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A-Mode Ultrasound Based Skull Registration for Surgical Navigation

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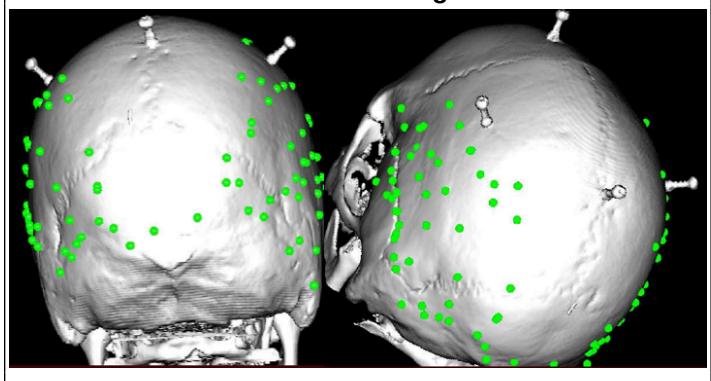
Introduction

Surgical navigation requires registration of the patient's anatomy to preoperative images. Traditionally this is accomplished with fiducials or skin surface tracings, but can be difficult with lateral or prone positioning. Here we show how an A-mode ultrasound can be used to register skull surface points through skin and hair on a cadaver model as accurately as traditional methods.

Methods

Three cadaver heads were fitted with bone screw fiducials for registration. A 7.5 megahertz ultrasound transducer was calibrated and tracked with a commercially available surgical navigation system. The distance from the tip of the ultrasound transducer on the cadaver skin surface to the skull surface was calculated using a digital signal processing algorithm developed at the Southern Illinois University department of biomedical engineering. The measured skull surface points were loaded into the standard registration software of the surgical navigation system. The individual skull surface points measured by ultrasound and their distance to the skull surface from the computed tomography scan of the cadaver head was calculated. Computed error metrics were then used to validate that ultrasound measured skull surface points could register the skull with increased accuracy for lateral and prone surgical positions.

Ultrasound Based Registration



Cadaver with bone screw fiducials and ultrasound registered points

Results

The error of the skull surface points as measured by the ultrasound probe was less than 1mm for most regions of the skull surface. Artificial hair saturated with ultrasound gel did not significantly affect measurements indicating that hair clipping would not be necessary for most patients.

Conclusions

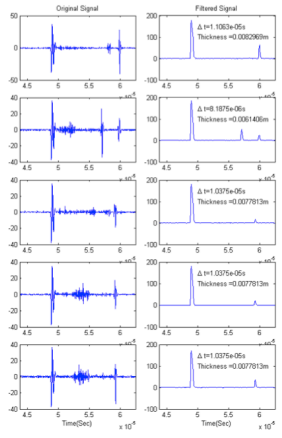
The computed error metrics after registration validated the hypothesis that ultrasound measurements of the skull surface can accurately register preoperative images to the patient on the operating table with cranial fixation. Surgical registration technology can use ultrasound measurements with the digital signal processing method we developed. This technological innovation can increase the accuracy of surgical navigation by replacing fiducials or tracing methods.

Ultrasound Processing

Digital Signal Processing Algorithm

Digital signal processing (DSP) algorithm for automatic detection of ultrasound waves peaks including two steps:

1. Low-pass filters to reduce high frequency noise: Butterworth Low-pass filter and Hilert transform.
2. Smoothing and detecting ultrasound peaks: Teager energy operator.



Description of how A-mode ultrasound signals are processed during cranial registration.

Error Analysis Results

Error Analysis Results

	Positions/Areas	Counted Points	Total Points	Averaged Error (mm)	Standard Deviation (mm)
Cadaver I	Top and back	77	135	0.7123 mm	0.2676 mm
	Side	62	75	1.1367 mm	0.1784 mm
	Cheekbone	18	43	2.1439 mm	0.5127 mm
Cadaver II	Top and back	46	93	0.4258 mm	0.1693 mm
	Side	57	82	0.7560 mm	0.1734 mm
	Cheekbone	19	39	1.9732 mm	0.4317 mm
	With Hair	14	31	0.2415 mm	0.0475 mm
Cadaver III	Top and back	91	91	0.9141 mm	0.2846 mm
	Side	25	31	1.0457 mm	0.1580 mm
	Cheekbone	13	21	1.7647 mm	0.5094 mm
Plastic Skull	Registration Points	350	350	0.2979 mm	0.0627 mm

Results analysis showing submillimetric error with A-mode ultrasound based registration for surgical navigation.

References

1. Raabe et al, "Face scanning for patient registration in intracranial image-guided surgery." Neurosurgery. 2002;50:797-803

2. P. Besl al et. "A method for registration of 3-D shapes", IEEE transactions on Pattern Analysis and Machine Intelligence, 14(2), 239-254, 1992.

3. Caversaccio M et al, "Practical aspects for optimal registration (matching) on the lateral skull base with an optical frame- less computer-aided pointer system." Am J Otol. 2000;21:863-870.

Learning Objectives

Understand the basics of surgical navigation and registration.

Understand how A-mode ultrasound can be used to register patient's to preoperative CT and MRI scans.