Quantification of Computational Geometric Congruence in Surface-based Registration for Spinal Intra-operative Three-dimensional Navigation

Daipayan Guha MD; Raphael Jakubovic MSc; Victor Xiao Dong Yang MD, PhD, MSc, BSc
Division of Neurosurgery, University of Toronto

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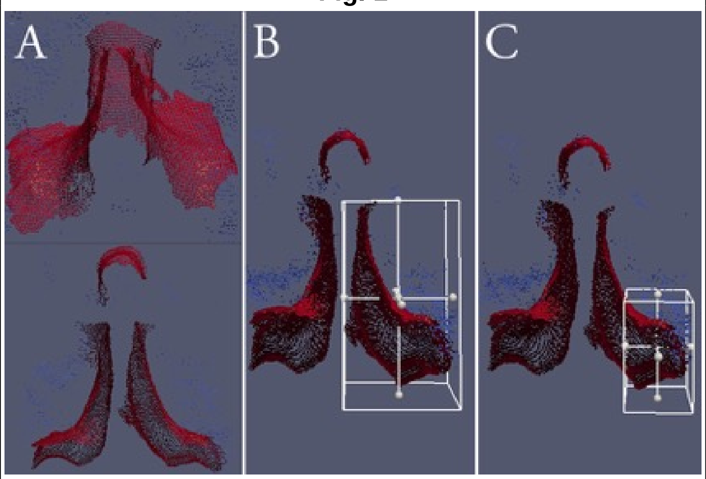
Introduction

Intra-operative navigation for spinal procedures may guide instrumentation placement and bony decompression. Navigation requires the alignment of patient bony anatomy to pre- or intra-operatively acquired imaging. Iterative closest-point algorithms used for registration are susceptible to failure in geometrically homogeneous regions, resulting in failed or inaccurate registration. Here, we computationally quantify geometric congruence in posterior spinal exposures, and identify predictors of potential navigation inaccuracy due to geometric homogeneity.

Fig. 1

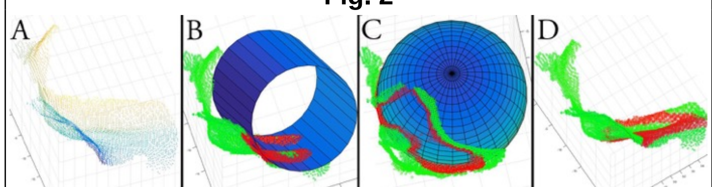


Reconstructed surface point-clouds including bilateral hemilaminae (Group A), unilateral hemilamina including base of spinous process (Group B), and unilateral hemilamina excluding base of spinous process (Group C).

Methods

A prospective pre-clinical trial of an optical navigation system was conducted in four human cadavers. Midline open exposures were performed from C1 to S1. 3D surface maps of the posterior elements at each level were generated optically, and their constituent point clouds reconstructed post hoc to include the bilateral hemilamina + spinous process (Group A), each unilateral hemilamina including the base of the spinous process (Group B), and each unilateral hemilamina excluding the base of the spinous process (Group C). Point clouds from each group, at each registered level, were computationally fitted to symmetrical geometries (cylindrical, spherical, planar). The degree of fit of each point cloud to a geometrically-symmetric shape was quantified using two metrics, the mean-adjusted coefficient of variation in the root-mean-square error (CoV-RMSE), as well as the proportion of total points fitted to the geometric shape (inliers to points ratio, ITPR).

Fig. 2



Fitting of reconstructed point clouds (A) to symmetrical geometries in cylindrical (B), spherical (C) and planar (D) configurations, using a RANSAC algorithm.

Results

In Group C, increased cylindrical, spherical and planar symmetry was seen at C1 and the subaxial cervical spine relative to all other regions. Inclusion of the base of the spinous process (Group B vs. C) decreased symmetry in all configurations, independent of spinal level. Registration with bilateral hemilamina did not significantly alter symmetry.

Conclusions

Geometric congruence is most evident at C1 and the subaxial cervical spine, with potential for increased navigation error. Inclusion of the base of the spinous process may mitigate the potential for registration error in unilateral approaches.

Learning Objectives

By the conclusion of this session, participants should be able to:
1) Identify the basic concepts of patient-to-image registration for neuronavigation.
2) Identify shortcomings in registration procedures for current neuronavigation systems
3) Define the concept of geometric homogeneity/congruence, in the context of patient-to-image registration

References

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