Limits on the Measurement of Structural Changes in Trabecular Bone using micro-CT

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Aims

Measures of trabecular architecture, such as trabecular thickness, connectivity and anisotropy, show correlations with bone strength but are not based on knowledge of the way in which bone fails. We wish to develop quantitative measures of bone quality derived from observed failure under stress. Some work observing structural changes under loading has previously been performed but it has been limited[1,2,3]. We wish to know the limits of the structural changes that can be measured, whether those limits arise from registration, segmentation or image acquisition.

Two pairs of images were acquired: one where the bone had the same positioning in the scanner and one where it did not. In the second case the images were registered After segmentation these were overlaid to show any differences (see below). Figure 1 shows that there are regions of difference between the images and that this is more pronounced in the case of the registered images. There are a number of possible causes for the differences, including segmentation error, poor registration and geometric distortion between images captured in different poses. We have investigated these possibilities.

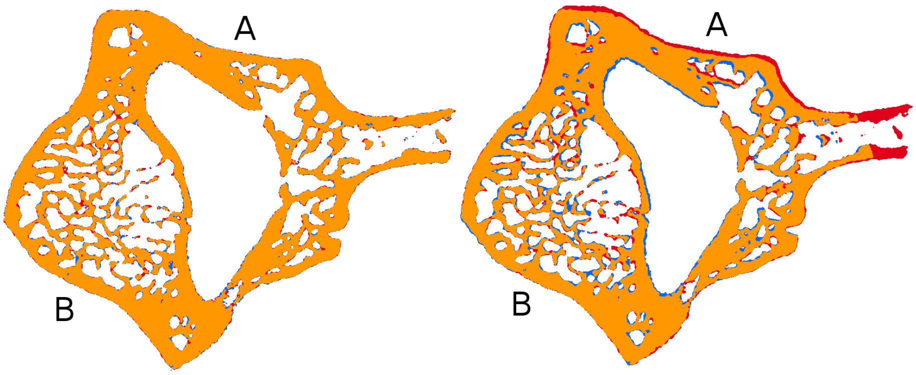

Figure 1: In the overlaid images on the left the bone had the same positioning in the scanner, on the right it had been removed between scans. Orange represents voxels present in both images. Blue and red represent voxels in only one image. Different positioning in the scanner appears to have increased errors in the resulting image.

Method

Images of rat lumbar vertebrae were acquired using a Skyscan 1072 micro-CT scanner and reconstructed using NRecon. The fiducial maker images (see below) were acquired with an isotropic voxel size of 11.24 μm; other images have a voxel size of 9.11 μm. Windowing and manual selection of threshold levels was performed in CTAn. The registration software described below was used to perform digital rotations; all other image processing and analysis was performed in Matlab. Where images have been segmented global thresholds were chosen manually for one image and automatically selected to produce the same bone volume in other images of the same bone.

Registration
The generalized registration task is to find the transformation of one image on to another that minimizes the differences between the images; the difference is evaluated by a cost function. Searching all possible transformations is prohibitively time consuming, instead a series of local searches are applied using heuristics appropriate for the image to attempt to ensure a global minimum is found.

We have used FLIRT[4,5], part of the freely available FSL package which is a set of tools used for the analysis of neurological MR images. Rigid body registration has been performed using the correlation ratio cost function.

Fiducial Markers
Glass beads 362 μm in diameter were fixed to the bone using cyanoacrylate glue to be used as fiducial markers. The centres of the spheres were located on the images using a Hough Transform. Implementing a spherical Hough transform to locate the spheres was considered too computationally demanding for these large data sets. Instead a series of circular Hough transforms were performed on all slices in all three directions. These coordinates were pooled, grouped into possible spheres and those not likely to represent a sphere discarded. Least squares fitting was used to accurately locate the centre of each potential sphere. Iterative closest point matching was used to find a transform to match sets of points from two images. Each pair of points was manually confirmed.

Results

Cost Function Evaluation
In order to determine if a global minimum was being found we evaluated the cost function at various rotations and as shown in figure 2.

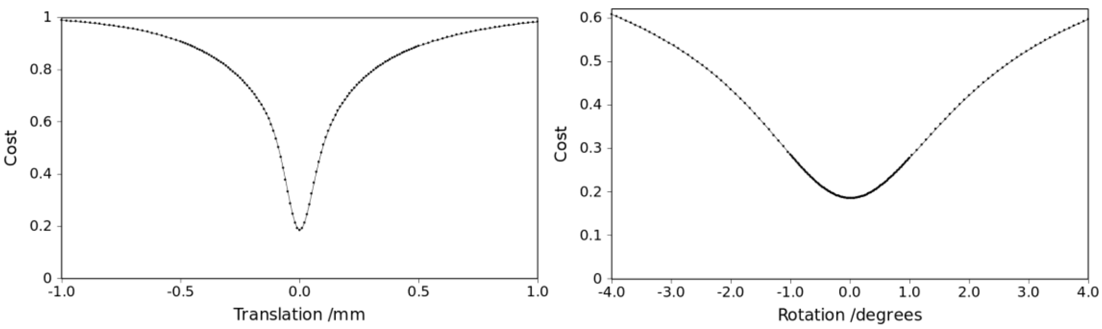

Figure 2: Cost functions were evaluated for various rotations and translations. The origin on the x-axis corresponds to the final registration. The global minimum will be found since the cost function is smooth.

Registration of Regions
If geometric distortion is present we would expect registration of smaller regions of the image to produce different registrations. The image was divided into octants and each registered independently. Each region produced transformations different from that using the whole image: from 13 to 179 μm in translation and from 0.16° to 3.71° in rotation.

Image Profiles
Rather than investigate all the various segmentation methods we have examined 1-dimensional image profiles directly. Following registration, the calculated transformation was used to obtain equivalent sample profiles from the images before and after rotation. This allowed us to compare edge profiles on different images while

avoiding the effects of interpolation introduced by registration. The results are shown in figure 3.

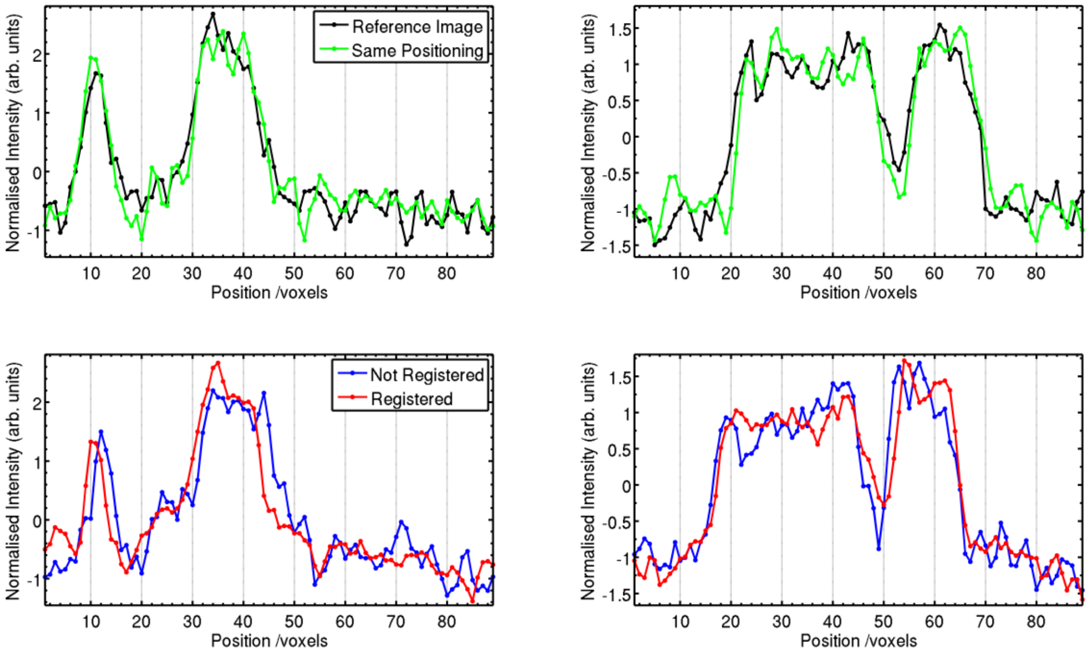

Figure 3: The profiles in each figure correspond to equivalent positions on the image. Those on the left are from a region where smaller errors are observed than those on the right (A & B on figure 1). The top profiles show a difference between repeat image acquisitions with no movement of the specimen while the bottom profiles are from the same image before and after registration.

<u>Fiducial Markers</u>

Two images of a bone with fiducial markers attached were taken; a typical slice is shown in figure 4. The positions of the markers were determined and one set was transformed onto the other. The resulting differences in the positions are shown in figure 5.

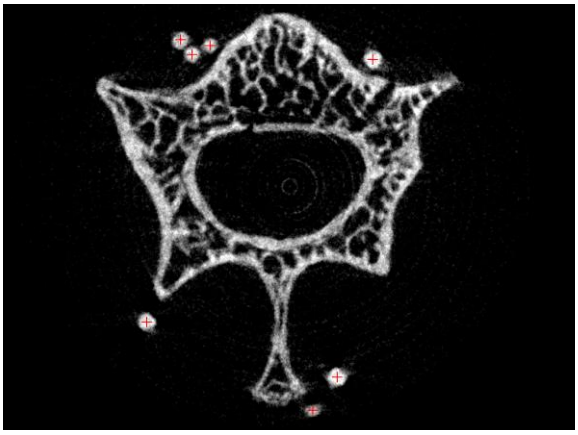

Figure 4: Slice from an image of bone with fiducial markers attached. The marks show the centers of the spheres projected on the slice.

Conclusion

Differences were observed in images taken of the same bone which were larger when the bone had been repositioned between scans. Examination of the cost function found that a global minimum was reliably found suggesting registration is not the cause of the differences. When regions were registered individually different transformations were found suggesting that distortions may exist in the image.

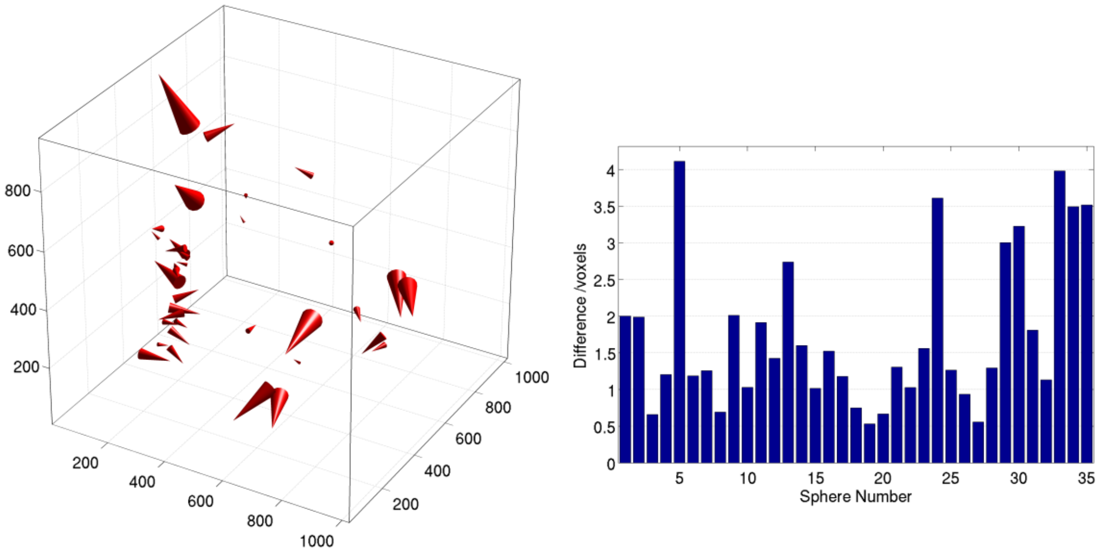

Figure 5: Differences between the coordinates of spheres after registration. The image on the left shows the direction and magnitude of the differences where the magnitude has been scaled up by a factor of 50.

Examination of image profiles confirms the differences in figure 1 and suggests two types of difference: one that occurs in between images acquired identically with the bone having the same position in the scanner and one that occurs when the bone has a different position in the scanner. Surprisingly the profile from this image appears to more closely match that from the reference image after registration has been performed.

Fiducial markers have been successfully used to perform a registration independently of the image based registration method. Geometric differences in the image would prevent all the points matching up. Since differences are observed it is now necessary to determine the limitations of this method using further images to determine if the differences are consistent and using robust statistics in the determination of the transformation.

References:

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