. The experimental protocol of imaging of 40 skin-lesions including 16 benign and 13 compound nevi, and 10 dysplastic nevi and malignant melanomas along with analysis of segmented regions representing blood volumes from ELM and TLM images show a significant potential in obtaining increased blood volume information from TLM images. Further the increase in the blood volume as obtained from the ratio of the segmented pigment distribution areas between a TLM image and an ELM image of a skin lesion, shows promising correlation with the lesion progression.

II. METHOD

A. Nevoscope

Schematics of surface illumination and transillumination techniques used in, respectively, ELM and TLM imaging methods using the Nevoscope are shown in Figure 1a. For TLM imaging of skin-lesions, the Nevoscope uses a ring-light source based transillumination to transmit light directly into the skin area surrounding the lesion at an angle so that the light is focused underneath the surface of the skin behind the lesion [13,19,20]. A virtual light source is thus created a few millimeters below the skin surface for uniform transillumination of a small area of the skin containing the skin-lesion. The skin lesion is positioned inside the transillumination ring through the opening providing a direct field of view to the digital camera through a zoom-lens assembly. In TLM imaging method, the light from the illuminator ring that is not reflected back due to a mismatch in refractive indices, enters into the skin and goes through multiple internal reflections and scattering. This light eventually gets diffused across the layers of the skin and back-scattered diffused light photons emerge from the skin to form a *transilluminated* image of the skin and skin-lesion.

Nevoscope design incorporates a ring-light source interface for transillumination, and an additional cross-polarized surface light source to providing all modes of ELM imaging including oil-based contact imaging by adding a glass faceplate in the front of the lesion housing space. A no-glass faceplate model can be used for non-contact cross-polarization or transillumination modes of imaging. A schematic diagram of the Nevoscope is shown in Figure 1(b). Two independent optical fiber based channels provide light from the halogen light sources to the annular

ring source for transillumination and ELM imaging via the four openings around the walls of the cylinder for surface illumination. Transillumination is achieved by the ring-light source only, which is in contact with the skin through the frontal interface to the skin. Surface illumination is achieved by four fiber light point sources reflecting light on to the skin from the walls of the Nevoscope. For cross-polarized ELM imaging, the polarized surface light is provided using another polarizing lens (cross-polarized by 90 degrees) and the ring-light source is turned off. The surface light intensity is adjusted by rotating a knob located on the light box. An optical magnification lens, with the ability of limited focal distance adjustment, is used for a 5 X magnification of lesions. For this study, we used an Olympus C2500 digital camera, which has excellent focusing and color rendition capabilities.

Figure 1(a). Schematic representation of surface-reflectance based epiluminescence imaging (top) and transillumination imaging (bottom) methods.

Figure 1. (b) A schematic diagram of the Nevoscope instrumentation.

B. Experimental Imaging Protocol

Patient were selected randomly from the clinical visits at the M.D. Anderson Cancer Center from the recommendations of attending dermatologists without regards to race or gender, but based purely on the appropriateness of pigmented lesions.. Each lesion was imaged using both ELM and TLM imaging methods using a Nevoscope designed through modifications on a Dermlite-II instrument to include TLM imaging methods [2]. After imaging, lesions were excised on voluntary basis or clinical reasons. The histopathology was performed at the M.D. Anderson Cancer Center for lesion classification and vascular blood volume measurements.

The pathology slides from the excised lesions were analyzed by an expert dermatopathologist at the University of Texas M D Anderson Cancer Center. The diagnosis was made blinded to the patient history or imaging results. The lesions were classified according to the list in Table 1. For this study, due to the low number of melanomas expected, dysplastic nevi were grouped with malignant melanomas for the computation of diagnostic accuracy.

C. Segmentation of Blood Volume Regions

In this study, each image, whether ELM or TLM, undergoes a completely automated procedure consisting of three main steps of processing, before the lesion in the image can be identified, namely preprocessing, segmentation, and data analysis. In turn, each main step consist of several sub-steps. The entire procedure is described below:

Preprocessing

- Quality control of the captured images to discard over exposed images or those with an air gap between the Nevoscope ring and the skin surface. The latter creates a shift in the captured image color space
- Resize: Original images have a very high resolution of 1368 x 1712 pixels and an approximate size of 1.5 MB. To reduce the size of an image, and thus increase the processing speed, images are resized to 256 x 320 pixels using bicubic interpolation. These values maintain the original aspect ratio of the image.
- Masking: Furthermore, images have a circular bright ring all around the lesion, due to reflection of light from the edge of the glass plate. To remove this bright ring of light, a binary mask with a circular diameter 256 pixels is generated, and centered at the center of the lesion, which is defined as the intersection of the two diagonals of the image. Then, the mask is multiplied with the image to produce a new image.
- Cropping: Finally, the Image is cropped to a 256 x 256 image to remove the extra black background around the disc.
- Hair Removal: The artifact can be removed, or its effect minimized, by median filtering the image with a structuring element of size of [1 x 4] and [4 x 1].

Image Segmentation

- Image normalization to control the dynamic range of the color space followed by histogram equalization for contrast improvement.
- $L^*a^*b^*$ color space transformation for better separation of the pigment information from the illumination and light intensity artifacts.
- The two types of images to be segmented: ELM and TLM contain information about the melanin and hemoglobin distributions respectively. Melanin information from the ELM images was highlighted by a combined color space obtained using: $(*a + *b) - *L$. Hemoglobin information from the TLM images was highlighted by a combined color space obtained using: $(L^*) \times (a^*)$.
- Adaptive threshold was calculated for the combined color space images using Otsu's method [3]. This thresholding technique chooses the threshold to minimize the intra-class variance of the black and white pixels.
- Threshold were used to convert the images in to binary images and the pigmented area was then segmented using standard morphological operations.

Data Analysis

- After segmentation of the ELM and TLM images the surface area of the segmented regions were calculated.
- The ratio of the melanin and hemoglobin pigment distribution area was correlated with the lesion type information obtained from pathological evaluation. Images using ELM and TLM imaging methods for forty lesions were segmented and the area of the segmented lesion was computed. Each image was verified independently by a dermatoptahologist for its segmented regions.

III. RESULTS

A total of 40 images comprising of 13 benign lesions, 18 dysplastic lesions and 9 malignant melanomas where used in this study. The range of ratios found based on the sample data were between 1.0177 and 1.0696 for benign lesions, 1.0963 and 1.2471 for dysplastic lesions, and greater than 1.7270 for malignant lesions. Based on the initial hypotheses the algorithm would yield a 69.23%, 77.78 % and 100.00% positive identification of the benign, dysplastic and malignant lesions respectively.

Lesion Type: NM= Benign DN=Dysplastic Nevus MM=Malignant Melanoma	Average TLM/XLM Ratio	Standard Deviation TLM/XLM Ratio
NM (n=13)	1.0416	0.018606
CN (n=18)	1.170894	0.04277
MM (n=9)	2.676643	1.392814

Table 1: Average and standard deviation of the TLM/XLM ratio for different lesion types.

IV. CONCLUSION

In this paper, a Nevoscope transillumination method to acquire vascular architecture information has been discussed and analyzed to compare with the lesion information provided by the epiluminescence imaging method for its ability to measure vascular information for characterization of skin-lesions. The analysis on the ratio of segmented regions from transillumination and epiluminescence has shown to be correlated with the pathology of the skin-lesion. It has been shown that the malignant lesions has higher ratio of the segmented regions computed from transillumination image to epiluminescence image of the same lesion due to increased blood flow. The benign lesions with normal blood flow provided the approximately the same segmented region computed from the transillumination and epiluminescence images. Thus, the transillumination images provides important information about vascular structure and blood flow around the lesion. Further work is being conducted to

more accurately determine the vascular information through multi-spectral Nevoscope imaging.

ACKNOWLEDGMENT

We acknowledge the kind support from the George A. Ohl Jr. Trust Foundation, and the Pfeiffer Foundation. We also thank Dr. Madeleine Duvic for clinical imaging.

REFERENCES

- [1] Wolff K, Binder M, Pehamberger H: Epiluminescence microscopy: a new approach to the early detection of melanoma. *Adv in Derm.* 1994;9:45-56
- [2] Dhawan A. P., "Apparatus and Method for Skin Lesion Examination", US Patent Number 5,146,923, 1992.
- [3] Otsu, N., "A Threshold Selection Method from Gray-Level Histograms," *IEEE Transactions on Systems, Man, and Cybernetics*, Vol. 9, No. 1, 1979, pp. 62-66.

Sample ELM image segmentation

Sample TLM image segmentation