The purpose of this study was to assess the precision of automatic computerized measurement of parameters that may be useful in the differentiation of malignant melanoma from benign pigmented skin lesions, and also to determine the feasibility of quantitative monitoring of skin lesions over time. Ten independent sequences of images were acquired with a MelaFind multispectral digital dermoscope for each of 12 benign or malignant pigmented skin lesions. The sequences of images were processed automatically to provide 10 independent measurements of the various parameters for each lesion. Parameters included lesion area, greatest 'diameter', perimeter, reflectance and asymmetry. The precision of each parameter determination was computed from the mean and standard deviation of the 10 measurements of that parameter. The relative errors in determining the lesion area, 'diameter' and perimeter were found to be 6%, 3% and 4%, respectively. Other lesion parameters that are used in differentiating melanomas from benign skin lesions were also analysed as a function of wavelength. In the blue band (about 430 nm) the relative error was about 7% for the mean lesion reflectance and about 7% for the asymmetry parameter. These results demonstrate the feasibility of using MelaFind for objective quantitative monitoring of changes in pigmented skin lesions over time. As suggested by some studies, such information is useful in the early detection of malignant melanoma. The results show that parameters obtained automatically from MelaFind images are sufficiently precise to allow pertinent parameters to be used to classify pigmented skin lesions. © 2000 Lippincott Williams & Wilkins

Key words: computerized image analysis, early diagnosis, malignant melanoma, multispectral digital dermoscope, pigmented skin lesion

Introduction

The incidence of malignant melanoma is increasing. The lifetime risk for melanoma was 1 in 1500 in the United States in 1930; it has been projected that it would be 1 in 75 in the year 2000.¹ Melanoma carries a high mortality rate once it metastasizes, and in fatal cases results in an average loss of 17.1 years of life.² However, melanoma is curable if diagnosed early.³

Early detection of melanoma poses a challenge to both general physicians and dermatologists. The accuracy of clinical diagnosis by dermatologists ranges from 64±75%.⁴ The use of a dermoscope may improve diagnostic accuracy; however, training and experience are needed to interpret the dermoscopic images.⁵

Further efforts towards early detection include the development of the clinical ABCD rules,⁶ dermoscopic ABCD rules,⁷ and a wide variety of computer-based image analysis systems.⁸⁻¹² All computer-based systems must perform certain essential functions. The first step is the digitization of photographic images or the direct acquisition of digital images of the skin lesions. The images must then be segmented to separate the lesion from the surrounding skin. Various lesion parameters are then computed from the segmented images, and parameters that are significantly different in melanomas and benign lesions are identified. These parameters can then be used for lesion classifica-
tion, i.e. for differentiation between melanomas and other pigmented cutaneous lesions. Thus, it is essential for the reliability of classification to determine the lesion parameters with high precision.

In the clinical setting, computer-based systems may provide diagnostic information, often based on a single-time examination of the lesion. However, there are indications that the history of a lesion may also provide important diagnostic information. In a recent paper, Kittler et al. evaluated the performance of ABCD rules for dermoscopy combined with information about changes in the lesion size, colour or shape, as well as about ulceration or bleeding, within 1 year prior to excision. Of the 356 small (less than 1 cm in diameter) pigmented skin lesions, 73 were diagnosed by histopathology as melanomas. This study found that the frequency of reported changes was significantly higher for the melanomas. Together with the ABCD scores, this information (based on patients’ reports) proved useful in differentiating melanomas from benign skin lesions.

Follow-up of pigmented skin lesions using digital epiluminescence microscopy was described by Braun et al. The changes (in colour, size, and architecture) in lesions were determined by visually comparing the digital images acquired over a period of 2 years. Two types of changes were documented: in colour only and in size and architecture. The latter type of change appeared to be correlated with ‘dysplasia’.

A study by Menzies et al. suggests that clinical history should be included in the diagnostic process. In this study, all nine melanomas that lacked characteristic dermoscopic features for melanoma had a history of change in colour, shape or size. These studies suggest that quantitative monitoring of changes in pigmented skin lesions should improve the diagnostic accuracy for melanoma.

In order to have reliable diagnostic value, assessment of the changes in the lesion should be objective and repeatable. This paper describes the MelaFind system developed by Electro-Optical Sciences, Inc. Our study was conducted to determine the precision of lesion parameter measurements with this system. The study results show that objective quantitative monitoring of pigmented skin lesions is feasible. The high precision of automatic parameter measurements with the MelaFind system also supports the feasibility of reliable classification of pigmented skin lesions.

Materials and methods

The MelaFind system

In our study we used the MelaFind multispectral digital dermoscope to acquire images of pigmented skin lesions. The system illuminates the skin with light in 10 narrow spectral bands in the visible and near-infrared. The illumination consists of filtered white light from a highly stable source. The filtered light is conveyed to the skin through a fibreoptic illuminator. A charge-coupled device (CCD) camera detects light in each of the 10 spectral bands used to illuminate the skin. Digital images acquired by the camera are then sent to a computer for processing.

The imaging system provides low noise, high resolution digital images at a high data transfer rate, with low distortion imaging over the entire field of view of about 2.5 × 2.0 cm. In the lesion plane, the pixel size is 20 × 20 μm. The monochrome CCD camera is contained in a unit mounted on an articulated arm that can be locked into position. The camera produces digital images 1280 × 1000 pixels in size. The illuminator is controlled by a stabilized power supply, the setting of which is adjusted automatically by the computer. Narrow interference filters, placed on a rotating wheel, are used to filter white light in bands from 430 nm to 950 nm. A fibre illuminator conveys the filtered light to the lesion, providing nearly uniform illumination at the skin surface. Non-uniformities of the illumination and the optical system, as well as the non-uniform response of the camera chip, are eliminated during calibration. Typically, the entire multispectral sequence of 10 images is acquired in less than 3 s.

The results reported here are from dermoscopic imaging, in which a layer of mineral oil is applied to the skin and a glass plate (at the front end of the camera unit) is placed over the oil layer. Slight pressure is applied, through the glass, to the skin throughout the imaging process, to minimize the problem of misregistration of images in different spectral bands. Based on the high repeatability of parameter estimation, misregistration is not important.

The system permits image data to be recorded in each spectral band over a large linear dynamic range, independent of skin type. In addition, each lesion image includes an image of a narrow strip of oil-free, diffusely reflecting calibration material, located along one edge of the field of view. The absolute reflectance of this material is known at each wavelength. The average image intensity in the strip region is used to obtain the absolute reflectance in every
pixel for every image in the multispectral sequence. This allows the colour calibration of the lesion images.

The database

Ten sequences of multispectral images were acquired for each of the 12 pigmented skin lesions. The 12 lesions consisted of one invasive melanoma (Breslow thickness 0.63 mm), one melanoma in situ, nine melanocytic naevi and one seborrhoeic keratosis. To ensure that the sequences were independent, the CCD camera was removed from the skin after each sequence, the lesion and surrounding skin were cleaned, oil was reapplied, and the camera repositioned on the lesion. Since air bubbles may affect the measured values of parameters such as reflectance, the operators previewed the images prior to acquisition and started again from the beginning of the procedure if bubbles were present. Since each sequence of images was acquired independently, the lesion location and orientation in the field of view of the camera varied from sequence to sequence. To reduce biases in the results, the lesion images were acquired using two different instruments at two different geographic locations (New York City and southern Florida) by five different operators.

Each sequence of multispectral images was analysed automatically. The first step in the image analysis is segmentation of the lesion from its surroundings in the field of view, as described previously. The resulting segmentation mask, one for each sequence, was used to compute parameters such as area and perimeter, and also to segment images in all the spectral bands. The segmented spectral images were used to compute the wavelength-dependent lesion parameters. The 10 independent values of each parameter obtained for each lesion were then used to compute the average value of that parameter as well as the standard deviation. An example of a multispectral sequence of images for a melanoma in situ is shown in Figure 1, together with the segmentation mask for this sequence.

Results

Figure 2 shows the results of the lesion area measurements. The error bars shown in the figure represent one standard deviation. The lesions ranged in area from about 2 mm² for the smallest naevi to over 100 m² for the melanomas. The relative errors were similar and the average relative error was only about 6%. If on two examinations the lesion area changed by more than about 12%, this change would be statistically significant at the 95% confidence level.

Figures 3 and 4 show the results for lesion ‘diameter’ and perimeter measurements, respectively. The ‘diameter’ is defined as the longest distance between two points located on the lesion border, as determined by the segmentation mask; the perimeter is the length of the lesion border. Again, despite a wide range of values for these parameters, the relative errors were similar and averaged about 3% for the ‘diameter’ and about 4% for the perimeter. This is consistent with the results shown in Figure 1 concerning area, since the error in area measurement should be about twice the error of measuring a linear dimension.

The MelaFind images also allowed determination of the absolute reflectance for each pixel in each of the 10 spectral bands. Figure 5 shows the average lesion reflectance at 430 nm (blue band). Melanomas, seborrhoeic keratoses and some naevi reflect only a few per cent of the incident blue light and thus appear rather dark. The average relative error in reflectance measurement at this wavelength was about 7%.

Lesion reflectance varies considerably with wavelength. As shown in Figure 6, the average reflectance increases from a few per cent in the blue to about 30–40% in the infrared. Similarity in the average reflectance between melanomas in situ and naevi is not uncommon. In addition, seborrhoeic keratoses often appear as dark as invasive melanomas. Figure 7 shows the means of the spectral lesion reflectance for 33 invasive melanomas, 30 melanomas in situ, 183 naevi and 22 seborrhoeic keratoses from the MelaFind image database. It can be seen that the four lesions shown in Figure 6 are representative of their types.

Colour variegation is considered to be characteristic of melanoma and is included in the clinical and dermoscopic ABCD rules. Since lesions are not usually pigmented uniformly, the lesion reflectance may vary greatly from pixel to pixel. The ‘colour variegation’ parameter, defined as the standard deviation of the lesion reflectance, is shown in Figure 8. The results are of high precision and show that, regardless of the lesion type, the pixel-to-pixel variability in reflectance appears to be maximum in the red band (650–700 nm).

Lesion asymmetry has long been recognized as a characteristic of melanoma, as evidenced by its
inclusion in the ABCD rules. The asymmetry parameter, shown in Figure 9, was computed as follows. First, in each spectral band the two orthogonal principal axes in the segmented image were located and the image was then rotated to make these axes parallel to the image edges. The difference of intensities was then computed for every pair of pixels with locations that are mirror

Figure 1. A sequence of multispectral images for a melanoma in situ, together with the automatically obtained segmentation mask for this sequence.
The asymmetry parameter for that axis is defined as the ratio of the sum of the absolute values of intensity differences and the total intensity in the segmented image. This normalization to the total intensity is necessary to ensure that the computed quantity is independent of the overall image brightness. It also makes the asymmetry parameter a measure of the fraction of the total lesion area that has different intensities on two sides of the principal axis.

![Figure 2](image1.png)

**Figure 2.** Automatic determination of the area of pigmented skin lesions. The error bars represent one standard deviation computed from 10 independent measurements for each lesion. The average relative error was about 6%. Changes in area in excess of 12% would be significant at the 95% confidence level.

![Figure 3](image2.png)

**Figure 3.** Automatic determination of the ‘diameter’ of pigmented skin lesions. The ‘diameter’ is defined as the longest distance between any two points on the lesion border. The error bars represent one standard deviation computed from 10 independent measurements for each lesion. The average relative error was about 3%. Changes in ‘diameter’ in excess of 6% would be significant at the 95% confidence level.

![Figure 4](image3.png)

**Figure 4.** Automatic determination of the perimeter (the length of the border) of pigmented skin lesions. The error bars represent one standard deviation computed from 10 independent measurements for each lesion. The average relative error was about 4%. Changes in perimeter in excess of 8% would be significant at the 95% confidence level.

![Figure 5](image4.png)

**Figure 5.** Automatic determination of the mean reflectance in the blue band (430 nm) of pigmented skin lesions. The error bars represent one standard deviation computed from 10 independent measurements for each lesion. The average relative error was about 7%. Changes in the mean reflectance in the blue band in excess of 14% would be significant at the 95% confidence level.
axis. The lesion asymmetry parameter is the sum of the parameters computed for the two principal axes. The results for four lesions are shown in Figure 9. Clearly, this parameter varies with wavelength, and so does the relative error of its determination. The relative error for the 12 lesions used in this study was about 7% in the blue band (430 nm). The separation between the two malignant and two benign lesions seen in this figure does not in itself prove that the asymmetry parameter differentiates melanomas from benign lesions. However, the spectral asymmetry parameters did differ significantly between the populations of naevi (183) and melanomas (63) in the MelaFind image database.

Figure 6. Automatic determination of the mean reflectance as a function of wavelength for four pigmented skin lesions. The error bars represent one standard deviation computed from 10 independent measurements for each lesion.

Figure 7. Population averages of the mean reflectance for melanomas (invasive and in situ), naevi and seborrhoeic keratoses from the MelaFind image database as a function of wavelength. These data show that the mean spectral reflectances of lesions shown in Figure 6 are similar to the population averages.

Figure 8. Automatic determination of the ‘colour variegation’ parameter as a function of wavelength for four pigmented skin lesions. For all the lesions shown, the ‘colour variegation’ parameter was maximum in the red bands (650–700 nm). The error bars represent one standard deviation computed from 10 independent measurements for each lesion.

Figure 9. Automatic determination of the asymmetry parameter as a function of wavelength for four pigmented skin lesions. The error bars represent one standard deviation computed from 10 independent measurements for each lesion. The asymmetry parameter is very important for the differentiation between melanomas and other pigmented lesions.
Discussion

The monitoring of melanocytic skin lesions over time was discussed by Stolz et al.16 The image acquisition system they used consisted of a hand-held three-chip CCD camera (Sony). The field of view of the camera was 1.18 × 1.18 cm and the pixel size in the lesion plane was about 22.7 × 22.7 µm. Image segmentation was performed manually, moving the cursor along the lesion border. The relative error in area determination was reported to be less than 10%. The digital database also allowed side-by-side comparison of lesion images acquired at different times in order to determine visually changes in colour and dermoscopic structures. In 25% of the cases studied, these changes occurred without a significant change in lesion area. The authors concluded that monitoring lesions over time requires more than the measurement of the lesion area alone.

The MelaFind system for the acquisition of multispectral images of pigmented skin lesions and automatic analysis of such images allows objective determination of lesion parameters. In this study of the precision of parameter measurements the relative errors in determining the lesion area, ‘diameter’ and perimeter were 6%, 3% and 4%, respectively. Such an analysis was also carried out for lesion parameters that have been found to help in differentiating between melanomas and other pigmented skin lesions. For example, the lesion asymmetry in the blue band (430 nm) was determined with an error of about 7%. In addition, the colour of the lesion could also be determined quite reliably and objectively; the average relative error in the blue reflectance was about 7%.

The multispectral images acquired by MelaFind allow determination of lesion parameters as a function of wavelength as shown for asymmetry, as well as different measures of the reflectance distribution within a lesion. Such spectral representations may prove to be useful in following changes in lesion colour and architecture over time.

Conclusion

This study demonstrates the feasibility of using the MelaFind system for quantitative and objective monitoring of changes in pigmented skin lesions over time. As suggested by some other studies, this information is useful in the detection of early malignant melanoma. The demonstrated precision of automatic parameter measurements suggests that reliable classification of pigmented skin lesions with the MelaFind system may be feasible.

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