Automatic definition of the central-chest lymph-node stations

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Abstract

Purpose Lung cancer remains the leading cause of cancer death in the United States. Central to the lung-cancer diagnosis and staging process is the assessment of the central-chest lymph nodes. This assessment requires two steps: (1) examination of the lymph-node stations and identification of diagnostically important nodes in a three-dimensional (3D) multidetector computed tomography (MDCT) chest scan; (2) tissue sampling of the identified nodes. We describe a computer-based system for automatically defining the central-chest lymph-node stations in a 3D MDCT chest scan.

Methods Automated methods first construct a 3D chest model, consisting of the airway tree, aorta, pulmonary artery, and other anatomical structures. Subsequent automated analysis then defines the 3D regional nodal stations, as specified by the internationally standardized TNM lung-cancer staging system. This analysis involves extracting over 140 pertinent anatomical landmarks from structures contained in the 3D chest model. Next, the physician uses data mining tools within the system to interactively select diagnostically important lymph nodes contained in the regional nodal stations.

Results Results from a ground-truth database of unlabeled lymph nodes identified in 32 MDCT scans verify the system’s performance. The system automatically defined 3D regional nodal stations that correctly labeled 96% of the database’s lymph nodes, with 93% of the stations correctly labeling 100% of their constituent nodes.

Conclusions The system accurately defines the regional nodal stations in a given high-resolution 3D MDCT chest scan and eases a physician’s burden for analyzing a given MDCT scan for lymph-node station assessment. It also shows potential as an aid for preplanning lung-cancer staging procedures.

Keywords Lymph node · Lung cancer · MDCT · 3D imaging · Thoracic imaging · Regional nodal station

Introduction

Lung cancer remains the leading cause of cancer death in the United States [1]. For disease diagnosis and staging, physicians rely on the internationally standardized TNM system for selecting suspicious anatomical sites, where T denotes tumor, N denotes central-chest lymph nodes, and M represents distant metastases [2–8]. In particular, the TNM system describes 14 distinct lymph-node stations within the chest, where anatomical and geometric landmarks define the extent and location of each station (Fig. 1; Table 1) [2–4].

Using the TNM station-definition criteria as a mental guide, the physician visually searches each station by manually scrolling through the two-dimensional (2D) sections constituting a patient’s three-dimensional (3D) multidetector computed tomography (MDCT) chest scan [4,9,10]; during this search, the physician identifies diagnostically pertinent lymph nodes, if any, contained in the stations. Later, the physician performs tissue sampling on the identified nodes, using a technique such as bronchoscopy, to make a
Table 1 Verbatim excerpt of the TNM system’s anatomical criteria for defining regional nodal stations 2, 5, 7, and 13 (reproduced by permission of the American College of Chest Physicians) [2,3]

<table>
<thead>
<tr>
<th>Station</th>
<th>Anatomical criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Nodes lying above a horizontal line drawn tangential to the upper margin of the aortic arch and below the inferior boundary of station 1 nodes</td>
</tr>
<tr>
<td>5</td>
<td>Subaortic nodes are lateral to the ligamentum arteriosum or the aorta or left pulmonary artery and proximal to the first branch of the left pulmonary artery and lie within the mediastinal pleural envelope</td>
</tr>
<tr>
<td>7</td>
<td>Nodes lying caudal to the carina of the trachea but not associated with the lower lobe bronchi or arteries within the lung</td>
</tr>
<tr>
<td>13</td>
<td>Nodes adjacent to the segmental bronchi</td>
</tr>
</tbody>
</table>

The complete set describes 14 stations

Table 1 presents the anatomical criteria for defining regional nodal stations 2, 5, 7, and 13 of the TNM system.

Modern MDCT scanners produce high-resolution 3D volumetric images that depict an extraordinary level of 3D anatomical detail [13–16]. When considering the pulmonary lymph nodes, the physician needs only focus attention on the small volumetric regions associated with the nodal stations. Cymbalista et al. were the first to propose MDCT-based station-definition guidelines, but only gave manually derived anecdotal results on 2D transverse-plane sections for a single MDCT scan [4]. A preliminary method has been proposed for assigning station labels to predefined lymph nodes in an MDCT scan, but it does not give 3D regional nodal station definitions and only provides labels for subgroupings of the TNM stations [17]. Ko et al. and Chapet et al. made more detailed efforts to identify the regional nodal stations depicted in MDCT images [9,10]. They defined the stations using manual region outlining on 2D transverse-plane sections. This manual approach, however, is not practical for general use, as it is extremely time-consuming and does not give reproducible results. In addition, it is dependent on a physician’s skill in translating the TNM anatomical criteria to series of 2D sections comprising a 3D MDCT scan.

Given the sheer volume of current 3D MDCT scans, it is well acknowledged that image assessment is overwhelming in general [14,15]. This is clearly an issue for TNM station assessment, as the limitations of recent work make it difficult to exploit the inherent detail of a given scan and don’t enable the long-term possibility of performing comprehensive lymph-node mapping and staging. Therefore, it is clear that a computer-based approach could be helpful for addressing these issues.

Our proposed computer-based system, referred as the Lymph-Node Station Mapper, performs fully automatic 3D regional nodal station definition. Given a patient’s 3D MDCT chest scan, the system first constructs a 3D chest model, consisting of the airway tree, aorta, lungs, and other anatomical structures. Next, drawing upon the TNM system’s station-definition criteria, further analysis extracts pertinent landmarks from structures constituting the chest model; these landmarks delineate the final 3D TNM regional nodal stations. Following this automated analysis, the system provides interactive tools that enable a physician to perform efficient