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Implementation of a Burn Scar Assessment System by Ultrasound Techniques

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***Abstract*—Tissue injury and its ensuing healing process cause scar formation. In addition to physical disability, the subsequent disfigurements from burns often bring negative psychological impacts on the survivors. Scar hypertrophy and contracture limit the joint motion and body function of the patient. With fast development of the current available technologies regarding the scar therapies, not only the process of wound healing has to be focused, but also the cosmetic and functional outcomes need to be emphasized. Therefore, proper evaluation and assessment of the healing process to nil scar status is highly recommended. However, the currently employed tools for scar evaluation are mostly subjective. For example, Vancouver General Hospital (VGH) scar index uses color, pigmentation, vascularity, pliability, and depth of the scar as dependent variables for scar evaluation. These parameters only estimate the superficial surface of the scar, but they can not evaluate the deeper tissue within dermis.**

Ultrasound is a safe, inexpensive, and multifunctional technique for probing tissue characteristics. In addition, its resolution is not inferior to other measurement techniques. Although 3D-ultrasound is available in clinical application, it's still not widely used in scar evaluation because of its high cost. In this study, we proposed a system for scar assessment using B-mode ultrasonic technique. By utilizing the reconstruction methods to search the scar border, many characteristic parameters, including depth, area and volume, can be estimated. The proposed method is useful in assisting the clinician to evaluate the treatment effect and to plan further therapeutic strategy more objectively. In this report, the quantitative assessment system was used to evaluate the scar of a seriously burned patient. In order to verify the reliability of systematic reconstruction method, we constructed a phantom to imitate the scar tissue. The results show that it can achieve more than 90% in accuracy.

I. INTRODUCTION

Burn injuries caused by various kinds of accidences have been widely seen. The patients who survive the accidence have to face not only the threat to their lives but also a long course of rehabilitation which needs a great amount of medical expenditure. Nowadays, burn injuries still cause high mortality rate even though we have advanced medical equipment. How to deal with scars left after burning and scalding is still a challenging issue to patients and doctors. What the plastic surgeon can do is to reduce the quantity of scars or to disguise the scars in the skin but not to remove them. The formation of scars obstructs a patient's mental condition and interpersonal relationship. In additional, the hyperplasia and contracture of the scar limit the range of motion and functional activities of the body.

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With the technological innovation of scar treatments, the treatments which mainly focused on wound healing in the past has been gradually promoted to the level of repairing and resuming the function of the scar surface. Therefore, assessment and analysis of the scar have become more and more important. However, the adopted assessment methods at present are mostly subjective. For example, according to the Assess, an indicator of scar evaluation proposed by General Hospital of Vancouver (Vancouver General Hospital scar index, VGH), the scars are usually evaluated by their color, pigmentation, vascularity, pliability and depth. In recent years, Tsap et al. [2-4] utilized the image principle (vision-based) to track the recovery situation of the scar, and set up a finite element model to analyze the mechanics of the scar. The result is comparatively objective and rational. Thus it can be further investigated in the future.

With the development of high-frequency ultrasound in recent years, the resolution of ultrasound image becomes higher and higher. Some studies have begun to use this technology for observing unusual or pathological change on the skin organization [5-7]. Although three-dimensional ultrasound imaging technique has been widely applied in clinical applications, this technique is mainly used to detect the depth of an organ and its cost is high which result in the less applicable in the assessment of scars. If a general B-mode ultrasonic device can be used to develop a system for scar evaluation, its convenience and simplicity will have the potential to be popularized in clinical application. Thus, the purpose of this research is to utilize the 2D ultrasonic technique to evaluate parameters related to scar characteristics and expect to offer a more convenient method for providing useful information to the clinicians.

II. MATERIALS AND METHODS

The major work of this research lies in developing a quantitative ultrasonic system for acquisition and evaluation of scar images. For image acquisition, the scar must be located accurately, and then the scar image is acquired for latter analysis. After image acquisition, we utilize a statistics critical value determinant method, Otsu's method, to convert an intensity image to a binary image for the searching of the fit image boundary. Secondly, the region growing method is applied to find out the boundary of the scar from a ultrasonic image with great precision. Other image pre-process method, such as median filter, is also utilized to reduce the noise effect for detecting the boundary of a scar more accurately.

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A. Acquisition of Ultrasonic Image of Scar

High-frequency ultrasonic technique provides a non-invasive and non-radioactive method for acquiring skin images which greatly contributes to clinical application in dermatology. This research uses a high-frequency 15-MHz transducer to produce the B-mode ultrasonic images with resolution lying within 60-120 μm. A sequence of ultrasound images of a scar is acquired by a professional doctor by parallel or fan-shaped scanning.

B. Image Enhancement

The main purpose of image enhancement is to make the image more suitable for further image processing. Since scar tissues with different characteristic are not easy to discriminate in ultrasonic images, the edges in some regions are more difficult to detect and analyze from the raw image. Therefore, it is necessary to enhance the image before detecting edges of scars using suitable image filters.

A general linear filter has functional restriction that information regarding the statistical distribution of noise used as the estimation parameter must be known in advance. The nonlinear filter, however, does not need to know the content of the image in advance, so it is easy to get rid of the noise for effectively facilitating edge enhancement. Median filter is a nonlinear filter, which is used in this study for noise elimination, since it can effectively restrain and filter out the random noise generated by the system. Its accuracy in segmenting objects from ultrasound images is also studied and verified in this study.

C. Image Segmentation

Image segmentation is to subdivide an image into the composition areas or objects. This research utilizes statistics critical value determinant method, i.e. Otsu's method, to segment an image into objects through histogram of gray-level or color value based on binary method. We also use image dilation from the form of disc structure element to close the gap. Its purpose is to join the edge gaps of the scar and obtain a continuous boundary after edge detection.

D. Edge Detection Using Region Growing Method

The seeds gather grow method (Region growing), as its name implied is to get similar image pixels together and grow into the same area on the basis of criterion defined from the sub area. The procedure starts from a seed, through the check of the property such as average gray or color value, and includes the pixels with property similar to the pixels in an area. The method considers the area around the seed and let the initial area grow up gradually until all the similar pixels are included. Therefore, the method is suitable for detecting blocks with continuous edges. However, it is improper for the image that the pixel property has great variation in the same area [11]. The following equation shows the rule of this method.

$(a)\ \bigcup_{i=1}^{n} R_i = R$

$(b)\ R_i$ is the continuous area, $i = 1, 2, 3 \ldots n$

$(c)\ R_i \cap R_j = 0,\ i \neq j$

$(d)\ P(R_i) = True,\ i = 1, 2, 3 \ldots n$

$(e)\ P(R_i \cup R_j) = False,\ i \neq j$

Among them, P represents a logic property in set R_i which is not an empty set. Condition (a) indicates that an image must be completely composed of all the existing segments, which means each pixel must lie in a certain area. Condition (b) requires the point in the same area must be continuous. Condition (c) points out whether an area is intersected with other areas. Condition (d) show that all pixels satisfied the same property in a segmented area, for example if the brightness of all pixels in R_i is the same then P (R_i) is true. Finally, the condition (e) indicates that the property for region R_i and R_j is different [8]. Its expression is as follows. First, we divide an image R_i into n*n pixels area, each area includes a seed to determine a threshold. Then, equation (1) is utilized to judge the pixels near the seed repeatedly.

$$\left| R(x, y) - \mu_i \right| \leq threshold \qquad (1)$$

Subsequently, we include the pixel with its property is similar to the pixels within the area by considering the pixels one by one to let the area grow up gradually. In (1), x and y represent the area in which the pixels have similar property to the seed, μ_i indicates the average property value of R_i. Then we can get the edge or the boundary location of the scar. The entire procedure is showed in Fig. 1 and the results after individual image processing steps are showed in Fig. 2.

E. Experimental Setup

In the experimental procedure, first of all, the image was acquired by scanning the skin with HDI-5000 high-frequency ultrasonic instrument. Using the assessment system, designed in our laboratory, by evaluating the scar parameters, the parameters including depth, area and volume of the scar were estimated to offer the doctor a tool for evaluating the efficacy in the course of treatment. The experimental setup and procedure are show in Fig. 3.

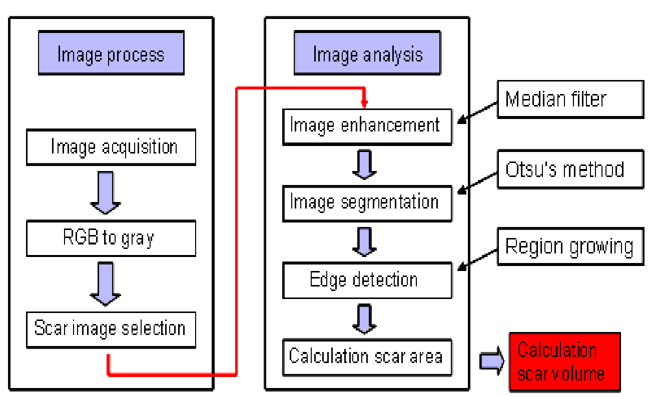

Figure 1. Procedure of image processing

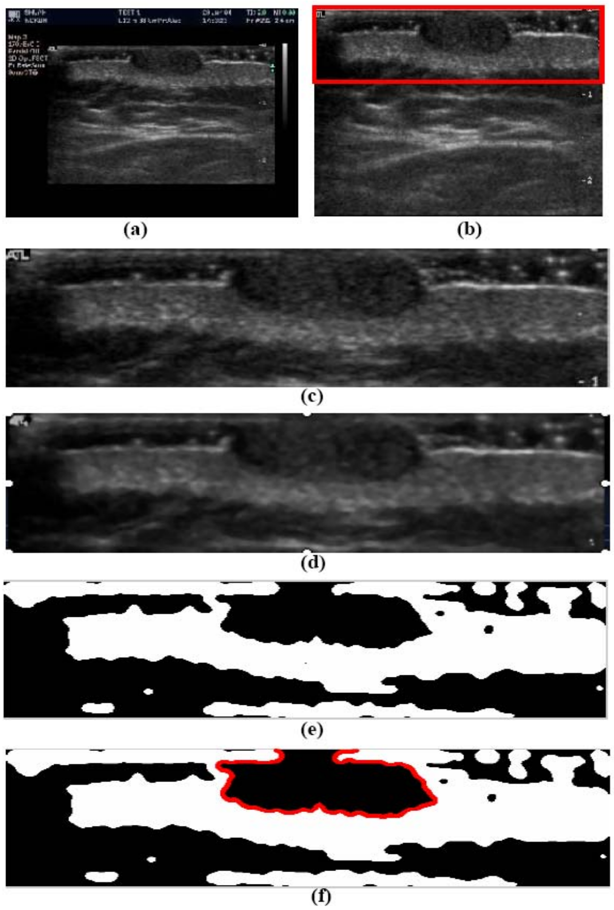

Figure 2. The results after individual image processing steps: (a) the raw image acquired from HDI-5000 ultrasonic instrument; (b) display of image area and region of interest (ROI) selection; (c) ROI display; (d) image after processing by a median filter (e) converted to a binary image with Otsu's method; (f) finding edge of the scar using region growing method

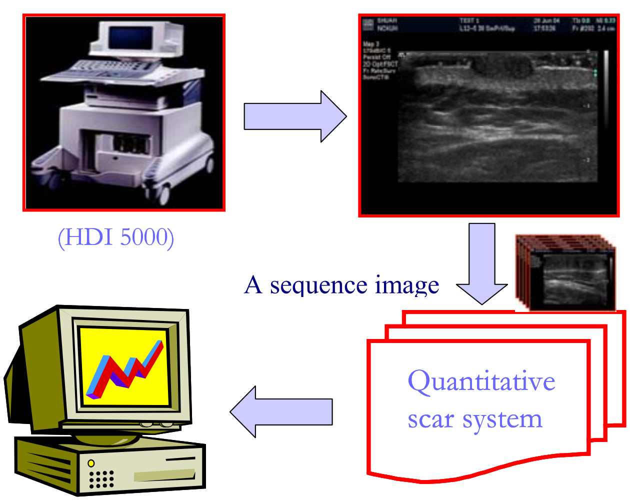

Figure 3. Experimental setup and procedure

F. Phantom Study

In order to verify the accuracy of image processing procedure, this research uses the phantom to imitate the reconstruction of the scar volume. At first, we utilize a phantom, which consists of two water balloons and an acrylic tetrahedron that covered pig skin to simulate the scar under human skin. Figure 4(a) shows the setup for phantom experiment. Then, we acquire a sequence of phantom images with steps of equal distance step from HDI-5000, as shown in Fig. 4(b), and calculate the volume according to (2).

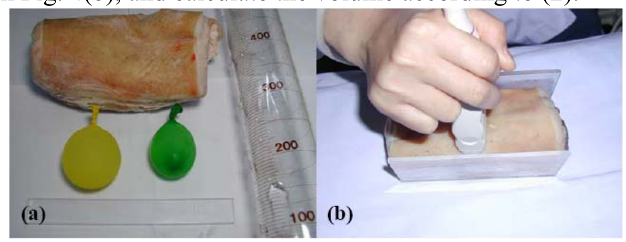

Figure 4. Setup of phantom experiment. (a) The phantom is consisted of two water balloons and an acrylic tetrahedron to cover pig skin. (b) Acquisition of a sequence of phantom images.

$$Volume = \sum_{i=1}^{n-1} \frac{(A_{i+1} + A_i) \times D}{2} \qquad (2)$$

In (2), where, n is the total number of images in a sequence; A_i is the frame area of the scar in the i-th image; D is the distance between two frames.

III. Experimental Results

A. Phantom Experiment

As shown in Table 1, the experimental results are compared with the volumes measured by Archimedean theorem. It can be found that the volume of the individual components in the phantom is similar to the volume calculated from the image sequence, except the acrylic tetrahedron with error as high as 50% and 11% before and after modification. The errors for the other components are less than 4%, and the accuracy of the volume reconstruction can reach as high as 90%. By considering why the error of the acrylic tetrahedron is much higher than the other phantoms, the speed of sound in the acrylic is about 2700m/sec which is higher than the speed in the soft tissue might be the main cause. In contrast, the speed of sound in the water is very similar to the soft tissue. The error is caused by the instrument setting that the default speed is based on the speed of the soft tissue. The ratio of the real depth of the acrylic tetrahedron and the depth of the ultrasound image is 0.56:1. After calibration, the error decreases from 50.1% to 10.95%, it also proves the accuracy of the volume calculation.

Table 1. Comparisons of experimental results with the volumes measured by Archimedean theorem.

Phantom	Experiment (cm^3)	Actual (cm^3)	Error (%)
Water Balloon 1	52.84	55	3.92%
Water Balloon 2	34.73	35	0.77%
An acrylic tetrahedron	8.38	16.8	50.1%
An acrylic tetrahedron (modified)	14.96	16.8	10.95%

B. Clinical Measurement

As show in Fig. 5, we utilize the developed scar assessment system to analyze the scar of one 78-year-old patient who was scalded by the high-temperature vapor. Prior to testing, all subjects were asked to provide written informed consents as approved by the ethic committee of the Cheng Kung Hospital. During the procedure of image acquisition, the clinician acquires the equidistant images of the scar by hand, as demonstrated in Fig. 5(b). Then the scar assessment system calculates the depth, area and volume parameters of the scar. As shown in Figs. 6 and 7, the system also provides the clinician with the function to display the depth and area in each frame image. This system can also calculate the volume of a scar.

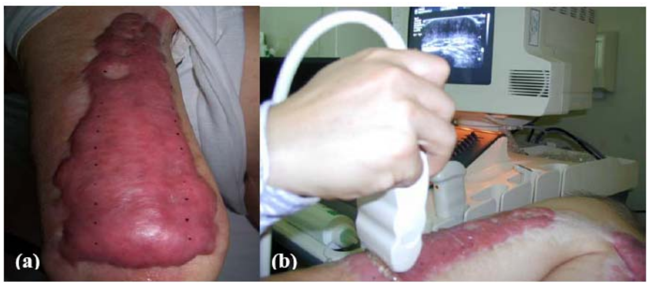

Figure 5. Clinical measurement of scar: (a) a scar scalded by high-temperature vapor and (b) manually acquisition of equidistant images of the scar

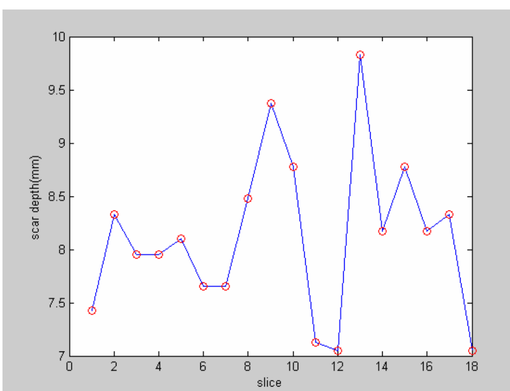

Figure 6. The depth of the scar for individual slices in an image sequence

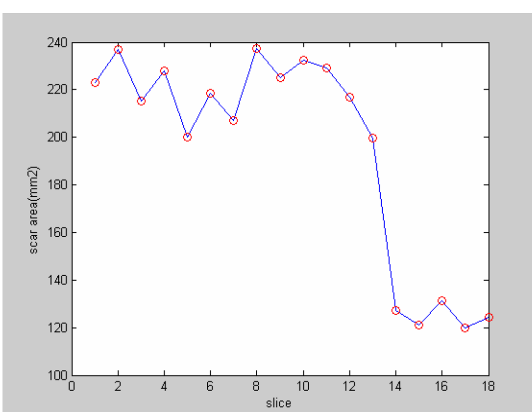

Figure 7. The area of the scar for individual slices in an image sequence

IV. Discussion and Conclusion

In this study, we utilize the phantom to imitate the structure of a scar for estimation of the scar volume to verify the accuracy of the system. The error of volume measured and calculated by the system is under 10%. According to the result of the reconstruction, the accuracy rate can reach 90%. At the present stage, we utilize the image processing methods to build an objective assessment procedure for evaluation of the scar during the course of treatment. As show in Fig. 8, in this preliminary study, a GUI (graphical user interface) was developed to be used for the display of patient information, acquired images, and the evaluated parameters using Matlab 6.5. In the future, we will focus on combining the evaluated parameter with the VGH scar index in the system to provide a more objective basis for evaluating the regenerative process of the scar. Also the function of 3D view of the scar will be provided in this system. We believe that the assessment system has great potential in clinical application for evaluating scar *in vivo*.

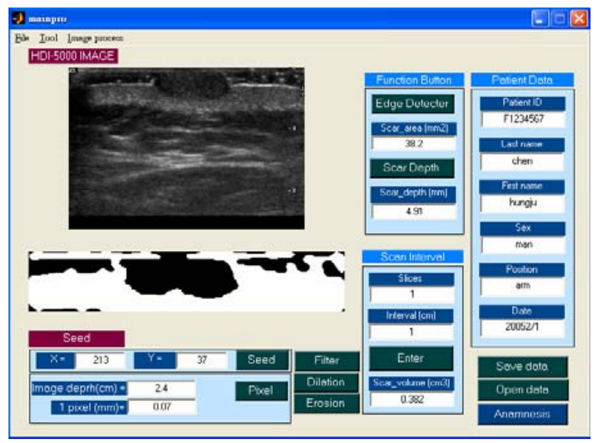

Figure 8. GUI for displaying patient information, acquired images, and evaluated parameters.

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