Computers in Biology and Medicine 43 (2013) 1341–1352

Contents lists available at ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/cbm

Fully automated computer-aided volume estimation system for thyroid planar scintigraphy

Jia-Yann Huang [a], Kun-Ju Lin [b,c], Yung-Sheng Chen [a,*]

[a] Department of Electrical Engineering, Yuan Ze University, 135 Yuan-Tung Road, Chung-Li 320, Taiwan, ROC
[b] Department of Nuclear Medicine, Chang Gung Memorial Hospital, Keelong, Taiwan, ROC
[c] Department of Medical Physics and Imaging science, Chang Gung University, Taoyuan, Taiwan, ROC

ARTICLE INFO

Article history:
Received 11 May 2012
Accepted 7 July 2013

Keywords:
Radioiodine therapy
Planar scintigraphy
Ultrasonography
Thyroid volume estimation
Contrast enhancement
Image segmentation
Adaptive thresholding
Morphology

ABSTRACT

Patient-specific dosimetry calculations are often performed for radioiodine therapy in patients with Graves′ hyperthyroidism. The radioiodine doses are typically calculated to deliver the desired amount of radiation based on gland size and radioactive iodine uptake. Thus the estimation of thyroid gland volume is of great importance for radioiodine therapy. In clinical practice, thyroid volume determinations are usually performed with ultrasonography (US) or with planar scintigraphy (PS). In traditional planar scintigraphic studies, the thyroid boundary is estimated using a fixed threshold value if the shape of the thyroid is well-defined or a manually drawn region of interest (ROI) if the thyroid shape is irregular. The thyroid volume is then calculated based on the area thus determined. Delineating the thyroid area on a planar scintigram is not easy when applying a fixed threshold value. Moreover, hand-drawn ROIs are time consuming, tedious, and highly operator-dependent. In this study, for a PS image, a fully automated thyroid volume estimation system mainly consisting of four steps, i.e. preprocessing, image contrast enhancement, image segmentation, and automated ROI finding, was proposed to obtain the maximum height and area of each thyroid lobe, and thus calculate the thyroid volume using either Himanka–Larsson′s formula or Allen–Goodwin′s formula. A set of 40 Graves′s disease patients regarded as training set were used to determine empirically some parameters operated in the system. A set of 30 Graves′s disease patients being independent of the training set, regarded as test set for thyroid volume measurements were used for comparisons and performance analyses. In this study, the US was adopted as a standard reference. The statistical analyses were performed with bias, precision, and relative differences. The results of thyroid volume estimation from the proposed approach correlated well with those from US, and the statistical performance analyses showed good agreement between them. In comparison, our automated approach with Allen–Goodwin′s formula had not only good correlation with US ($R^2=0.99$) but also the best bias (0.8), precision (± 2.32 ml), and low relative differences ($2.2 \pm 6.1\%$). It is expected that this automated computer-assisted approach can help physicians in the determination of patient-specific administered activities for treatment of thyroid disease.

1. Introduction

Medical therapy, radioiodine therapy, and surgery are the three main methods to treat patients with Graves′ disease. Radioiodine therapy is recognized as the safest, simplest, least expensive and most convenient form of treatment for adults with uncomplicated hyperthyroidism [1–4]. Due to the radiation safety regulations, individual dosage protocols are vital in several countries [5]. The protocol usually based on estimations of thyroid volume and radioiodine uptake can be expressed in a standardized dosage formula.

$$D = V \times [100\%/U] \times C \tag{1}$$

Here D represents the radioiodine therapy dosage (MBq), U is the radioiodine uptake (RAIU, %) at 24 h after radioiodine administration, C is a constant (usually, 3.7 MBq/g) [6,7], and V is the thyroid volume (ml). RAIU is measured at nuclear medicine departments, whereas the thyroid volume is normally estimated by ultrasonography (US). From (1), it is obvious that the accuracy of radioiodine therapy dosage is proportional to that of thyroid volume estimation. Developing a useful method for accurately estimating thyroid volume is thus of great importance.

Magnetic resonance imaging (MRI) has excellent spatial resolution and soft-tissue contrast and can thus provide accurate estimates of thyroidal volumes. However, MRI is not readily available in all clinical settings. Ultrasonography (US), although more likely to be used in daily practice, does not provide nearly as accurate estimates of thyroidal volumes (with uncertainties of 15–20% [8–12]) and is not widely available in nuclear medicine departments [1]. Therefore,

* Corresponding author. Tel.: +886 3 4638800x7113; fax: +886 3 4639355.
E-mail address: eeyschen@saturn.yzu.edu.tw (Y.-S. Chen).

0010-4825/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.compbiomed.2013.07.006

there is a need to develop a comparably accurate thyroid volume measurement method based on planar scintigraphy (PS) to avoid the dependence on other imaging techniques.

van Isselt et al. [13] compared the accuracy of three image modalities, i.e. PS with ^{99m}Tc injection, single-photon emission computed tomography (SPECT), and US, for the estimation of the thyroid volume in patients with Graves′ disease. These three image modalities were compared with MRI as the reference standard. For the PS study, a median filter was adopted to suppress image noise. A rectangular ROI was manually drawn. This ROI included the entire thyroid gland while excluding all non-thyroid foci of activity. Within the hand-drawn ROI, an area of 5×8 pixels with maximum count intensity was automatically calculated. Adopting a threshold of 30% of this maximum value, an isocontour was created around the thyroid gland. The thyroid area (A) was the number of pixels within the isocontour multiplied by the pixel size. The thyroid volume (V) was then calculated using the formula

$$V = 0.33 \times A^{3/2} \quad (2)$$

which was described by Himanka and Larsson [14]. van Isselt et al. [13] reported that PS correlated poorly with MRI ($R^2 = 0.61$) and suffered from a considerable bias.

Pant et al. [1] estimated thyroid volumes in Graves′ disease by PS (^{99m}Tc injection) and SPECT. The results of the scintigraphic method were compared with those obtained by US. Through phantom studies, the optimum threshold level was found to be 20% of the maximum count intensity in the planar scintigram. The volume of each lobe was measured using the formula

$$V = A \times L \times K \quad (3)$$

which was described by Allen and Goodwin [15] where V, A, and L denote thyroid volume, area of the frontal projection of the thyroid lobe, and height of the thyroid lobe, respectively. Pant et al. [1] used approximately the parameter $K = 0.32$ in their study and obtained the correlation coefficient (r) between PS and US was 0.99. However, both planar technologies, PS and US, have their limitations for accurate estimates of goitrous or irregularly shaped glands.

In traditional PS studies, the thyroid boundary was usually estimated using a fixed threshold value if the shape of the thyroid is well-defined or a manually drawn region of interest (ROI) if the thyroid shape is irregular, like van Isselt et al.′s work [13]. Delineating the thyroid area on a PS is not easy when applying a fixed threshold value. Moreover, hand-drawn ROIs are time consuming, tedious, and highly operator-dependent. To overcome this disadvantage, the aim of this study is thus to develop a fully automated (i.e. operator-independent) PS image segmentation for the estimation of thyroid volume.

The proposed approach for segmenting the region of thyroid lobes from a PS image is based on a set of image processing techniques. Due to the pepper noise embedded and the inherent low contrast characteristic of a PS image, it will be first smoothed and then image contrast enhanced for the facility of later image segmentation. The image segmentation mainly composed of adaptive thresholding, components labeling, and a set of morphological operations is used to distinguish the PS image into background and foreground, where the foreground represents the wanted thyroid gland region. Finally, some reference points from the thyroid gland region will be located automatically in order to delineate the two thyroid lobes (left and right) for obtaining the maximum height L and area A of each lobe. Thus the whole thyroid volume can be calculated.

According to the result of van Isselt et al.′s work [13], even though the bias was not negligible US had the best correlation with MRI ($R^2 = 0.97$) and the best precision. For the purpose of evaluations, in this study the thyroid volume estimated by US was taken as the reference standard for comparison with results obtained by the related PS techniques (van Isselt et al.′s approach [13] and Pant et al.′s approach [1]) as well as the proposed fully automated approach. A high-resolution ultrasound scanner (GE, 3200) was used by one experienced radiologist to estimate the thyroid dimensions. The volume of each thyroid lobe was computed by the standard formula for ellipsoid volume [16],

$$V = (\pi/6) \times a \times b \times c \quad (4)$$

where a, b, c denote the measured maximum height, width, and depth, respectively, for each lobe. The whole thyroid volume was the sum of the volumes of the two lobes.

The rest of this paper is organized as follows. In Section 2, a brief description of patients and images for the study is first introduced. Then the detailed algorithms of the proposed approach are described. The results and discussion are presented in Section 3 and Section 4, respectively. Finally, the conclusion of this study is given in Section 5.

2. Materials and methods

2.1. Patients and images

Planar scintigraphic studies were performed on 30 patients with Graves′ disease (21 females and 9 males, mean age 42 years, range 24–73 years) at 24 h after ingestion of 3.7 MBq of ^{131}I-iodide. The acquisition was done on a dual-head gamma camera (Siemens,

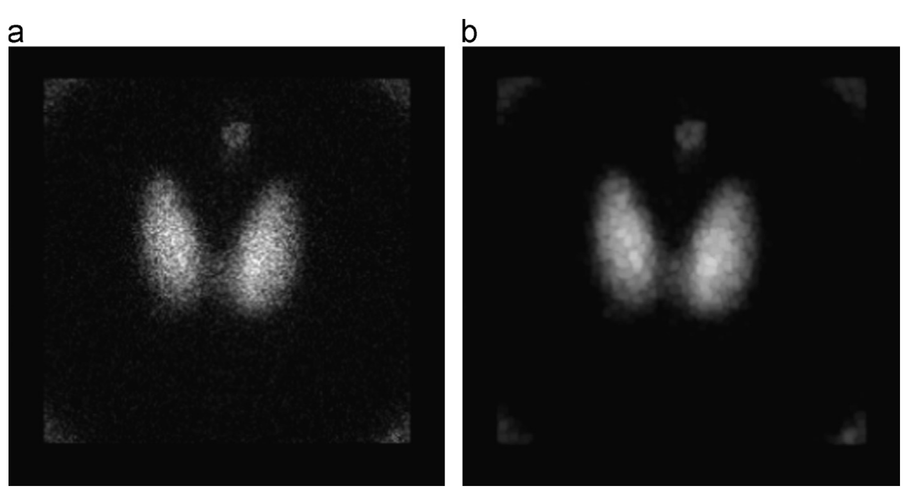

Fig. 1. Illustrations of (a) a planar thyroid scintigram ($\mathbf{I}^{org}$), and (b) a smoothed and maximized planar thyroid scintigram ($\mathbf{I}^{max}$).