Iterative reconstruction for segmentation of trabecular bone from in vivo microCT

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Aims. MicroCT allows the in vivo imaging of small animal bone structures. To detect subtle alterations in bone structures over time or between different mouse models, a sensitive segmentation method is required. The segmentation becomes problematic when image resolution decreases, as is the case for in vivo imaging. Murine trabecular bone can have dimensions similar to the system resolution, leading to blurred and less intense trabeculae in the reconstruction. To correctly segment even the thin bone structures, we attempt to incorporate the blurring of the projection data due to the microCT scanner, which is characterised by the point spread function (PSF) of the scanner.

The filtered backprojection reconstruction method does not allow incorporation of the PSF. Instead, the blurred projections can be corrected for the PSF prior to reconstructing using deconvolution techniques. Unfortunately these techniques are very sensitive to noise, and in vivo scans are rather noisy due to dose constraints. As incorporation of the PSF is unsatisfactory using filtered backprojection, we investigate whether an iterative reconstruction technique is more robust and whether it is feasible to use in everyday scanning.

Method. Iterative reconstruction techniques generally start from a uniform image that serves as estimate of the reconstruction, and iteratively refine this estimation. In each iteration the projections of the current reconstruction estimate are calculated and compared to the measured projections obtained during the microCT scan. The difference between current estimate projections and the measured projections is backprojected and added to the reconstruction estimate. This procedure is iterated until convergence, i.e. until the current calculated projections are equal to the measured projections.

As any real world measurement contains noise, the two sets of projections will never match exactly and the method will keep cycling. To resolve this issue, iterative reconstruction techniques can be formulated in a statistical framework, resulting in a search for the most likely reconstruction given the projection data [1]. Even in the presence of noise a most likely image will be found. The statistical model also allows incorporation of prior information about the object to be reconstructed. In our bone application, we know that the image consists of a limited number of tissues: usually bone, soft tissue and air. When for a certain voxel the projection data is indecisive for an attenuation value, the prior information can nudge the voxel towards an attenuation value that is close to that of one of the expected tissues. The prior can be implemented by modelling every tissue as a Gaussian, requiring knowledge about the number of tissues and their expected attenuation values. Instead, we use a variation on the joint entropy prior that needs no image specific input, but yields a clustered histogram as well [2].

A projection and a backprojection need to be performed in each iteration of the iterative reconstruction, making it a computationally expensive technique. In return more flexibility in
defining the projector is obtained. If the calculated projections are smoothed with a kernel similar to the PSF of the scanner, the effect of the PSF is incorporated and the reconstruction estimate is expected to be sharper.

**Experiment.** The tibiae of four male Bl6 mice were scanned in vivo using the SkyScan1076 microCT scanner at a pixel size of 9 micron. The mice were immediately sacrificed and the excised tibiae were scanned ex vivo in the SkyScan1172 microCT scanner with a pixel size of 5 micron. Both in vivo and ex vivo projection data sets were reconstructed using the filtered backprojection method available in NRecon (version 1.5.1.4; SkyScan). Additionally, the in vivo projection data was reconstructed using the presented iterative approach. The reconstructed region was restricted to the central slice of the object to make the iterative reconstruction feasible with respect to its computational burden.

All reconstructions were segmented using a global threshold. As it is well known that the global threshold is incapable of correctly segmenting thin objects relative to the resolution, the filtered backprojection reconstruction of the in vivo data was also segmented using the adaptive thresholding in CTAn (version 1.9.1.0; SkyScan). The three reconstructions of each tibia were registered to each other and this relationship was used to transfer a delineated region of interest (ROI) to the two other reconstructions. To evaluate the performance of the in vivo reconstruction and segmentation techniques, 2D bone parameters were calculated from the ROIs using CTAn for every approach and the results were compared. The high resolution ex vivo segmentation is considered as golden standard. Comparisons were based on the percentage error from the golden standard, which is 100 times the actual difference between the measurement and the golden standard, divided by the golden standard.

**Results.** As can be seen in table 1, the conventional reconstruction method with a simple global threshold leads to errors of 30% or larger for both bone volume fraction (BV/TV) and trabecular thickness (Tr.Th). Replacing the threshold by a more advanced technique that takes the local background into account improves these errors to 10%. The presented iterative reconstruction approach further reduces the trabecular thickness error by half. The different segmentations do not have a large effect on the trabecular number (Tr.N). These results are confirmed by visual inspection of the reconstructions and their segmentations in figure 1.

An important issue is the computation time. Calculating the iterative reconstruction of one slice of a 1000x1000 pixel image currently takes approximately one hour. The same slice takes only a few seconds to be reconstructed by filtered backprojection.

<table>
<thead>
<tr>
<th>Reconstruction</th>
<th>Threshold</th>
<th>BV/TV (%)</th>
<th>Tr.Th (%)</th>
<th>Tr.N (%)</th>
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</thead>
<tbody>
<tr>
<td>Filtered backprojection</td>
<td>Global</td>
<td>29.96</td>
<td>35.06</td>
<td>8.87</td>
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<tr>
<td>Filtered backprojection</td>
<td>Adaptive</td>
<td>10.03</td>
<td>11.32</td>
<td>12.48</td>
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<td>Iterative Reconstruction</td>
<td>Global</td>
<td>10.86</td>
<td>5.26</td>
<td>11.10</td>
</tr>
</tbody>
</table>

Table 4. Mean percentage error from the golden standard over all animals for the different reconstruction and thresholding methods of in vivo data.
Conclusion. We have presented an iterative reconstruction technique for in vivo microCT data that improves estimates of trabecular thickness compared to filtered backprojection reconstructions. The strength of the approach is that incorporates the PSF of the scanner. The major drawback of the method is the computational complexity. Executing image manipulation tasks that can be parallelised on a graphics processing unit (GPU), results in speed gains of a factor 10 up to 100 times compared to running the task on a central processing unit (CPU). To achieve the speedup required to make the iterative approach feasible in everyday scanning, the method could be implemented on the GPU.

References.