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● *Original Contribution*

AUTOMATED SKIN SEGMENTATION IN ULTRASONIC EVALUATION OF SKIN TOXICITY IN BREAST CANCER RADIOTHERAPY

Yi Gao,*[1] Allen Tannenbaum,† Hao Chen,* Mylin Torres,*§ Emi Yoshida,* Xiaofeng Yang,* Yuefeng Wang,* Walter Curran,*§ and Tian Liu*§

*Department of Radiation Oncology, Emory University, Atlanta, Georgia, USA; †Department of Electrical and Computer Engineering, University of Alabama at Birmingham, Birmingham, Alabama, USA; and §Winship Cancer Institute, Emory University, Atlanta, Georgia, USA

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Abstract—Skin toxicity is the most common side effect of breast cancer radiotherapy and impairs the quality of life of many breast cancer survivors. We, along with other researchers, have recently found quantitative ultrasound to be effective as a skin toxicity assessment tool. Although more reliable than standard clinical evaluations (visual observation and palpation), the current procedure for ultrasound-based skin toxicity measurements requires manual delineation of the skin layers (*i.e.,* epidermis-dermis and dermis-hypodermis interfaces) on each ultrasound B-mode image. Manual skin segmentation is time consuming and subjective. Moreover, radiation-induced skin injury may decrease image contrast between the dermis and hypodermis, which increases the difficulty of delineation. Therefore, we have developed an automatic skin segmentation tool (ASST) based on the active contour model with two significant modifications: (i) The proposed algorithm introduces a novel dual-curve scheme for the double skin layer extraction, as opposed to the original single active contour method. (ii) The proposed algorithm is based on a geometric contour framework as opposed to the previous parametric algorithm. This ASST algorithm was tested on a breast cancer image database of 730 ultrasound breast images (73 ultrasound studies of 23 patients). We compared skin segmentation results obtained with the ASST with manual contours performed by two physicians. The average percentage differences in skin thickness between the ASST measurement and that of each physician were less than 5% (4.8 ± 17.8% and −3.8 ± 21.1%, respectively). In summary, we have developed an automatic skin segmentation method that ensures objective assessment of radiation-induced changes in skin thickness. Our ultrasound technology offers a unique opportunity to quantify tissue injury in a more meaningful and reproducible manner than the subjective assessments currently employed in the clinic. (E-mail: tliu34@emory.edu) © **2013 World Federation for Ultrasound in Medicine & Biology.**

Key Words: **Skin segmentation, Radiation toxicity, Breast cancer radiotherapy, Breast ultrasound.**

INTRODUCTION

Radiation-induced toxic effects on skin, including skin thickening, swelling and hardening, are the most common, debilitating, short-term and long-term side effects of breast cancer radiotherapy (Small and Woloschak 2006). Although recognized for decades, the assessment of skin toxicity is carried out subjectively by physicians through visual evaluation and palpation. We, along with other researchers (Huang et al. 2007; Liu et al. 2010; Warszawski et al. 1998; Zhou et al. 2009), have recently reported that ultrasound can be used to quantitatively assess skin toxicity after radiotherapy for breast cancer. In particular, skin thickening was observed in almost all post-radiotherapy patients (Huang et al. 2007; Liu et al. 2010), making it an important parameter in ultrasonic evaluation of skin toxicity.

The major challenge in ultrasonic skin evaluation is accurate skin segmentation (delineation) on B-mode images. Human skin has two layers: the epidermis and the dermis. The tissue below the dermal layer is the hypodermis (subcutaneous tissue) (Fig. 1). On the 10-MHz-frequency ultrasound B-mode images (Fig. 2a), the normal epidermis and dermis have bright, well-defined boundaries; whereas the relatively thin epidermis appears as a single echo band. However, after breast radiotherapy, radiation-induced damage to the basal layers of dermal

Address correspondence to: Tian Liu, Department of Radiation Oncology, Emory University School of Medicine, 1365 Clifton Road NE, Atlanta, GA 30322, USA. E-mail: tliu34@emory.edu

[1] Department of Electrical and Computer Engineering, University of Alabama at Birmingham, Birmingham, AL, USA

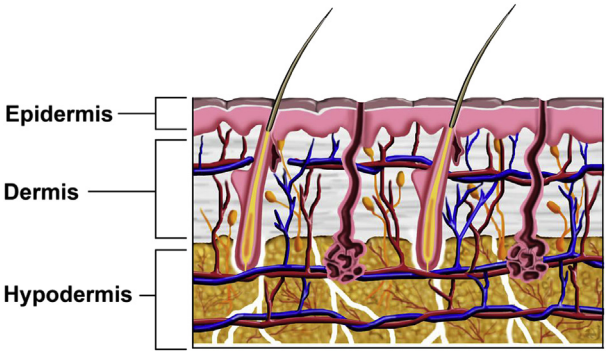

Fig. 1. Schematic diagram of the skin. Skin comprises two layers: epidermis and dermis. The hypodermis lies under the dermis.

cells (Archambeau et al. 1995; Fajardo et al. 2001) can often result in decreased contrast at the hypodermis interface, as shown in Figure 2b. Identification of this interface is a demanding task even for experienced physicians. In our previous skin toxicity studies, the skin was manually delineated, and inter-observer reliability was determined (Yoshida et al. 2012). Nevertheless, manual segmentation is time consuming. In addition, such extensive human interaction inevitably induces subjectivity into the process.

In this article, we report the development of an automatic skin segmentation tool (ASST) based on the active contour method with two major modifications. The active contour (snake) method has had a large audience in the image segmentation community since its proposal by Kass et al. (1988). To deal with skin segmentation, one major modification introduces a dual-curve evolution technique that is used to detect the epidermis-dermis and dermis-hypodermis interfaces. The other modification is that the proposed algorithm uses a geometric active contour framework as opposed to the previous parametric algorithm (Lagarde et al. 2005), which requires parameter input before segmentation. The main advantage of the proposed ASST algorithm is that it fully automates skin delineations on ultrasound breast images. Furthermore, we found that the ASST could accurately segment both normal skin and radiotherapy-damaged skin.

The remainder of the article is structured as follows. In the next section, Methods, we introduce our ASST algorithm and emphasize the modifications made to the active contour methods. In the Results section, we describe the findings of our clinical study of ASST using 73 breast ultrasound examinations (730 B-mode images), including 365 normal breast images and 365 post-radiotherapy breast images. The ASST results were compared with physicians' manual contours of the skin layers, and statistical analyses were conducted to evaluate the performance of the ASST. In the Discussion, we highlight the strength of the proposed automatic segmentation algorithm.

METHODS

Theory behind the automatic skin segmentation tool

The proposed skin segmentation algorithm, illustrated in Figure 3, consists of two major components. First, a Riemannian metric (Caselles et al. 1997; Kichenassamy et al. 1996; Siddiqi et al. 1998) is derived from the image information, and the curve is evoled by minimizing its length under the Riemannian metric, in order to converge to the desired epidermis-dermis interface. Next the dermis-hypodermis interface is identified through a two-step optimization process. The "center line" of the dermis is determined in the first step; the dermis-hypodermis interface is located in the second step.

Epidermis-dermis interface segmentation

In this section, we describe the method used to identify the interface between the epidermal and dermal layers. The intensity of the ultrasound image to be

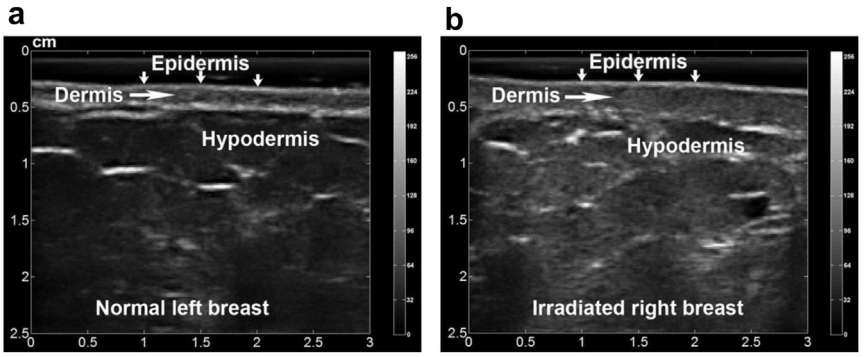

Fig. 2. Ultrasound B-mode images of an (a) untreated (normal) breast and (b) irradiated breast. The two layers of the skin, epidermis and dermis, can be seen in both images. Radiation-induced skin injury is evidenced by the skin thickening and segmented dermis-hypodermis interface on the B-mode images.