Evaluation of segmentation using lung nodule phantom CT images

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ABSTRACT

Segmentation of chest CT images has several purposes. In lung-cancer screening programs, for nodules below 5-mm, growth measured from sequential CT scans is the primary indication of malignancy. Automatic segmentation procedures have been used as a means to insure a reliable measurement of lung nodule size. A lung nodule phantom was developed to evaluate the validity and reliability of size measurements using CT images. Thirty acrylic spheres and cubes (2- 8 mm) were placed in a 15-cm diameter disk of uniform-material that simulated the lung. To demonstrate the use of the phantom, it was scanned using our hospital's lung-cancer screening protocol. A simple, yet objective threshold technique was used to segment all of the images in which the objects were visible. All the pixels above a common threshold (the mean of the lung material and the acrylic CT numbers) were considered within the nodule. The relative bias did not depend on the shape of the objects and ranged from -18% for the 2-mm objects to -2.5% for 8-mm objects. DICOM image files of the phantom are available for investigators with an interest in using the images to evaluate and compare segmentation procedures.

Keywords: computed tomography, CT, phantom, lung cancer, screening

1. INTRODUCTION

Clinical trials are evaluating early detection of lung cancer using CT.[1,2] The Radiology Department of Brigham and Women's Hospital has a lung-cancer screening program. The primary indication of malignancy of nodules of diameters less than 5 mm is growth measured with sequential CT scans.[3,4] Such a protocol requires an accurate and reproducible measurement of lung nodule volume. Imaging a lung nodule phantom as part of a screening protocol can be used to establish the validity and reliability of CT measurements of lung nodule volume.

Automated procedures to diagnosis lung nodules using chest CT images are being actively investigated.[5,6,7,8] Automatic segmentation procedures are being used as a means to insure a reliable measurement of lung nodule size. Yet if lung cancer screening using CT is to succeed, then procedures should exist to account for the differences in CT equipment and these automated analysis procedures. We are proposing an approach to evaluate the differences between size measurement procedures through the use of a lung nodule phantom.[9] Such a phantom was used to evaluate human visual estimates of nodule size.[10] We demonstrate its use by determining the validity of CT size measurements of acrylic balls and cubes in lung simulating materials.

2. METHODS AND MATERIALS

2.1 Lung Nodule Phantom

The lung nodule phantom contains 15 acrylic balls and 15 acrylic cubes placed on approximately the same plane in a 15 cm disk of simulating lung material (-700 HU, The Phantom Laboratory). A 1.3-cm acrylic rod and hole transit the phantom. Figure 1 is 1.25-mm section through the plane of the plane of the objects. Each ball and cube was weighed before fabrication of the phantom. This phantom was scanned using our hospital's lung-cancer screening protocol. The phantom is place on the chest of each patient during the CT exam (Figure 2).

A reference volume and reference linear dimension of each object was calculated from the weight of each object assuming an acrylic density of 1.19 g/cm3. The balls were assumed to be spheres and cubes were assumed to be perfect cubes. The weights, volumes, and linear dimensions of each object in the phantom are listed in Appendix 1. We call these values reference standards. (A reference value is derived from a procedure that provides an estimate of size that is more accepted as

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accurate than the procedure under study. A reference standard that is the best is called a "gold standard." Our gold standard is based on the weights of the acrylic balls and cubes).

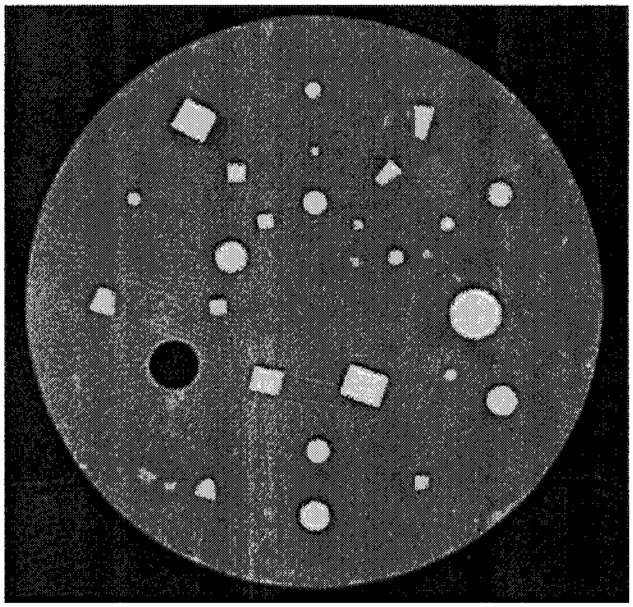

Figure 1. CT Section of lung nodule phantom

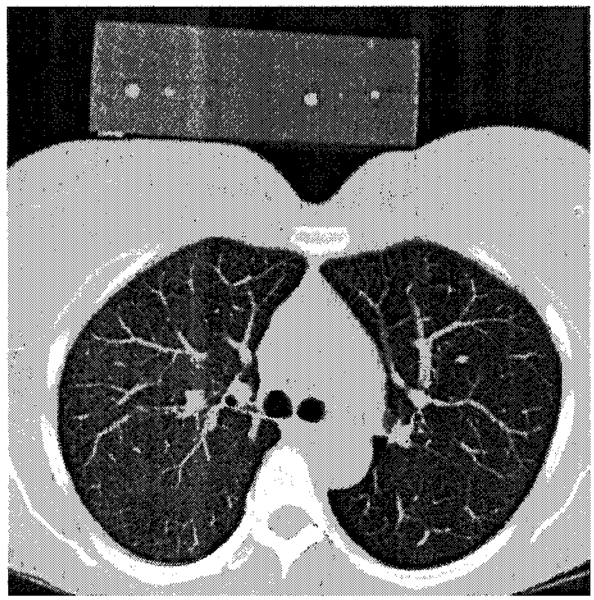

Figure 2 Lung nodule phantom on patient

2.2 CT scan technique of demonstration analysis

Multi-detector CT scanning of the lung nodule phantom was performed with Siemens Volume Zoom CT scanner using 1.0-mm collimation with pitch of 4, and 1.25-mm slice sensitivity profile width. The tube rotation time was 0.5 sec using a tube current of 40 mA , tube potential of 140 kV, and 0.7-mm focal spot size. The pixel size was 0.3574 mm and the section increment distance of 0.5mm. Reconstruction filter was designated B70f.

2.3 Image reference standard

Image reference standards are calculations that use the image data to estimate size. Because the background is relatively uniform, a simple thresholding procedure was used as the image reference standard for the lung nodule phantom image. Thresholding means that the area of each nodule in each section was determined from the number of pixels contained in each nodule feature that were above a specified threshold level. The threshold value was identical for all images in the volume image set.

The threshold procedure produced an estimate of the number of pixels in each image section. The estimate of the volume of ball or the cube was the sum of the area times the voxel volume. Voxel volume is the product of the pixel area and section increment distance. A diameter of each ball was calculated from its volume assuming that the ball was a sphere. The length of side of each cube was calculated from its volume assuming a perfect cube. These are the same assumptions that were made for the gold standard reference calculations.

The image reference sizes were calculated for several threshold values. The thresholds were specified as the value above the background in units of percentage of the difference between the background CT number and the CT number of the 1.3-cm acrylic rod image. These image reference sizes will provide the means to study improved measurement procedures. For example, procedures that compensate for partial volume and loss of resolution would be expected to have less bias. The errors with the threshold procedure are understood so comparison of bias between the improved and a standard threshold procedure provide insight into the nature of errors associated with the improved procedure. Finally, the image reference values will identify caused by errors in slice increment or pixel size specifications.

2.4 Relative bias.

Relative bias was calculated for image reference sizes. Relative bias was the "percentage" difference between the estimated and gold standard size. Relative bias is more useful than absolute bias, because absolute bias may be small just because the object is small. The interesting biological changes are relative changes. For example, a 1- mm change of 2-mm nodule is a 50% change, while it is only a 5% change of 20-mm nodule.

3. RESULTS

The precision of the volume measurements was 5% and did not depend systematically on the size or shape of the object. Figures 3 and 4 demonstrate that relative bias is essentially same for ball and cubes. The magnitudes of the relative bias for the volume measurements are 3 times the magnitudes of the relative bias for the length measurements. The threshold procedure that used the CT number midway between background and the acrylic (50% curves) underestimated the volume of objects.

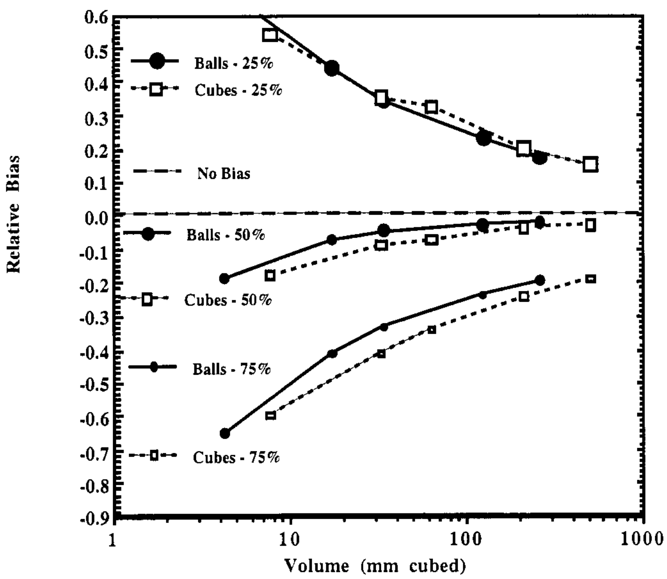

Figure 3. Relative bias of volume image reference measurement

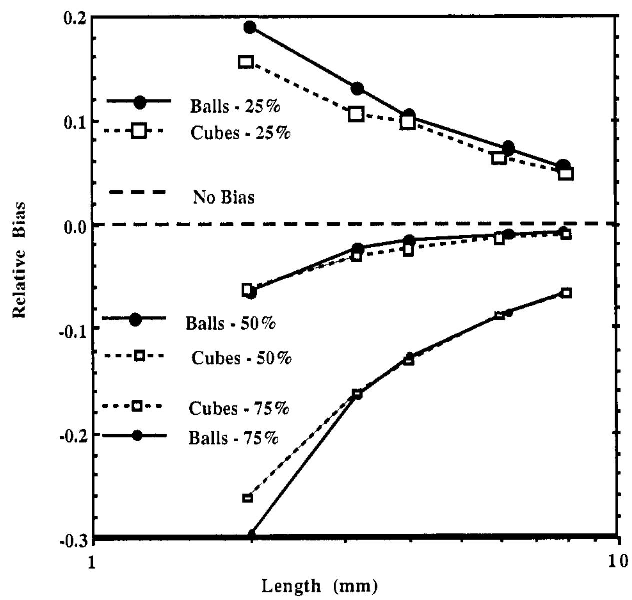

Figure 4. Relative bias of length image reference measurement

4. DISCUSION

The larger relative bias for smaller objects was caused for blurring of edge both in the plane of the section and orthogonal to the section. The images of the smaller objects can be used to evaluate resolution recovery procedures that correct for the effects of the loss of resolution. The small relative bias for the larger objects may be caused by specification of errors in slice increment, pixel size or specified density of acrylic. This suggests that the scanning the lung nodule phantom and evaluating the volume of the objects contained within it may be useful in quality assurance programs, which use CT to screen for lung cancer.

While this phantom is simple its is just a first step. Yet, if a procedure doesn't work in this simple situation, why would one expect the procedure to work in complex chest backgrounds? Performance on this phantom will provide a bound on performance for more complex backgrounds. The phantom simplicity will make it useful for quality assurance protocols. Also investigators can test their bias and precision predictions, those predictions can then be used to optimize estimation procedures and the optimizations can verified.

Future plans include evaluations of the effects of reconstruction filter variation on bias, effects of noise on the precision segmentation procedures, and comparison of CT scanner designs. DICOM image files of the phantom are available to investigators with an interest in using the images to evaluate and compare segmentation procedures.

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APPENDEX 1 -REFERENCE SIZES OF OBJECTS IN THE PHANTOM

Figure A-1 is key for the balls and cubes in the lung nodule phantom as view from the same perspective as Figure 1. The number by each feature is an index for each row in Table A-1.

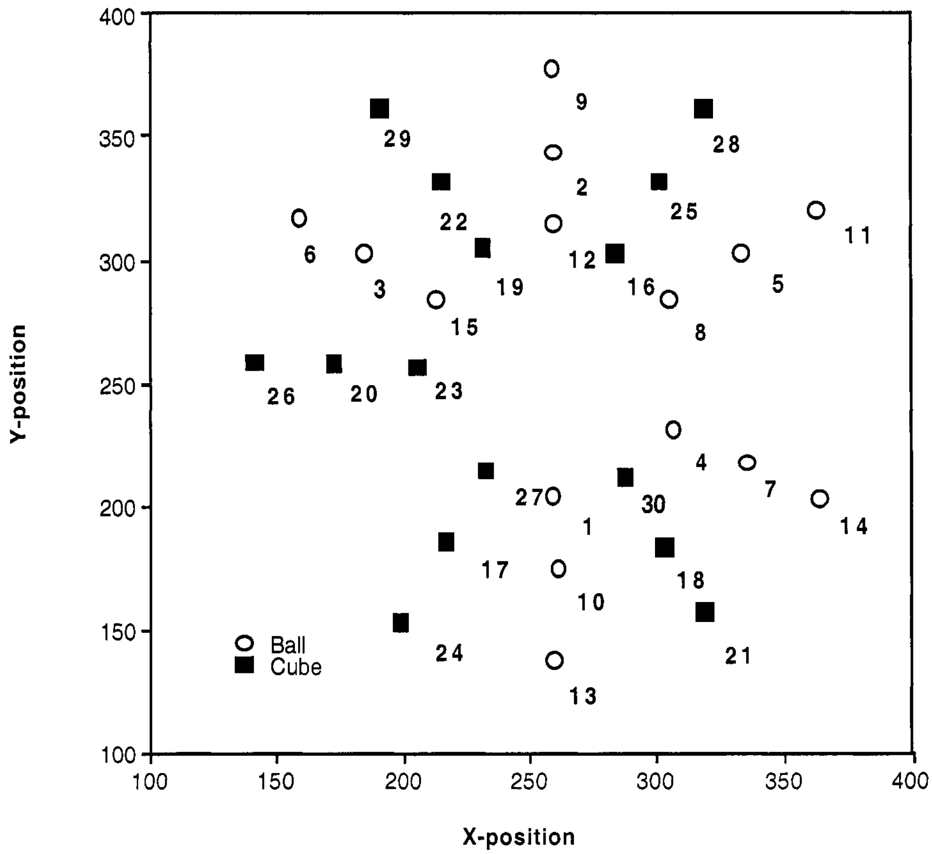

Figure A-1 Locations of the centers of the nodule objects in lung nodule phantom. The unit of position is a pixel

Index	Weight (g)	Volume (cubic mm)	Size (mm)
1	0.0051	4.3	2.015
2	0.005	4.2	2.002
3	0.005	4.2	2.002
4	0.0204	17.1	3.199
5	0.021	17.6	3.230
6	0.0204	17.1	3.199
7	0.0404	34.0	4.017
8	0.0404	34.0	4.017
9	0.0403	33.9	4.014
10	0.1474	123.9	6.185
11	0.1484	124.7	6.199
12	0.1501	126.1	6.222
13	0.3053	256.6	7.884
14	0.3105	260.9	7.928
15	0.3107	261.1	7.930
16	0.0089	7.45	1.956
17	0.0091	7.65	1.970
18	0.0091	7.65	1.970
19	0.0387	32.5	3.192
20	0.0382	32.1	3.178
21	0.0384	32.27	3.184
22	0.0754	63.36	3.987
23	0.0752	63.19	3.983
24	0.0755	63.44	3.988
25	0.2527	212.3	5.966
26	0.2521	211.8	5.961
27	0.2511	211.0	5.953
28	0.6086	511.4	7.997
29	0.6051	508.4	7.981
30	0.5965	501.2	7.944

Table A-1 Weight, volume, and linear dimension of each specific objects in lung nodule phantom. Volumes were derived from the weights assuming a density of 1.19. The linear dimensions were calculated from volumes assuming the objects were spheres or cubes, whichever shape was appropriate.