Semi-automatic Method for 3D Registration of Trabecular Bone Images in Serial Studies

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INTRODUCTION

Micro-MRI of trabecular bone has significant potential for longitudinal evaluation of the structural implications of aging or treatment with antiresorptive drugs. However, since bone architecture is highly heterogeneous at the peripheral skeletal locations (e.g. distal radius or tibia), detection of changes relative to baseline values, demands high reproducibility in the selection of the scan location [1]. Prospective localizer image-based scan volume prescription is essential but not sufficient to ensure that the baseline and repeat studies are adequately matched. We have developed a semi-automated method for volume registration that facilitates the selection of identical analysis volumes in different scans of the same anatomical location. The algorithm is based on iteratively minimizing the difference image following adjustments of the retest volume position and orientation. The method was tested on micro-MRI images of the wrist and tibia of perimenopausal women, acquired at baseline and 1 month. The 1 month retest volumes were registered against the baseline and this information was used to generate volume of interest (VOI) masks that selected the same analysis volume for both acquisitions.

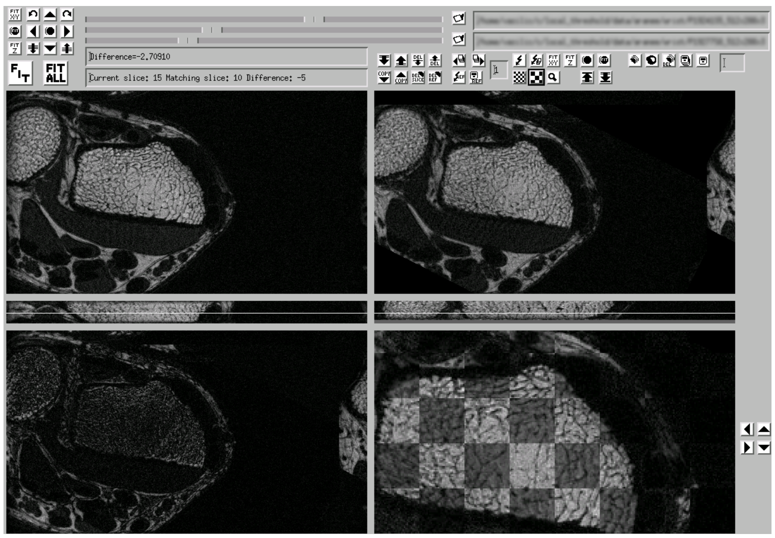

Fig. 1. Screen-shot of the IDL application developed to perform the registration. Top left, first two rows, an axial and reformatted coronal slice of the baseline volume. Top right, first two rows, corresponding slices of the currently registered retest volume. Lower left corner shows the absolute value of the difference of the two axial slices show in the first row. Bottom right, superposition of baseline and registered repeat scan slice interleaved in a checkerboard pattern and magnified to facilitate visual inspection.

METHODS AND THEORY

An IDL application was written that enabled the user to load and view a baseline volume and up to ten retest volumes to be aligned to the loaded baseline. While all loaded volumes and their adjustment parameters were kept in memory, only one retest volume could be viewed and adjusted at a time. Four axial and two coronal views were displayed as shown on Fig. 1: the current slice of the baseline, the current slice of the selected retest volume, a reformatted coronal view of the baseline and the retest, the absolute value of the difference of the current baseline and retest slices and a magnification of the baseline and retest slices combined in a checkerboard pattern as a visual aid to asses mutual agreement. The baseline volume position and orientation were fixed and the retest in-slice rotation and translation and slice offset relative to the baseline were varied. The user would first manually adjust the in-plane translation and rotation as well as the slice offset of the retest volume to match the baseline to a good approximation. These manual adjustments establish the initial conditions for the algorithm that then proceeds to automatically search for the optimal in-plane rotation and translation as well as the slice offset. The search process minimizes the sum of the absolute difference between baseline and retest. In finding the in-plane translation and rotation the program only considers the difference between the middle slice of the baseline and the corresponding slice of the retest determined using the current best estimate of the slice offset between the two volumes. To find the slice offset the program considers the center slice in both volumes with the retest slice translated and rotated by the current best estimates of the in-plane translation and rotation. To find the optimal match the algorithm first determines the rotation and translation, followed by the slice offset. This process is repeated iteratively until there is no change in the metric.

Using the registered in-plane translation and rotation and slice offset the program allowed retest masks to be generated from a mask specifying the baseline VOI. The baseline mask could be loaded from an external file or generated within the program. If the slice offset was such that some of the registered retest masks would fall outside the acquired retest volume the mask would be made smaller and the corresponding smaller baseline mask would be used to generate masks for all retests. The masks generated using the registered retest volumes would then be saved to be used in the analysis.

RESULTS AND CONCLUSION

The algorithm was tested on 9 pairs of wrist scans and 10 pairs of ankle scans of perimenopausal women. If the finally accepted registration required any operator adjustment the automated registration was considered to fail. This was done in cases were the algorithm obviously misregistered the volumes or visual inspection of the enlargements showed inconsistencies. In 45% of the wrist pairs the automated registration failed. The algorithm worked without a need for final operator intervention in 81% of the ankle scans. In many scans the manual adjustment of the initial condition was not needed. On average registration took 2 minutes and if masking was also needed the whole process took on average 5 minutes. Parameters calculated using the program described here were consistent with parameters calculated using VOIs masked manually by visual inspection of trabecular structure patterns. Fig. 2 shows the test-retest plot for the topological surface density [2] (a measure of the trabecular plate to rod ratio) calculated for the analyzed volume in the distal radius, corresponding to an intraclass correlation coefficient of 0.82.

The algorithm failures occurred for two main reasons. In one case the two volumes were also misregistered by a rotation perpendicular to the slice axis for which the algorithm does not currently correct. This would produce partial alignment in several slices that could not give a unique fit. Currently, the program is being improved to also be able to correct for these rotations. In the second case, when the two volumes were misregistered by a large rotation, the difference between the two slices being matched would be dominated by regions in which there was no data due to the clipping of the rotated slice. The new method has two major advantages over the manual registration procedure. First, registration is semi-automated which removes operator bias in the VOI choice and speeds up the registration process. We anticipate improved precision and success rate with the addition of correction for rotations perpendicular to the slice axis. Lastly, the new program allows for registration and selection of a common VOI in studies involving repeat scans at multiple time points which was previously impossible.

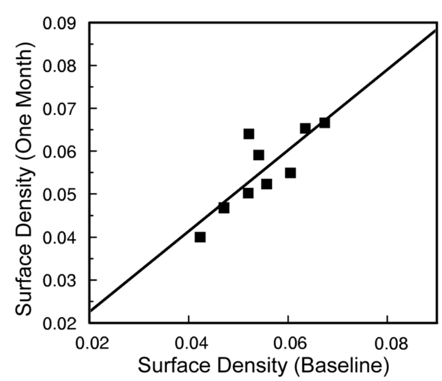

Fig.2 Test-retest plot for topological surface density [2] measured in the wrist.

[1] D.C. Newitt et al., Osteoporosis International, 2002; 13: 278-87.
[2] F. W. Wehrli et al., J Bone Miner Res, 2001; 16: 1520-31.