Integrating Intraoperative C-Arm CBCT for Image-Guided Robotic Surgery

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2013
Oropharyngeal Cancer

Standard of Care:

- Radiation +/- chemotherapy
  - Estimated 11-43% swallowing complications
  - 15% long term PEG, i.e. feeding tube, dependency
- Open surgery
  - Invasive techniques
  - Long recoveries
  - Need for PEG
  - Long term functional deficits

[ShileySG-OtoHNS2006 48% G tube required]

[J. Richmon, MD, Johns Hopkins Medicine]
Challenges of Robotic Surgery

• **“Tip of the Iceberg Phenomenon”**
  - Inability to directly visualize anything but the superficial-most portion of the tumor
  - Need to rely on experience to know exactly where the tumor is relative to normal anatomy and preoperative image data.

• **Unfamiliar approach**
  - Most surgeons trained in “outside-in” approach
  - TORS reverses this and is disorienting to inexperienced surgeons

• **Intraoperative patient deformation**
Image Guidance Workflow

PREOPERATIVE

Plan_{CT}

Preop CT/MR

Planning Data

INTRAOPERATIVE

Endoscope T_{CT} = (Endoscope T_{CBCT})(CBCT T_{CT}) Plan_{CT}

Intraop CBCT

CBCT T_{CT}

Intraoperative Plan

Robot

Intraoperative Update

Endoscope T_{CBCT}
Augmented Stereo Depth Perception
Shared Memory + svlStream

svlSampleImageRGBStereo
(Recon, i.e. Camera Plane)

svlSampleImageRGBStereo
(Recon)

svlSampleImageRGBAStereo
(Recon)

svlSampleImageRGBStereo
(Saggital)

svlSampleImageRGBAStereo
(Fluoro)
• **Johns Hopkins**
  • Jeremy Richmon, MD, PhD

• **Image Guidance**
  • Video overlay + Depth with tool tracking (TT) in CBCTA
  • Fluoro overlay on CBCTA

• **Experiment: Tumor resection**
Pseudotumors & Syngo iGuide
Psuedotumor placement
Experimental Scenario Set 1

- Excised porcine tongue with embedded sphere
  a) Image Guidance: None
  b) Image Guidance: Video overlay + Tool tracking* in CBCTA

- Porcine animal with balloons injected into base of tongue (BOT)
  c) (Left BOT) Image Guidance: Fluoro overlay in CBCTA
  d) (Right BOT) Image Guidance: Video overlay + Tool tracking* in CBCTA

*tool offset calibration used one-time point-based registration
Feedback

- Distracting to have deformation of the tongue while the overlaid image remained stable and no longer reflective of reality

- Need guidance for margins

- Most BOT tumor have superficial surface indicator
  - 80% visible in MRI
  - 30% visible in CT

- Fluoro overlay on CBCTA very helpful at gauging depth of resection and vessels

- Need improved tool tracking
Resection Fiducials
Resection Fiducials

2 (36.06,124.59,187.68), 0.000
3 (69.23,46.36,197.64), 0.000
(45.57,85.98,84.95), 0.001
(76.09,42.92,181.89), 0.001
Margins & Tool Tracking

Depth cue

Tumor

Margin

10 mm

Tooltip

Control Point (joint/wrist)

2 mm

-2 mm

< -2 mm
<table>
<thead>
<tr>
<th>Experiment Model</th>
<th>Image Data</th>
<th>Guidance</th>
<th>Margin</th>
<th>Image Guidance</th>
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<tr>
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Set2c, Set2d, In-vivo Porcine
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<th>Experiment</th>
<th>Specimen [mm^3]</th>
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<th>Tumor [mm^3]</th>
<th>Margin/Specimen</th>
<th>Margin/Ideal Margin</th>
<th>Tumor/Margin</th>
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Observations

• Current workflow provides image guidance appropriate on approach

• After tissues resection guidance (overlay) is outdated
  – experimental estimates observed up to 10mm error for tool tracking
  – Augmented model update needs to be more robust

• Preliminary workspace analysis show that with TORS a partial scan of 30-40 degrees with robot docked and a full scan with arms extracted while PSC base remains stationary
Tool Tracking Accuracy

- Tool tracking measured with rigid tool had < 1.5mm in X,Y,Z axis

- In labs we observed up to 10mm of delta, postulated error source:
  - Joint errors
  - SUJ position
  - Lack of continuous tracking
  - External forces

Analysis:
- Calibrate for tool tracking
- Register dowel fiducials
- Place tools at dowel and measure distance of tracked tool position to 3D position of dowel

- In different SUJ positions (Orthogonal or TORS)
- 8 mm needle driver (continuous tracking)
- 5 mm monopolar cautery (continuous/initial tracking)
Tool Tracking Accuracy

- CAD model with Cartesian coordinates
  - CBCT with metal dowels and gadget corners has too much artifact
  - Used CAD model, fabrication error measured by caliper (<0.1 mm)
# 5 mm (initial) x 60

<table>
<thead>
<tr>
<th>5 mm ALL</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>RMS</th>
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<tr>
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<table>
<thead>
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<th>5 mm SUJ Ortho</th>
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PVALUE          0.7548   0.0002   0.7967   0.0005
## 8 mm (continuous) x60

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PVALUE (Orth vs TORS) 0.0211 0.1110 0.6011 0.4343
## 5 mm (continuous) x60

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PVALUE (Orth vs TORS) 0.1838 0.7838 0.1854 0.6601
Observations

• p-values showed SUJ/position to camera does not seem to matter if continuously tracked

• 5 mm tool more difficult to track
  – Higher joint errors
  – Less visible marker area in FOV

• Continuously marker-based tracking reduces error for tools down to < 5mm, unaddressed sources of error include:
  – joint encoder errors
  – external forces
  – marker placement
Other Clinical Applications

6/7/2013: Cochlear Implant

10/2/2013: Nasal Pharyngeal

10/09/2013: Lung
A Modular System Architecture

Image Guidance System

<<application>> ITK-Snap
<<Data>> vtk Mesh

<<package>> cisst
<<3DUserInterface>>
ui3VisibleObjects
ui3Behavior
ui3MasterArms
ui3SlaveArms
ui3Manager

<<stereo vision>>
svlFilterSourceVideoCapture
svlFilterTargetRenderer
svlFilterCameraCalibration

<<Component>>
mtsComponentManager
sawIntuitiveDaVinci

daVinci
Children’s National Medical Center, DC
  • Kevin Cleary PhD
  • Diego preciado MD, PhD

Feasibility of using daVinci
  • tool attachment adapter
  • magnification
  • loss of haptics
  • jitter

Workflow for image guidance with video augmentation
Drill Adapter

- X: suction/irrigator
- Y: drill
- Z: tool adapter
Workflow

(a*) Expose mastoid and retract ear forward to fix screw fiducials

(b*) Acquire preoperative CBCT

(c*) Segment critical structures

(d) Position robot

(e) Attach tools/adapters

(f*) Robot to CBCT Registration

(g) Perform cochlear implant surgery using robot

(h*) Insert implant
Results

• Successful insertion of wire phantom into basal turn of cochlea

• Adequate exposure of round window

• There was no injury or surgical breach of the tegmen tympani, sigmoid sinus, or facial nerve
Observations

• Tool adapter supported natural fluid drilling motion
  – Adequate visual and auditory feedback

• Due to workspace constraints (tools & camera) during inner ear work (cochleostomy) daVinci endoscopy was subjectively felt to be inferior to the standard stereo vision conferred by a stereo binocular microscope

• Preop CBCT very useful, surgeon decided fluoro wouldn’t add value to procedure*


*patients often adolescent and radiation should be limited
• Dr. Holsinger
• Dr. Richmon

• Skull base parapharyngeal tumor resection
  – Morbid
  – High risk, proximity to inner carotid
  – 100,000 cases/year in Canton China
Paratumor Fiducials 10/09/2013

- **Phantom:** dry lab, canine
- **Workflow:**
  - Place pseudotumor
  - Place metal bbs around tumor using iGuide, with and without robot
    - Average 10-15 mins/fiducial (inc path planning)
$X_A^{3D}$: preop 3D volume

$X_{Bj}^{3D}$: $j$th intraop 2D fluoro

$T_{\text{calib},j}$: transformation from $S_w$ to $S_{\text{intra},j}$

$X_C^{3D}$: intraop 3D surface from disparity

$S_{\text{pre}}$

$S_{\text{intra},j}$

$S_w$

$T$: transformation from $S_{\text{pre}}$ to $S_w$

- Rigid($t_x,t_y,t_z,w_x,w_y,w_z$)
- Deformable

Stereo endoscopes

$X_C^{3D}$