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Analysis of Digitized Lateral Fluoroscopy Images to Quantify the Volume Displaced by the Diaphragm

K. Shen1, R. Chandrasekhar1, Y. Attikiouzel1, B. Singh2,3 and K. E. Finucane3
1Australian Research Centre for Medical Engineering, 2Department of Physiology, The University of Western Australia, and 3Department of Pulmonary Physiology, Sir Charles Gairdner Hospital, WA 6009, AUSTRALIA.

Abstract: Methods have recently been developed for accurately measuring the volume displaced by motion of the diaphragm (AVdi) and the contribution of the diaphragm to inspired volume. These methods require accurate measurements of (i) the surface area swept by the diaphragm during inspiration, (ii) the area within this that is occupied by the vertebral column and associated tissues, and (iii) the diameter of the lower rib cage. Existing methods of measurement are labor intensive and slow. In this study, we present a more accurate and efficient system for the acquisition, distortion correction, interactive segmentation and functional analysis of fluoroscopic images. This new non-invasive technique will allow earlier and more accurate detection of abnormal diaphragm function and have a direct clinical application.

Keywords – interactive segmentation, distortion correction, image analysis, image registration, diaphragm function

I. INTRODUCTION

The main muscle of inspiration is the diaphragm and it accounts for 50-60% of inspired volume in healthy subjects [1, 2]. The function of the diaphragm can be impaired in many common disorders of breathing, such as emphysema, asthma and neuromuscular diseases. These impairments are difficult to detect because the displacement of the diaphragm within the chest cannot be measured directly and conventional methods for examining its function are neither sensitive nor specific. Methods have recently been developed for accurately measuring the volume displaced by motion of the diaphragm (AVdi) and the contribution of the diaphragm to inspired volume by imaging the lower chest wall using chest X-rays [1, 2], and lateral fluoroscopy [3, 4]. These methods rely on the experimentally verified linear relationship between the mean axial motion of the diaphragm and the volume it displaces [5], and on accurate modeling of diaphragm shape [1-4].

Lateral fluoroscopy produces a series of cine images from which individual frames are identified, captured, corrected for distortion and quantitatively analyzed. Existing methods of analysis are labor intensive and subjective because they are manually performed on a transparency over a TV screen displaying the images. Moreover, these images are subject to distortion in the imaging chain, which further complicates analysis. The need therefore exists for a more robust, efficient and user-friendly environment where these functional measurements may be undertaken by a layperson in a clinical setting. The purpose of this study is to present a complete and working system for this method, and to evaluate its characteristics, which will serve as a foundation for future clinical studies.

II. IMAGE ACQUISITION AND PROCESSING

A. Image Acquisition and Enhancement

Lateral images of the lower chest were acquired using a digital fluoroscope (Toshiba CAS 8000 DSA, Tokyo, Japan) at a rate of 15 frames per second and were then recorded onto super VHS videotape (Fuji, Pro) using a super VHS video-recorder (Mitsubishi, HS-E82(A), Japan). Images were converted to digital format (bitmap or TIFF) using a monochrome video capture card (National Instruments PCI 1409) and LABVIEW software.

Images were identified in the breathing sequence, which represent the end-expiratory (Residual Volume—RV) and end-inspiratory position (Total Lung Capacity—TLC) of the diaphragm for the breath of interest. Raw images were often small in size and poor in contrast. On a typical digitized fluoroscopic image, the pixels were within a very narrow range of low intensities. In a reference image (RI), the operator interactively selected the region of interest (ROI). Subsequent images were cropped via cross-correlation with the RI to yield the ROI. Zero-anchored histogram equalization was then applied to the ROI to improve the contrast and perception of the image.

B. Image Correction

An efficient routine was developed in MATLAB® to correct for geometric distortion in the image (~ 20s to correct 629 calibration points). The imaging system exhibited rotational, approximate pin-cushion [6] and decentering [7] distortions as well as a shift in the optical center of the image. A calibration object, namely a metallic grid with cross-points 1 cm apart, was imaged. The positions of the cross-points in the image were compared with their ideal positions in the object. A mathematical relationship was derived and used for image distortion correction. Both rotational distortion and shift in the optical center were corrected by inspection. Pin-cushion and decentering distortion were modeled with nth degree polynomials and Conrady’s model for decentering distortion [8] respectively.

C. Image Registration

During fluoroscopy for each patient, two radio-opaque ball bearings were attached to the skin overlying the 10th thoracic vertebra on the posterior chest wall and one ball bearing to the anterior chest wall over the lower sternum. The posterior ball bearings were used as control points in the registration of the RV image upon the TLC image in order to allow interactive segmentation of the relevant portions of the two images.
III. EXPERIMENTAL RESULTS AND FUNCTIONAL ANALYSIS

A. Interactive Segmentation and Functional Analysis

A very large dynamic range was encountered in the fluoroscopic images, which also suffered from poor contrast of the diaphragm contour. The principal difficulty here lies in the ability to track the diaphragm contour accurately and easily across different frames. We performed interactive segmentation of the contour of the diaphragm (Fig 1) as the first and the most important step in the computerized analysis. Then, (i) important structures were identified and annotated (Fig 1 (a), (b)); (ii) Data sets were corrected for distortion and fitted with polynomials (Fig. 1 (c)); (iii) Points of intersection between the fitted polynomials were derived numerically; (iv) The following lengths and areas were calculated: the surface area swept by the diaphragm, the length of the diaphragm at RV and TLC, the diameter of the rib cage and the spine, and the area of the spine within the area swept by diaphragm. These measurements were then used to quantify the volume displaced by motion of the diaphragm ($AV_d$).

B. Experimental Validation and Results

To examine the validity of this system of acquisition and processing, we compared measurements obtained by interactive analysis with those obtained manually. We imaged four calibration objects with known dimensions and found that the differences in lengths and areas obtained by the interactive method and direct physical measurements were <2.2% (data for 1 calibration object is shown in Table I) indicating a high degree of accuracy. We also compared functional measurements in 10 patients with those obtained manually by a second (blinded) operator (data for 2 patients are shown in Table I). Differences between methods were of a greater magnitude, and we attribute this in part to differences in segmentation between the two operators. In the near future, we hope to develop a system for the semi-automatic segmentation of the diaphragm contour and thus provide a more systematic method for the identification of major structures. This will mitigate variations in operator segmentation. In conclusion we have demonstrated the feasibility, objectivity, efficiency, and accuracy of this interactive computerized method compared with the existing manual method, and this augurs well for future routine clinical use.

REFERENCES