KINEMATIC ACCURACY AND PRECISION OF SURFACE REGISTRATION AND VOLUME REGISTRATION MEASUREMENTS IN A CADAVERIC BONE COMPUTED TOMOGRAPHY (CT) PHANTOM

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INTRODUCTION
Surface and volume registration methods are now in widespread use in the three dimensional (3D) analysis of joint kinematics. However, there have not been many studies that have attempted to quantify the accuracy (validity) of these methods when analyzing bony displacements in linear and rotational motion. This is a comparative study determining the accuracy and precision (variability) of kinematic measurements derived from three different registration methods (surface, volumevoxel, manual) using an unmarked cadaveric bone phantom scanned in a 64-slice CT scanner.

METHODS
The CT phantom was constructed using a digitally calibrated bone boredoming machine. It consists of a base with a number of accurately placed holes (± 0.001 mm). The bone or scanning portion consists of a cleaned distal half of a cadaveric radius and ulna individually potted into two plastic tubes with polymethylmethacrylate (PMMA) cement. These plastic tubes are of exact sizes to the holes in the base such that a light press fit was achieved. By varying the position of the tubes relative to one another in the base of the template, various linear and angular changes can be simulated with great accuracy and precision. A total of 5 linear conditions and 6 angular conditions can be produced using this CT phantom (Fig 1).

A 64-slice CT scanner (Siemens SOMATOM Sensation 64) was used for this study as it was the most advanced scanner in clinical use today. A total of 11 conditions (5 linear and 6 angular) were scanned. The DICOM image data at voxel size of 0.156252 x 0.4 mm3 were downloaded into Analyze 6.1 program.

For surface registration, the distal radius and ulna bone images were thresholded, segmented, and individually saved as binary images. For volume (voxel) registration and manual registration, the bones were only segmented without any thresholding done, so that the volumetric grey level information was maintained. All registrations were performed within Analyze 6.1 with voxel and surface registrations being entirely automatic without any manual input.

By permuting the 5 linear conditions, we were able to perform comparisons of 10 linear conditions (0.25 mm, 1 mm, 1.25 mm, 2 mm, 3 mm, 3.25 mm, 4 mm, 5 mm, 5.25 mm). By permuting the 6 angular conditions achieved by axial rotations of the tube with the radius bone, we were able to perform comparisons of 12 angular conditions (15° x 5, 30° x 4, 45° x 2, 60° x 1). Two registration trials were performed for each condition yielding a total of 20 linear conditions and 24 angular conditions analyzed. The resultant transformation matrices were then converted to angular or linear measurements by a custom Matlab 7.01 program.

Statistical analysis was performed with JMP 5.1 statistical software using paired Student’s t-test to compare means.

RESULTS
In terms of linear measurements, manual registration turned out to be the most accurate with a mean absolute error of 0.179 mm (SD 0.151 mm). This was followed by voxel registration which had a mean absolute error of 0.712 mm (SD 0.388 mm). The most inaccurate was surface registration which had an absolute mean error of 1.244 mm (SD 0.712 mm) (Chart 1).

The accuracy of angular measurements were the best and were statistically similar for manual and voxel registration methods. By comparison, the accuracy of surface registration for angular measurements was significantly poorer (Chart 2).

Precision (variability) was calculated by comparing the results of the first and second registration trials. Voxel and surface registration methods demonstrated absolutely no variability in all the measured linear and angular conditions, whereas the mean variability of manual registration was 0.0953 mm (SD 0.127 mm, 95% CI 0.0047 – 0.186 mm) for linear displacements and 0.149° (SD 0.312°, 95% CI 0.0432 - 0.254°) for angular displacements.

DISCUSSION
Manual registration is still the most accurate registration method, albeit tedious. However, it has a small amount of variability and imprecision. For kinematic studies demanding very high accuracy, manual registration methods might be preferred. Surface registration methods are the most inaccurate based on our study. This could be due to the fact that binary images versus grey level images had to be used when performing surface registrations. Surface registration is thus not a recommended method unless other registration methods are not available or feasible. Overall, voxel registration using grey level images is the preferred registration method in terms of accuracy, precision, and automation.

Further improvements in registration algorithms will be expected. Until then, automatic registration methods will still require frequent manual verification to minimize errors.

REFERENCES

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