Image Guidance in Head and Neck Surgery: Current State and Future Opportunities

Joseph Paydarfar, MD FACS
Associate Professor of Surgery - Otolaryngology
Chief, Section of Otolaryngology, Audiology, and Maxillofacial Surgery

THE ABILITY TO RESECT TUMORS OF THE HEAD AND NECK REQUIRES ADEQUATE ACCESS AND VISUALIZATION

TRADITIONAL SURGICAL APPROACHES FOR LARYNGEAL AND PHARYNGEAL RESECTION

"Outside-In"
- Trans-mandibular
- Trans-cervical

Advantages
- Excellent exposure
- Critical structures are identified prior to tumor resection
- Can palpate and assess depth of tumor

Drawbacks
- Increased operative time
- Increased morbidity
OPEN APPROACHES ASSOCIATED WITH SIGNIFICANT PERI-OPERATIVE MORBIDITY AND LONG TERM COMPLICATIONS

SURGICAL PARADIGM SHIFT

INSIDE-OUT APPROACH
Could Intraoperative Imaging Improve Safety and Efficacy?

- Unique Dartmouth imaging resource:
  - Center for Surgical Innovation (CSI)
  - 2 Operating Rooms
  - 1 Procedure Room
  - Intra-operative CT and MRI systems
  - Intra-operative navigation
  - Animal and human use

Retractors and scopes used are metal and not CT/MRI compatible.

3D printed CT/MRI compatible laryngoscopy system.

**CURRENT STATE OF LOCALIZATION ACCURACY: LOCALIZATION EXPERIMENT IN CADAVER MODEL**

**Significant improvement in target localization (21%)**
12.8 ± 9.9 versus 10 ± 7.5 mm

**Significant reduction in task completion time (25%)**
22 minutes down to 16 minutes

**Conclusions:**
Although intraoperative imaging improves target localization, clinically surgeons were still off target by 10 mm or more

IMAGE GUIDED SURGICAL NAVIGATION IN TORS/TLM

• Successfully used in sinus and skull base surgery, neurosurgery, orthopedic spine
• Actively researched in GI, GU, thoracic surgery, others

IMAGE GUIDED SURGICAL NAVIGATION IMPROVES SAFETY SINUS SURGERY

- Systematic Review
- IGS vs non-IGS
- Major complications significantly less in IGS group:
  - Entry into any area outside sinuses (eye, brain)
  - Post-op bleeding requiring surgical intervention
  - Abort procedure for any reason

USE OF IMAGE GUIDANCE DURING ENDOSCOPIC SINUS SURGERY
Combined TORS and IGS to resect 3 tumors in the parapharyngeal space.

Fused PET/CT images for IGS resection of recurrences at the base of skull.

Localize joint during TMJ surgery. 11 patients navigation assisted resection vs 31 non-navigation infratemporal fossa tumors. Significantly higher rate of complete resection in navigation group.

"...the most obvious disadvantage of the computer-aided navigation is the drifting of soft tissues, which puzzled many surgeons... As for the resection of tumors in the infratemporal fossa, the principal threat is drifting of the internal carotid artery."

Application of computer-assisted navigation systems in oral and maxillofacial surgery.

FOR TRANS-ORAL SURGERY, PRE-OPERATIVE CT DOES NOT REFLECT THE INTRA-OPERATIVE REALITY.
PROOF OF CONCEPT: SURGICAL NAVIGATION WITH INTRAOPERATIVE IMAGING TO IMPROVE LOCALIZATION ACCURACY


HIGH LEVEL OF REGISTRATION ACCURACY (<= 1 MM)
LIMITATIONS IDENTIFIED USING SURGICAL NAVIGATION WITH INTRAOPERATIVE IMAGING

- Intra-operative contrast enhanced CT imaging is required (specialized operating room)
- Optical tracking not as effective, EM tracking accuracy may be affected by metallic instruments
- Tumor delineation with smaller tumors on CT can be difficult
- Repositioning the scope requires: Obtaining new CT
- Increased radiation exposure and OR time
- Tri-planar view (coronal, axial, sagittal) is not ideal

PRE-OPERATIVE

INTRA-OPERATIVE

DEFORMATION MODEL

AUGMENTED REALITY OVERLAY

Examples of Non-rigid Registration

<table>
<thead>
<tr>
<th>Technique</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correspondences/Feature based (Thin-Plate Spline)</td>
<td>Correspondences align well/exactly; fast</td>
<td>Need to define corresponding features; no physical properties</td>
</tr>
<tr>
<td>Probabilistic/Point set: (Coherent Point Drift)</td>
<td>No need to define corresponding features; excels at overall shape matching</td>
<td>Struggles with smooth/featureless point clouds; prior segmentation required; no physical properties</td>
</tr>
<tr>
<td>Image/Intensity based: (Demons, Mutual Information/Gradient Descent)</td>
<td>No need for prior segmentation; Uses image intensity as features</td>
<td>Slow; no physical properties</td>
</tr>
<tr>
<td>Physics/Model based</td>
<td>Physical properties!</td>
<td>Slow; Prior segmentation/model building required</td>
</tr>
</tbody>
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PROTOCOL TO STUDY UPPER AERODIGESTIVE TRACT DEFORMATION

Patient placed under general anesthesia

Fiducial markers are placed along the tongue

Pre-laryngoscopy CT scan is obtained

CT compatible laryngoscope is introduced and placed in suspension

Intraoperative contrast CT scan is obtained

Deformable image registration for cone-beam CT guided transoral robotic base-of-tongue surgery

TLE improved from 11.2 ± 5.0 mm vs. 5.8 ± 2.5 with IGS

Patient placed under general anesthesia

Fiducial markers are placed along the tongue

Pre-laryngoscopy CT scan is obtained

CT compatible laryngoscope is introduced and placed in suspension

Intraoperative contrast CT scan is obtained

PROTOCOL TO STUDY UPPER AERODIGESTIVE TRACT DEFORMATION

Patients undergoing staging or operative laryngoscopy

No dentition (reduce artifact)

ID without prior treatment

5 with prior radiation

480x705

10
QUANTIFY DEFORMATION DURING LARYNGOSCOPY

Mandible Displacement

Hyoid Displacement

Tongue Deformation

Prior radiation significantly affects deformation

Differences in translation and rotation of mandible and hyoid bone

Reduced pharyngeal airway volume

Visualize tissue and tumor deformation during laryngoscopy


PRIOR RADIATION SIGNIFICANTLY AFFECTS DEFORMATION

VISUALIZE TISSUE AND TUMOR DEFORMATION DURING LARYNGOSCOPY
QUANTIFY FORCES GENERATED DURING OPERATIVE LARYNGOSCOPY


SUMMARY OF WORK COMPLETED TO DATE

Avg peak force of 50 lbf recorded on scope!
10 lbf on chest!
F.R.A.N.K.: FUNCTIONAL REFERENCE ANATOMY KNOWLEDGE

- Collaboration with University of British Columbia
- Hybrid model: Combines both FEM and multi-body methods
- Generic template of head and neck structures
- Patient-specific model created by registering template to segmented CT images


FUTURE DIRECTIONS

- Pressure and position data to drive dynamic modeling in cadaver and clinical studies
- Develop CT/MRI compatible retractors for TORS applications
- Incorporate EM tracking with robotic instrumentation
- Examine the use of lower resolution intra-operative imaging (O-Arm) in cadaver models

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