phasized that in applications such as registration of the head for cranial surgery, RMSE is a "relative" indication of registration accuracy.

A true measure of registration accuracy is a three-dimensional volumetric assessment of registration relative to "ground truth." Ground truth is a known point within the registration data set that can be compared between the image space and physical space. For instance, in the setting of cranial surgery, a fixed point such as the tip of the anterior clinoid or some other discrete bony landmark could be used. Registration is often achieved with an acceptable RMSE and yet the error is seemingly significant when compared to a "ground truth" point.

The authors correctly point out that it has been an assumption that bone-based fiducials are more accurate than skin-applied fiducials. When based on the RMSE, these two registration methods are comparatively equivalent. I am not surprised by the finding given the magnitude of the values and standard error (2.76 ± 1.19 mm and 2.25 ± 0.95 mm).

The authors' discussion relative to "tip-to-landmark" measurements is simply an assessment of sustained accuracy. It is important to recognize that sustained accuracy is critical in the event that re-registration with internal fiducials is required.

The study is unique in that the authors directly compared bone-based fiducials and skin-applied fiducials in the same patient. As long as one remembers the relative assessment of registration accuracy depicted by RMSE, these registration methods can be assumed to be relatively equivalent.

Stephen Papadopoulos, M.D.¹

Commentary

This article by Dr. Ammirati and his group compares the accuracy of registration of two different fiducial systems. The first system uses skin implants and the second uses bone implants.

The authors conclude that the skin fiducials are as accurate as the implanted bone fiducials and therefore represent a logical alternative. Their closing comments suggest that bone-implanted fiducials may be better for certain indications but these are not well identified in this paper. The importance of any system's registration accuracy is that it allows adjustments should table position, operator position, or the like change during the case. Unfortunately, brain shift is still an issue that is not addressed by surface fiducials in preregistration, but at least the process allows a start from a safe basis.

This article contributes to efficiency in the operating room. In terms of time and money spent on fiducials, this efficiency means that this system continues to be competitive with other systems of intraoperative navigation. If bone implants are not needed routinely, as this article suggests, patients are spared discomfort, the operating room is spared the expense, and accuracy is not sacrificed.

Kenneth F. Casey, M.D.²

Peter J. Jannetta, M.D.²

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Skull Base, volume 12, number 3, 2002. ²Department of Neurosurgery, Allegheny General Hospital, MCP/Hahnemann University, Pittsburgh, Pennsylvania. Copyright © 2002 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10002, USA. Tel: +1(212) 584-4662. 1531-5010,p;2002,12,3,131,131,ftx,en;sbs00285x.