INTRODUCTION

In order to effectively quantify the impact of metastatic tumor involvement in the spine (volume, progression, type) it is necessary to accurately segment the vertebral body. In many cases of lytic disease the tumor may breach the cortical shell of the vertebral body (Figure 1). Though very precise, manual segmentation techniques involve extensive and time-consuming user interaction. More automated techniques such as thresholding or region growing have difficulty defining the boundary between tumor tissue and surrounding soft tissue when imaged with CT.

A potential solution to automated segmentation of metastatically-involved vertebrae with cortical shell destruction may be found in the application of image registration techniques. Registration is the spatial alignment of two distinct scans. Registration can be used to segment structures by warping an existing segmentation to the geometry of the scan of interest.

The objective of this study is to validate deformable registration as a means to segment tumor-bearing vertebrae. It is hypothesized that deformable registration can be used to transform a segmentation of an existing atlas to a patient scan in order to automate accurate vertebral segmentation in the metastatic spine.

METHODS

Computed tomography (CT) scans were collected from 6 patients with spinal metastases secondary to breast cancer. Vertebral body from T4 through L5 were imaged (scans were taken with an axial slice thickness of 1.25mm and a resolution of 512x512 pixels). Healthy levels from each patient were cropped and segmented with a semi-automated threshold based approach (Amira 3.1.1, TGS Berlin) to obtain a healthy atlas for each level of the spine from T4 through L5.

To segment the metastatically involved vertebral levels registration of an atlas vertebral segmentation was performed through an initial spatial alignment of the vertebral bodies followed by an automated affine registration (Amira). The atlas used in this registration-segmentation routine was a scan of a healthy vertebra was manually segmented. Before the implementation of the deformable registration algorithm, all voxels in the atlas and patient scans with intensities below 150 Hounsfield (HU) units were set to 0 HU to prevent soft tissues from negatively affecting the registration.

A three-dimensional demons deformable registration was implemented in a multi-resolution framework (ITK, NLM Bethesda) with 35 iterations per resolution level with decreased downsampling in each progressive level. After the completion of each resolution level, the deformation field is upsamplled to the resolution of the next finer level. Deformable registration begins on the coarsest resolution level of the multi-resolution pyramid with 8x downsampling in the transverse directions and 2x in the axial direction. At the second resolution level registration continues with another 35 iterations at 2x downsampling in the transverse directions and no downsampling in the axial direction.

The last level to be completed is the finest and most computationally intensive level of the pyramid with no downsampling in any direction. Between each iteration, the deformation field is smoothed by convolution with a Gaussian (σ = 2 voxels) to improve convergence of the algorithm [1]. The number of iterations and amount of downsampling in the multi-resolution pyramid was chosen to balance computation time with improvement in registration accuracy. The deformation field produced by the deformable registration algorithm was then applied to the segmentation and a nearest neighbor interpolator was used to transform the segmentation of the atlas, producing an automated segmentation of the patient scan.

To test the algorithm, CT scans of tumor bearing vertebrae with similar scanning parameters to those of the atlas scans were collected from 5 patients with spinal metastases secondary to breast cancer. Lesions apparent in these vertebra included osteolytic, osteoblastic, and mixed lesions with or without distinct foci. 6 vertebrae with contained tumors and 4 vertebrae with breached cortical shells were analyzed. In total 10 thoracic and lumbar vertebral bodies were segmented using the automatic demons based approach and compared to a gold standard segmentation produced by a semi-manual threshold based method. The quality of the automatic segmentation was determined by calculating how many voxels were concurrently within both the automatic and the manual segmentation of the patient scan. This value was then compared to the volume of the automatic and manual segmentations to determine the relative volume contained in both segmentations. An average of each relative volume was used to determine quality of fit. The use of the same vertebral level and an adjacent level as the atlas was compared in the registration.

RESULTS

The deformable registration technique was able to successfully segment metastatically involved vertebrae with and without breach of the cortical shell. Similar performance was evident when using an atlas from an adjacent level as compared to using an atlas of the identical vertebral level (Table 1). Quality of the automatic segmentation ranged from 87.67% through 96.22% concurrency. Comparisons of inter-user semi-automated segmentations yielded a similar maximum of 96% concurrency. A continual decrease in accuracy is observed in moving superiorly in the spine from L5; this decrease is most prominent above T7 (89.48%).

<table>
<thead>
<tr>
<th></th>
<th>Same Level Atlas (mean + σ) %</th>
<th>Adjacent Level Atlas (mean + σ) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lumbar n=4</td>
<td>95.09 ± 1.57</td>
<td>95.66 ± 0.92</td>
</tr>
<tr>
<td>Thoracic n=6</td>
<td>92.47 ± 2.85</td>
<td>91.26 ± 2.09</td>
</tr>
</tbody>
</table>

Table 1: Percent Concurrency between Automatic and Manual Segmentation for all Vertebral Levels

Average computation time for registration and transformation of the segmentation was 1min 4sec ± 18sec over 9 timed runs on a 3 GHz Intel Pentium 4 with 1 GB RAM. In comparison, semi-automated segmentation takes at least 10 to 15 minutes per level dependent on user skill and scan quality.

DISCUSSION

Atlas-based segmentation is able to overcome many problems inherent to more conventional segmentation techniques such as region growing and thresholding. By maintaining curvature of the atlas, segmentations are able to accurately differentiate between trans-cortical tumors and surrounding soft tissue of identical intensity. Atlas-based segmentation is also significantly faster than manual delineation of the volume or semi-automated threshold based methods. Most errors in the automatic segmentations were found near the upper and lower endplates. Future work is needed to improve the algorithm to better differentiate between disc tissue and bone and to account for large differences in shape (i.e. osteophytes) between the atlas and the patient scan which can cause significant inaccuracies in the segmentation. Clinical application of this segmentation algorithm centers on tumor quantification and tracking of progression or treatment effect in the metastatic spine.

REFERENCES


ACKNOWLEDGEMENTS Canadian Breast Cancer Research Alliance