Background / Motivation

- Mastoidectomy is a common otologic procedure performed to gain access to middle and inner ear
- Removal of all or part of mastoid portion of temporal bone
- Vital anatomical structures embedded within the bone
- Image-guided robotic milling could improve safety and save time
- Specific application: Acoustic Neuroma (AN) tumor removal
  - Goal: Robot performs bulk removal of bone; surgeon performs delicate resection of tumor

Design Considerations

(a) Analysis of Forces in Temporal Bone Milling

Parameters Tested:
- Burr type/size: larger fluted burrs should be used where possible to minimize force
- Drill angle: lower angles should be employed to avoid large force spikes
- Depth, velocity, bone removal rate: use shallower/faster cuts as opposed to slow/deep cuts
- Bone type: lower forces overall in pneumatized bone vs. cortical bone (but higher variation)

(b) Workspace Analysis

- Standard mastoidectomies and translabyrinthine AN cases analyzed
- XYZ Motion and One rotational DOF required
- Workspace approximately an inverted cone with elliptical cross-section (45 MM x 52 MM axes) and depth of 49 MM

Target bone volume
Facial Nerve
Semicanal
I.A.C.

Robot Prototype

- 4 DOF Robot – 3 linear joints, 1 rotational joint
- Drill passes through center of robot to reach target anatomy
- Robot attaches to patient via a pre-positioning frame (PPF)
- Piezoelectric actuators used for two joints
- Brushless DC motors used for two joints
- PPF scanned with patient and spheres serve as both attachment points and fiducial markers

Surgical Workflow

1. Automatic segmentation of critical structures and manual segmentation of target bone volume from pre-operative CT scan

2. Attach pre-positioning frame (PPF)

3. Intra-operative CT scan of patient and PPF

4. Transform pre-operative target bone volume to intra-operative CT scan

5. Localize fiducial markers, plan safe milling path and convert to robot trajectory

6. Attach robot and begin procedure

Experimental Results

(a) Free Space Accuracy Evaluation

- Mastoid segmentation superimposed onto scan of phantom
- Positional accuracy measured at several critical points

<table>
<thead>
<tr>
<th>Location</th>
<th>Mean TRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skull Surface</td>
<td>0.38±0.28 MM</td>
</tr>
<tr>
<td>Facial Nerve</td>
<td>0.42±0.26 MM</td>
</tr>
<tr>
<td>Vestibule</td>
<td>0.43±0.26 MM</td>
</tr>
<tr>
<td>Internal Auditory Canal</td>
<td>0.42±0.24 MM</td>
</tr>
</tbody>
</table>

(b) Cadaver Experiments (Ongoing)

- Automatic segmentation of vital structures
- Mastoid segmentation superimposed onto scan of phantom
- Positional accuracy measured at several critical points

References / Acknowledgements


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