Purpose: Intraoperative cone-beam CT (CBCT) offers potentially improved surgical guidance and patient safety. Fast, accurate deformable registration is important to incorporating preoperative images and planning within up-to-date CBCT while accounting for anatomical changes. Conventional registration typically fails to account for tissue excised between scans and simply "moves" voxels within the image. We propose a novel method that introduces an extra spatial dimension as a "sink" for voxels of excised tissue.
Methods: The Demons algorithm was modified to include a fourth dimension (for 3D registration) into which voxels are "ejected" if above an intensity difference threshold between CBCT scans. The method was tested using a cadaveric head undergoing deformation and excision typical of sinus and skull base surgery guided by C-arm CBCT. Performance was quantified in comparison to conventional Demons in terms of freedom from erroneous deformation and accuracy of voxels "ejected" versus actually excised tissue.
Results: Conventional Demons registration caused erroneous warping and geometric error in the presence of tissue excision. The modified Demons algorithm overcame these difficulties and was observed to accurately eject voxels from the image in the region of excision. In clival drillouts, mean (max) error from erroneous deformation was reduced from 0.7 (5.1) mm to 0.4 (2.1) mm for the proposed approach, and the fraction of tissue properly removed from the excision volume improved from 31% to 97%.
Conclusion: Adding extra dimensionality to the registration problem allows proper handling of excised tissue, a critical consideration in surgical guidance. The proposed method maintained accurate registration of preoperative images and planning data within up-to-date CBCT despite tissue excisions without significant increase in computational complexity and within the familiar Demons framework. Residual errors were primarily due to partial volume artifacts causing fine structures not to meet the ejection threshold, and there was negligible spurious ejection of unexcised tissue.

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