A Computer-Assisted System for Diagnostic Workstations: Automated Bone Labeling for CT Images

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Although accurate information on thoracolumbar bone structure is essential when computed tomography (CT) images are examined, there is no automated method of labeling all the vertebrae and ribs on a CT scan. We are developing a computer-aided diagnosis system that labels ribs and thoracolumbar vertebrae automatically and have evaluated its accuracy. A candidate bone was extracted from the CT image volume data by pixel thresholding and connectivity analysis. All non-bony anatomical structures were removed using a linear discriminate of distribution of CT values and anatomical characteristics. The vertebrae were separated from the ribs on the basis of their distances from the centers of the vertebral bodies. Finally, the thoracic cage and lumbar vertebrae were extracted, and each vertebra was labeled with its own anatomical number by histogram analysis along the craniocaudal midline. The ribs were labeled in a similar manner, based on location data. Twenty-three cases were used for accuracy comparison between our method and the radiologist's. The automated labeling of the thoracolumbar vertebrae was concordant with the judgments of the radiologist in all cases, and all but the first and second ribs were labeled correctly. These two ribs were frequently misidentified, presumably because of pericostal anatomical clutter or high densities of contrast material in the injected veins. We are confident that this system can contribute usefully as part of a picture archiving and communication system workstation, though further technical improvement is required for identification of the upper ribs.

KEY WORDS: Computer-aided diagnosis, bone labeling, CT, PACS, ribs

INTRODUCTION

Although accurate information on the thoracolumbar bone structure is essential when CT images are examined, ascertaining unquestionably the anatomical numbers of the ribs and the

thoracic and lumbar vertebrae from axial CT images alone is complicated. When bone lesions of the ribs and the thoracic and lumbar vertebrae have been detected, observers are required to refer to a CT localizer; however, it is tedious and time-consuming. On the other hand, several articles have described how to count ribs on CT using landmarks to determine their precise location¹⁻³. However, these methods are sometimes tedious and imprecise, and the landmarks are difficult to identify.

When the picture archiving and communication system (PACS) workstations are used and multiplanar reformation (MPR) images such as coronal and sagittal images showing the landmark objects (e.g., first cervical, 12th thoracic, or fifth lumbar vertebra) are available, the anatomical numbers of

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bone lesions may be identified. However, it takes time to count the number of ribs and thoracic or lumbar vertebrae. Furthermore, when the CT slice is thicker, subtle bone lesions may not be identifiable on MPR images. To our knowledge, only two reports describe automated methods of bone labeling on a CT scan^{4,5}. We are developing a computer-aided diagnostic system for use on the PACS workstation that labels ribs and thoracic and lumbar vertebrae automatically, and we have evaluated the accuracy of our method.

MATERIALS AND METHODS

Bone Labeling Algorithm

Figure 1 shows the flow chart of this bone detection and bone labeling system. First, a candidate bone was extracted from the input volume data (slice thickness, 1 mm) of the CT image by applying multiple pixel thresholding to the CT data and then detecting the regions of connected voxels obtained at each threshold. We used thinner CT data (slice thickness, 1 mm) than that of the CT images for regular interpretations in order to detect narrow intervertebral and intercostal spaces, to segment each bone and to classify more precise bone regions in the anatomical clutter. The typical histogram of the CT values of all of the input CT data showed three or four distributions based on air, soft tissues, enhanced vessels and bones from low to high CT values, though they overlapped each other. Then, the thresholds between the distributions were determined automatically by analyzing the histogram. Next, the regions of connected voxels were obtained using three-dimensional (3D) connected component labeling for the distribution of "enhanced vessels" and "bones," respectively, using the detected thresholds in order to classify bones and enhanced vessels by the following methods. After the candidate bone regions were extracted, morphological operations of dilation were applied sequentially to the candidate bone regions to compensate for artifacts caused by partial volume effects. The contrast-enhanced vessels and calcified lesions could also be extracted because CT values overlapped with those of bone in this first step.

On the other hand, the candidate bone was classified as being in the thorax and abdomen or in

the pelvis and legs. The thorax and abdomen contain more air, because of the presence of the lungs, than do the pelvis and legs, whereas the pelvis and legs contain more bone matter in the form of the pelvic bones, femurs, and so on than do the thorax and abdomen. These regions were therefore classified by determining the ratios between air, soft tissues and bones using histogram analysis of the CT values. The various parts of the image of the candidate bone were then classified as representing bone, calcified lesions, or enhanced vessels according to a linear discriminate analysis using the effective features of distribution of CT values, the gradient strengths of the voxel values, and the anatomical characteristics of each independently classified region. The CT values of enhanced vessels may be distributed more uniformly than those of bones and calcified lesions. The gradient strengths of the voxel values of bones and calcified lesions may become greater than those of enhanced vessels. The effective features of anatomical characteristics such as the locational information or the morphological features used for classification were adaptively selected according to the body parts to which each candidate region belonged (e.g., distance from the body surface was used for classification of the thoracic and abdominal bones, as in the case of the vertebrae and ribs—close to the thoracic and abdominal surface—and the length-breadth ratio in the Z axis—in which the femurs lie—was used for the pelvis and below). In these ways, all non-bony anatomical structures were removed.

Thirdly, the vertebrae were separated from the ribs according to their distances from the center of the vertebral body on the axial CT projection images, and each vertebra was segmented by analyzing the histogram of CT values calculated along the craniocaudal midline of the extracted vertebral column. The ribs were segmented by extracting the continuous components using 3D connected-component labeling. The rib cartilages and sternum tended to impede segmentation of the rib cage, rib by rib, because the ribs are connected by them and so they were removed by eliminating an area 45° wide, anterior to the vertebrae, and with its apex lying along the center of their anterior surfaces on the axial images. Finally, the ribs and the thoracic and lumbar vertebrae were clearly extracted. Figure 2 shows a 3D CT image

Fig 1. Schematic diagrams of the computer algorithms for a detection of ribs and thoracic and lumbar vertebrae and for b bone labeling.

constructed using images from which the ribs and vertebrae have been extracted.

The lowest pair of ribs was then identified as the 12th ribs using the slice locations of Digital Imaging and Communications in Medicine tags. The 12th thoracic vertebra was also identified from its adjacent relationship with the rib. Other ribs and vertebrae were then labeled with their own anatomical number according to their location relative to the 12th rib and thoracic vertebra.

We installed this program on one of our PACS (Synapse 3.0 MR-001; Fujifilm, Tokyo, Japan) workstations for this study. When an operator placed a cursor over each vertebra or rib and

clicked, the assigned number appeared at the upper-right corner of the viewer (Fig. 3a).

CT Scanner

The CT scanner used in this study was a 16-detector-row CT scanner (Aquilion; Toshiba Medical Systems, Tokyo, Japan). Parameters for the scanning were 120 kVp automatic exposure control (Real Exposure Control, Toshiba Medical Systems), 16×0.5 -mm collimation, 0.5 s rotation time, 15 helical pitch, 30–35 cm field of view, 512×512 matrix size. Scan data were reconstructed at slice thicknesses and intervals

Fig 2. 3D CT image after processing to extract the ribs and vertebrae. The left first rib is not extracted correctly in this case.

of 1 mm for this study and of 7 mm for regular interpretations.

Evaluated Cases

One radiologist evaluated the accuracy of this fully automated bone labeling technique on clinical cases using his own judgment. Twenty-three chest ($n=21$) and chest-abdominal ($n=2$) CT cases in which the entire length of the 12th ribs was scanned consecutively by one of the CT scanners in our institute in 1 day were studied in a comparison of the accuracy of our method with that of the radiologist with 25 years experience in CT diagnosis. For the radiologist's evaluation of each case, he used composite coronal CT images such as that shown in Fig. 4, consisting of curved MPR images of extracted vertebrae and maximum-intensity projection images of extracted ribs. The locations of clicks over each vertebra or rib on

axial images are shown on the composite images. The radiologist defined the lowest ribs as the 12th ribs and then identified the 12th thoracic vertebra by its contiguity with the rib. Other ribs and vertebrae are defined according to their location relative to the 12th rib and thoracic vertebrae.

Table 1 shows the profiles of 23 patients. The mean age of the 13 male and ten female patients was 67.5 years (range, 52–85 years). The indica-

Fig 3. Display examples of the axial CT images on which automatically labeled numbers of ribs and/or thoracic vertebra are displayed. The number of a the sixth vertebra appears when the plus cursor is clicked, as indicated here by an arrow. b Another display example (not used in this version for the clinical evaluation of this study), one in which all of the numbers (the third, fourth, fifth, and sixth ribs and the sixth vertebra) are displayed and labeled correctly. c All of the numbers except for the left first rib (arrow) are displayed and labeled correctly at the level of the first anterior costochondral junction. The left first rib is not labeled because it was misidentified as an adjacent contrast-enhanced vessel.

Fig 4. A composite coronal CT image. When the *plus* cursor is clicked on the axial image (Fig. 3a), the location is shown on the composite images (*plus* symbol).

tions for CT were lung or mediastinal neoplasms in 11 patients, abnormal chest shadows in conventional radiography in four, aortic lesions in four, obstructive lung diseases in two, and pulmonary embolisms in two. These cases also had some minor bone degenerations or complications: mild-moderate spondylosis deformans in all cases, osteoporosis in ten, mild scoliosis in one, and multiple compression fractures of lumbar and thoracic vertebrae in one. These cases included six rapid-bolus contrast-enhanced, seven contrast-enhanced, and ten non-enhanced studies. For a rapid-bolus contrast-enhanced study, after a 20-gauge catheter was placed in an antecubital vein, 100 mL of nonionic contrast material with an iodine content of 350 mg/mL (iomeprol, Iomeron,

Eisai, Tokyo, Japan) was injected at 3 mL/s using an automatic power injector (Dualshot; Nemoto-Kyorindo, Tokyo, Japan). The scan delay was determined using a bolus-tracking technique. Scanning was started 10 s after the trigger threshold of aortic contrast enhancement reached 100 HU. For contrast-enhanced study, after a 22-gauge catheter was placed in an antecubital vein, 100 mL of nonionic contrast material with an iodine content of 300 mg/mL was injected at 1.0–1.5 mL/s using the automatic power injector. Scanning was performed 20 s after the administration of the contrast material was finished.

RESULTS

The automated labeling of the thoracic and lumbar vertebrae was concordant with the judgments of the radiologist in all cases, and all but the first and second ribs were labeled correctly. The first ribs were not scanned in two cases. Twenty-seven of 42 scanned first ribs (64%) and one of 46 second ribs (2%) were mislabeled. These misidentifications were caused by failure to achieve segmentation from bones other than ribs, namely, the clavicle and the sternum (96%, 27 of 28 misidentified ribs), high densities of contrast material in the injected veins for contrast-enhanced cases (7%, two of 28 ribs)

Table 1. Patient Profiles

Factors	(n = 23)
Sex (M/F)	13/10
Age (years)	67.5 ± 11.0
Indications for CT	
Lung/mediastinal neoplasm	11
Chest abnormal shadow	4
Aortic lesion	4
Obstructive lung disease	2
Pulmonary embolism	2
Bone degenerations or complications	
Spondylosis	23
Osteoporosis	10
Scoliosis	1
Compression fracture	1
Contrast enhancement	
Dynamic	6
Enhancement	7
None	10

Data are presented as means ± SD

and mis-segmentation of the first ribs from the second ribs (4%, 1 of 28 ribs; Table 2, Fig. 3c). The major diseases, minor bone degenerations, and complications of these cases did not cause mis-identification of the ribs.

DISCUSSION

The automated bone labeling of ribs and thoracic and lumbar vertebrae is a very useful task in CT diagnosis when lesions in these bones are detected. However, a literature search revealed only two reports of automated anatomical bone labeling. Naegel⁴ reported the anatomical labeling of vertebrae from 3D CT scan images. He detected the 12th thoracic vertebra, which is the last vertebra articulated with the ribs, then labeled the vertebrae using anatomical numbering by reference to the 12th thoracic vertebra. Although he labeled all the vertebrae correctly, he did not touch upon the segmentation or labeling of the ribs. We used almost the same labeling method for vertebrae. However, he did not evaluate the results of labeling of the upper thoracic vertebrae because the only target of CT examination in his cases was the abdomen. The automated labeling of the upper thoracic vertebrae in CT was not discussed at all. He and our group both used histogram analysis for detecting intervertebral spaces and for segmentation of the vertebrae. Because the intervertebral spaces become narrower, the higher the spinal level, the more difficulties can be expected in segmentation of the upper thoracic vertebrae. Our results in labeling the upper thoracic vertebrae suggest that these methods are also effective for the labeling of these vertebrae.

On the other hand, Staal et al.⁵ reported a technique of automatic rib segmentation and

labeling in CT, which is accurate for over 80% of all ribs. However, they stated that the first ribs were not marked because they were not always visible in the CT scans of their cases. Furthermore, they tested their method only with non-enhanced CT and did not consider the influence of contrast material at all. The automated labeling of the first ribs was not discussed at all. Our results showed that the first and second ribs, especially the former, were frequently misidentified. Our interpretation of the causes of mislabeling of the first two ribs suggested that the major difficulty of the automated labeling of these ribs results from erroneous identification as bones other than the ribs and from misclassification of the first and second ribs, presumably by pericostal anatomical clutter. The other difficulty is the high densities of contrast material in the injected veins in contrast-enhanced cases (Fig. 3c). Although we have not yet tried introducing the method of model matching to the ribs and vertebrae, whose initial locations can be estimated from anatomically standardized bone structures, this approach may improve the identification performance on the first and second ribs. Examinations of non-enhanced CT prior to enhanced study and bone classification by dual-energy CT are helpful in avoiding the adverse effects of contrast material; however, this could lead to an increase in radiation exposure. Further investigation of the anatomical details surrounding the first two ribs and development of a method for accurate segmentation and labeling are needed.

We installed this program on only one PACS workstation for this study. However, a thin client is an important feature for clinical use of this method to reduce management and cost. Our PACS works using thin client architecture. The thin client solution for this program can be achieved by incorporation into the functions of the PACS.

For access to this program, we used the clicking of a cursor over the region of interest of the bone. Accessing this program is easy, simple, and user-intuitive. Another option is one in which all of the numbers are labeled and displayed (Fig. 3). Access to the program and displays should be toggled depending on an individual user.

Our study has limitations. Firstly, although we used randomly selected clinical cases, there were no cases with obvious bone lesions such as bone destruction, severe deformity, and anomalies ex-

Table 2. Mislabeled Ribs

	Number of ribs (%)
Rib (n = 42)	
1st	27 (64)
2 nd	1 (2)
Cause of mislabeling (n = 28)	
Erroneous identification as other bones	27 (96)
High densities of contrast material	
in the injected veins	2 (7)
Misclassification of first and second ribs	1 (4)

cept for some minor bone diseases (Table 1). There were no cases with bone lesions described in the reported studies^{4,5}, so that the targets of these studies appear to have been normal bone cases. Scoliosis, osteophytes generated by spondylosis deformans, or compression fractures could influence the results of detection of the craniocaudal midline of the vertebral column or the intervertebral spaces used for segmentation of the vertebrae because of the abnormal lateral curvature of the spine, narrowing of the intervertebral spaces, or deformities of the vertebrae. Osteoporosis could influence the results of extraction and classification of bones because of the decrease of density. Although mild degrees of these frequently seen bone diseases were found in our cases, they did not influence the results of bone labeling, but severe bone diseases were not included in this study. Such diseases, however, could cause misclassification of bones and lead to mislabeling.

A second limitation is that the number of cases in the study was small. Naegel⁴ evaluated 26 cases for the labeling of vertebrae, Staal et al.⁵ tested 20 cases for that of ribs, and we evaluated 23 cases for that of both whole vertebrae and ribs. These appear to be the only reports that exist on this topic. And thirdly, our system did not support cases of abnormal numbers of vertebrae (e.g., transitional vertebral body) or ribs. There are no reports that describe automated CT scan bone labeling that supports these variations. For normal cases, our automated method resulted in the correct labeling of ribs and vertebrae. The next step is further evaluation of a large number of subjects including various cases of abnormal bone lesions and variations for the clinical use of this technique. Evaluation of large numbers of cases including

various bone lesions and variations is now needed to facilitate clinical use of this technique.

CONCLUSIONS

Almost all ribs and all thoracic and lumbar vertebrae were readily labeled automatically on axial CT images by our method. We strongly believe that this system could serve as a useful addition to the armamentarium on a PACS workstation, although further technical improvement is required for identification of the upper ribs.

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