

Digital volumetric measurement of cutaneous leishmaniasis lesions: Blur estimation method

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Abstract

Background: Cutaneous leishmaniasis is a common parasitic infestation in Iran. With recent advantages in digital imaging, we have devised a novel non-contact objective method of measuring lesions.

Aim: The aim of the study was to design a software system that analyzes images of cutaneous leishmaniasis lesions, objectively assess and monitor volume.

Methods: A photographic technique along with an image processing algorithm was applied to extract a three-dimensional map of the lesion from a simple two-dimensional picture. This method recovers depth on the basis of blur estimation. A macro lens with a low depth of field was used to blur the objects out of focus. To assess and compare the results, a polymer mold of the corresponding lesion was made and filled with liquid. The volume of liquid corresponded to the volume of the lesion. A total of thirty-seven patients were enrolled, and 48 lesions were analyzed.

Results: The mean volume measured by image processing was 159 μl (range: 8–685 μl), in comparison to an average of 170 μl (range: 6–800 μl) obtained from the molds. This was not significantly different. Statistical analysis by the Pearson correlation test showed a 'very good fit' correlation between these measured volumes ($P < 0.001$, $r = 0.938$).

Limitation: The location and height of lesions were two important limitations in implementing this technique. If the lesion location is in the curvature region of body or the lesion height is less than 1 mm or more than 1 cm, this method will lose precision and accuracy.

Conclusion: Image processing with blur estimation technique is an accurate and precise method to measure the volume of lesions in cutaneous leishmaniasis.

Key words: Blur estimation, computer-assisted image processing, cutaneous, depth of field, leishmaniasis, photography

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Introduction

Cutaneous leishmaniasis has a worldwide distribution, but is endemic in parts of Asia and Africa, the Mediterranean basin and South America. It is caused by the leishmania protozoa, which is transmitted by the bite of an infected female phlebotomine sandfly. Clinically, it begins as a small, well-demarcated papule at the inoculation site. It may then enlarge into a nodule or plaque, and

eventually becomes ulcerated or verrucous.^{1,2} Despite the progress made in treatment protocols of cutaneous leishmaniasis, there have been few advances in the objective assessment of lesions during treatment. Traditional physical examination and simple methods are used in the assessment of clinical outcome. Physical

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examination includes inspection and palpation, where information such as morphology, size, color and consistency of the skin lesion are obtained. The evolution of lesions is assessed by comparing data from physical examination during successive visits, and the approximate rate of change is determined.^{3,4} This is based on the clinical experience of dermatologists, which is difficult to standardize.

During the last decade, objective non-contact and dermatologist-independent clinical assessment methods have been developed. The use of digital imaging to monitor and assess skin lesions has become popular as an auxiliary tool in conventional clinical assessment, which helps to evaluate the clinical course.⁵ Several systems have been designed for photographic analysis of skin lesions. They are utilized mainly in pigmented lesions and chronic skin ulcers. As the equipments are expensive and usage needs experience, they are not routinely used as an alternative to clinical assessment.^{4,6-8}

In this study, cutaneous leishmaniasis is an example of infiltrative cutaneous lesion that can be objectively evaluated using a method of digital image processing. The tools include inexpensive and easy-to-use hardware and software, which extract and analyze the quantitative data of digital images taken from lesions. The lesion volume was the most important parameter assessed in this study. The most challenging part in calculating the volume is measuring the height. A three-dimensional map needs to be created from a single two-dimensional image of the lesion. The depth recovery from a two-dimensional image is achieved by image processing. Several passive techniques have been introduced by researchers.^{9,10} An example of this application is seen in laparoscopic surgery, where a technique was developed to create a three-dimensional view of the surgery site.¹⁰ These techniques are divided into two categories. The first category needs only one image, depth recovery from the depth of field by blur estimation being an example. The second category needs more than one image, which is obtained by using more than one camera, or changing the camera parameters and position. Shape-from-motion, shape-from-shading, stereoscopy, structured light and time-of-flight are examples.

Depth recovery from blur estimation technique was used to measure the volume of lesions in our study. To the best of our knowledge, this method has been applied for the first time in dermatology.

Methods

Thirty-seven patients with cutaneous leishmaniasis referred to Imam-Reza Hospital, Mashhad, Iran, were enrolled in the study of six months' duration. The inclusion criteria were a positive direct smear for Leishman bodies, compliance for photography and mold casting of the lesion. Lesions that were in hard-to-photograph anatomical regions were excluded. Informed consent was obtained from all patients. Based on the general condition of the patient, speed and availability of equipment, depth recovery from blur estimation method was used to evaluate the lesion volume of patients with cutaneous leishmaniasis.

When images are captured with a small depth of field, objects that are away from the focal plane are out of focus and perceived as blurry. This effect usually occurs at relatively large apertures, or when the focal plane is close to the lens (such as a macro lens). Any image that includes objects in focus and out of focus could therefore be segmented in terms of depth. By measuring the size

of this blur, we can produce a three-dimensional depth map of the same image. We used a method proposed by Hu and De Hann for blur estimation.¹¹ In their approach, they reblurred the signal twice by two Gaussian kernels, to determine the local blur of the signal. To review other blur estimation methods, we refer the reader to published papers.¹²⁻¹⁴

To understand the technique of volume measurement from blur estimation, let us assume the skin and lesion as layers of wood. We have assumed that the lesion as layered so that each layer has a thickness of 1 mm. This is depicted in Figure 1, in which the last layer of wood with the sharpest view represents the skin or baseline. The layers of wood in the foreground represent the lesion. We focused on the last layer, and the other 1 mm thick layers were blurred. The amount of blurring over a layer is almost specific. If we can measure this amount, we can relate the blurring to the distance from the baseline.

The concept of depth from focus involves calculating distances to points in an observed scene. This parameter is determined by modeling the effect that the camera's parameters have on obtained images with a shallow depth of field.¹⁵ This technique does not require special scene illumination and needs only one camera.¹⁶ If a camera has a very limited depth of field, only points in the observed scene that are at the same distance from the camera will be in perfect focus. Other points in the scene, at different distances from the camera, will be out of focus. Therefore, an object out of focus will produce a blur such that its degree depends on the object distance from the focus or depth. If we can estimate the amount of blurring, we can estimate the relative depth.¹⁷

Based on equations stated by Pentland on depth-from-defocus¹⁸, it would be possible to measure absolute depth, if we would know all the camera's parameters and object distance from lens and blur size. However, this is practically impossible to determine as the



Figure 1: The skin and lesion are assumed as a wooden layered shape. The last piece of wood with the sharpest view represents the skin or baseline, and the layers in the foreground represent the lesion

parameters which are varying are uncontrollable. Therefore, the passive method was used. In passive method, the optical system was calibrated using standard samples with specific height from 1 mm to 1 cm with 1 mm increasing steps. After calibration we knew each 1 mm distance from focus point produces how much blur ring. Then photos of lesions were taken with same optical system and arrangement. After that, images were processed using blur estimation algorithm.¹⁹ Lesional area was gridded with fine mesh and multiplication of the area of each mesh and its height produces the mesh volume. Summation of all mesh volumes is the lesion volume. Based on the standard samples and image processing program, we calculated height from 1 mm to 1 cm with 1 mm steps.

An important issue associated with depth from focus is the horizontal and vertical resolutions of this method. Each point on the object plane creates corresponding point on the image plane of camera sensor. These points on image plane have usually a circular disposition called the circle of confusion. The diameter of this circle, which depends on the lens parameter, determines the horizontal resolution. In fact, in image analysis, this is the least limit to extract useful information. The radius of circle of confusion, ρ , can be derived using Fourier optics:²⁰

$$\rho = 1.22 \lambda f \quad (1)$$

where λ is the wavelength of light and f is the aperture number of the lens.

Vertical resolution describes the variation of point size in image plane in regard to change of distance from focal point in object plane. Using derivative of depth of field formula, we can determine the vertical resolution:

$$\frac{\partial R}{\partial V} = \frac{1}{2} \frac{F^2}{f(O-V)^2} \quad (2)$$

where V is the distance of point on object from focal point, R is the blur size, F is the focal length and O is the distance from the lens to the point of interest.

We used the Nikon D7000 DSLR camera with AF-S DX Micro NIKKOR 40mm f/2.8G macro lens that produces a shallow depth of field. The lesional and perilesional skin were exposed normally to the lens and kept fixed. We put a ruler near the lesion for convenience. The normal skin around the lesion was kept in focus, and the lesion was blurred because of convexity and displacement from the focus point. The amount of blurring is directly proportional to the height of the lesion from the normal skin. The images were processed using MATLAB code. The border of the lesion was delineated [Figure 2]. In the following step to determine the local blur, the selected area reblur with two Gaussian kernels and two blur pictures (A and B) are produced. The R pictures in Figure 3 show the difference between these two pictures and original image. In the blur map, a darker color is a larger amount of blur and finally the program calculates the volume of the lesion in microliters [Figure 3]. To validate the results of this method, a mold of the lesion was prepared using Speedex Putty, an incremental silicon derivative. This mold was filled with liquid by a Hamilton microliter syringe. The volume of liquid required to fill the mold corresponds to the volume of the lesion.

The statistical analysis of this study was performed using SPSS version 16 (SPSS Inc. Released 2007. SPSS for Windows,



Figure 2: Delineation of the lesion boundary

Version 16.0. Chicago, SPSS Inc.). The paired t -test was used to compare dependent quantitative data. Pearson correlation test was used to investigate the correlation between quantitative data. A P value of less than 0.05 was considered statistically significant.

Results

Forty-eight lesions of cutaneous leishmaniasis were studied. The size of the lesions varied from 2 mm × 2 mm to 25 mm × 40 mm. Figure 4 shows the frequency distribution of these lesions at different anatomic sites. The volume of lesions was measured by an image processing program (blur estimation algorithm) and mold cast. The mean volume measured by the image processing program was 159 μ l (range: 8–685 μ l), and was 170 μ l (range: 6–800 μ l) with the mold. The percentage difference between both methods was 6.4%, and statistical comparison using the paired t -test showed no significant difference ($P = 0.298$). The measured volume was identical in 7 (14.6%) of 48 lesions. The percentage difference between volumes was less than 5% in 23 (47.9%) lesions. The frequency distribution of the rate of difference between volumes obtained by image processing and mold is shown in Figure 5. The Pearson's correlation test indicated a strong relationship between the volumes measured by image processing and mold ($r = 0.938$, $P < 0.001$).

Discussion

Recovery of depth from blur estimation is an inexpensive and easy method to measure the volume of cutaneous leishmaniasis lesions, thus easily monitoring their size during treatment. It is based on blurring caused by the object distance from the lens focal point. We were unable to find any similar study in dermatology. Additional studies and comparison with more accurate methods of determining the lesion volume are required to assess the efficacy of this technique. In addition, designing more complex algorithms or using other image processing techniques can achieve higher accuracy.

We measured the volume of lesions by processing the digital images using depth recovery from blur estimation method. The accuracy and precision of this method was confirmed using molds of the same lesions for comparison. According to the results, the algorithm can calculate a wide range of lesion volume (<20–700 μ l). Based on the lens and calibration chosen, lesions that have a height of 1 mm to 1 cm can be measured by this method.

Limitations

To analyze the images and achieve desired results, certain conditions must be fulfilled while taking a picture of a skin lesion.

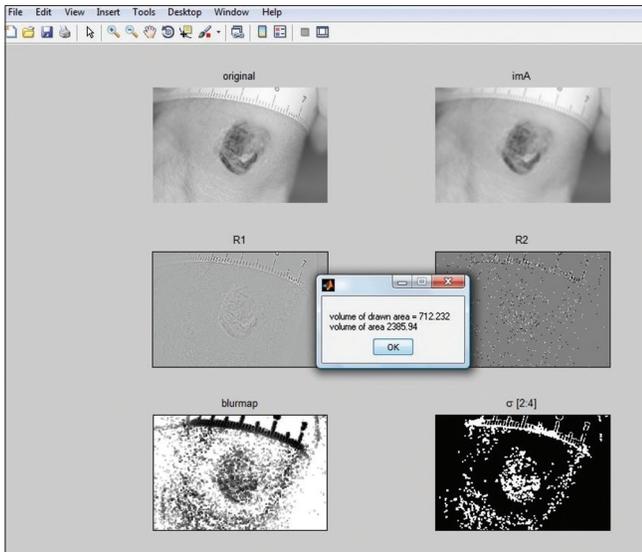


Figure 3: In the last step of analysis after blur estimation, the program calculates the volume of the lesion (as the volume of the drawn area) in microliters

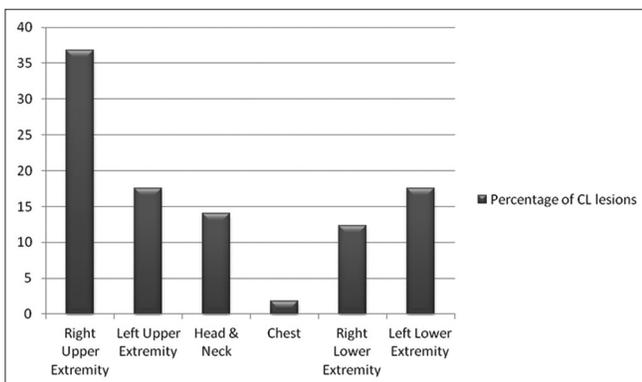


Figure 4: The frequency distribution of lesions according to anatomic sites (n: 48 lesions, CL – cutaneous leishmaniasis)

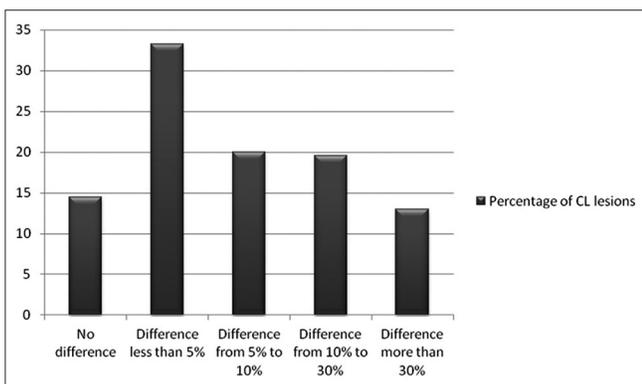


Figure 5: The frequency distribution of the rate of difference between volumes obtained by image processing and mold (n: 48 lesions, CL – cutaneous leishmaniasis)

The lesion must be perpendicular to the lens; otherwise two points of the same height will be recorded at different levels. Sometimes, a lesion may be located at a location where perpendicular shooting

is difficult. Anatomic curvature of a region (such as knees) where the lesion is located can also be cause of a measurement error. Another limitation was that lesions with a height of <1 mm or >1 cm could not be accurately measured because of the lens and calibration used.

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Conflicts of interest

There are no conflicts of interest.

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