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

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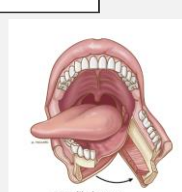
THE ABILITY TO RESECT TUMORS OF THE HEAD AND NECK REQUIRES ADEQUATE ACCESS AND VISUALIZATION

TRADITIONAL SURGICAL APPROACHES FOR LARYNGEAL AND PHARYNGEAL RESECTION

"Outside-In"

Trans-mandibular

Trans-cervical



Mandibulotomy

Advantages	Drawbacks
Excellent exposure Critical structures are identified prior to tumor resection Can palpate and assess depth of tumor	Increased operative time Increased morbidity

OPEN APPROACHES ASSOCIATED WITH SIGNIFICANT PERI-OPERATIVE MORBIDITY AND LONG TERM COMPLICATIONS

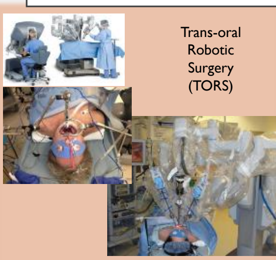
TABLE V.
Literature Reporting Mandibulotomy-Related Complications.

Authors	Year	No.	Osteotomy Site	Osteotomy Shape	Fixation	Poor Wound Healing (%)	Fixation Failure (%)	Total Complications (%)
Dziegielewski et al. (current study)	2009	220	PM	SS	DIW - CMP	7.7	2.7	10.5
Nam et al.[8]	2006	103	Med, PM, Lat	Straight, SS, notch	DIW, 2 MCPs, 2 MCPs - DIW, BCP, MCP+BCP	8.7	6.8	18.4
Uglesic et al.[25]	2004	24	Med	Straight	Lag screw	12.5	0	12.5
Dai et al.[19]	2003	19	Med	Notch	2 CMPs	52.6	5.3	57.9
		23	PM	Notch	2 CMPs	39.1	0	39.1
Genty et al.[26]	2001	107	Med, PM, Lat	Straight, oblique, SS	DIW, CMP	14.9	14	28.9
Bertrand et al.[24]	2000	61	Med	Straight, notch	Recon plate	4.9	8.2	16.4
Eisen et al.[7]	2000	30	Med	Straight, SS	CMP	16.6	0	20
Smeele et al.[11]	1999	48	Med, PM	Straight	DIW, CMP, recon plate	12.5	10.4	22.9
McCann et al.[9]	1994	31	Med, PM, Lat	Straight	Miniplate, comp plate, recon plate, EDCP, OFP	35.5	25.8	61.3
Shah et al.[14]	1993	22	PM	Notch	DIW	27.3	13.6	40.9
		34	PM	Notch	CMP	20.6	8.8	29.4
Christopoulos et al.[22]	1992	69	NS	SS, notch	DIW, CMP	41.9	0	33.3
Sullivan et al.[17]	1992	26	Med, PM, Lat	Med, PM Lat	DIW, BCP	11.5	7.7	23.1
Dubner & Spiro[7]	1991	313	Med, PM	Straight, notch	DIW, CMP	20	0	20
Davidson et al.[15]	1989	44	Med	Straight	AO plate	13.6	11.4	36.4

No. = number of cases; PM = paramedian; SS = stair-step; DIW = direct interosseous wire; CMP = compression mini-plate; Med = median; Lat = lateral; MCP = monocortical plate; BCP = bicortical plate; Recon plate = reconstruction plate; Comp plate = compression plate; EDCP = eccentric dynamic compression plate; OFP = orthopedic flat plate; NS = not specified; DCP = dynamic compression plate; AO plate = Arbeitsgemeinschaft für Osteosynthese.

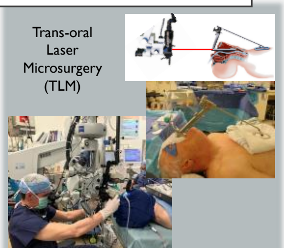
10-61%

SURGICAL PARADIGM SHIFT



Trans-oral Robotic Surgery (TORS)

Trans-oral Laser Microsurgery (TLM)

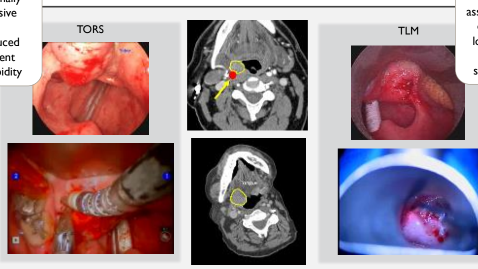


INSIDE-OUT APPROACH

Benefits

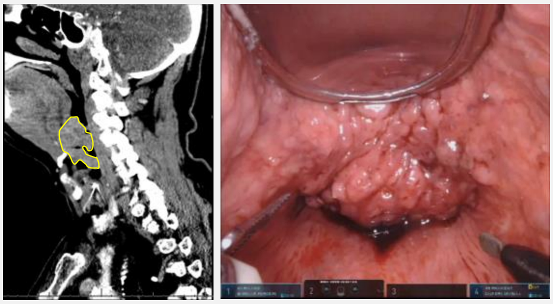
Minimally invasive

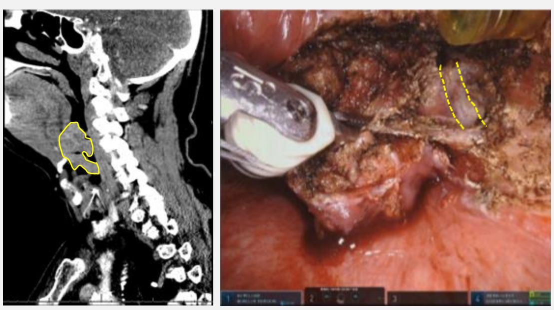
Reduced patient morbidity



Issues

Cannot assess tumor depth or location of critical structures





Original Research—Head and Neck Surgery

Positive Margins by Oropharyngeal Subsite in Transoral Robotic Surgery for T1/T2 Squamous Cell Carcinoma

Otolaryngology–
Head and Neck Surgery
2018, Vol. 158(4) 660–666

Michael J. Persky, MD[1], William G. Albergotti, MD[2],
Tanya J. Rath, MD[3], Mark W. Kubik, MD[2], Shira Abberbock, MS[4],
Mathew Geltzeiler, MD[2], Seungwon Kim, MD[2],
Umamaheswar Duvvuri, MD, PhD[2], and Robert L. Ferris, MD, PhD[2]

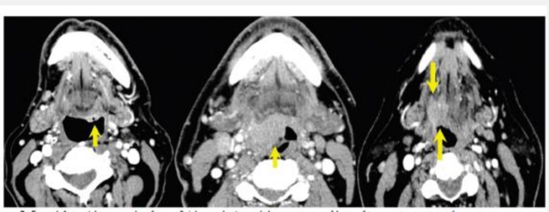


Figure 2. From left to right, example of superficial, exophytic, and deep patterns of base of tongue tumor growth.

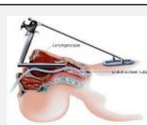
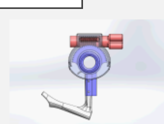
COULD INTRAOPERATIVE IMAGING IMPROVE SAFETY AND EFFICACY?

- 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

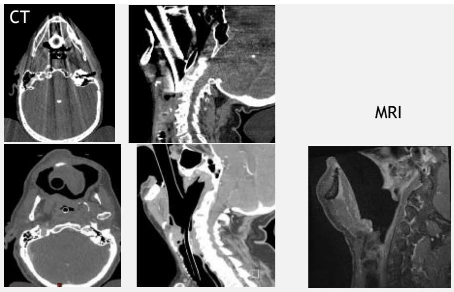



Metal Laryngoscope

Our Laryngoscope

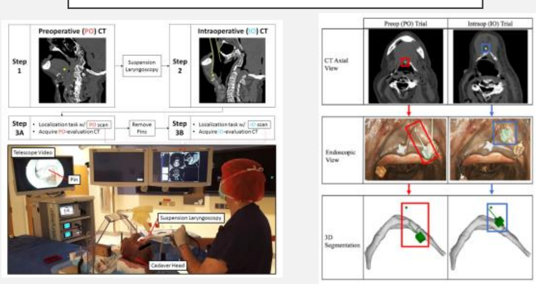
CT

MRI



Paydarfar JA, Wu X, Halter RJ. MRI- and CT-Compatible Polymer Laryngoscope: A Step toward Image-Guided Transoral Surgery. *Otolaryngol – Head Neck Surg*. 2016;610:1-3.

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

P. Kahng, X. Wu, N. Ramesh, D. Pastel, R. Halter, J. Paydarfar, "Improving target localization during trans-oral surgery with use of intraoperative imaging," IJCARS, Feb. 2019.

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

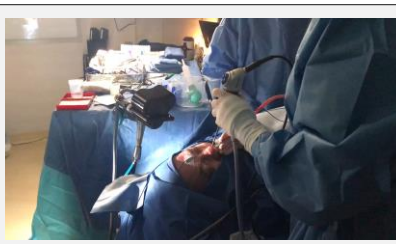

Systematic Review Otolaryngology–Head and Neck Surgery 149(1) 17–29

Image-Guided Surgery Influences Perioperative Morbidity from Endoscopic Sinus Surgery: A Systematic Review and Meta-Analysis

Dustin M. Dalgorf, MD[1], Raymond Sacks, MD[2], Peter-John Wormald, MD[3], Yuresh Naidoo, MD[3], Ben Panizza, MD[4], Brent Uren, MD[5], Chris Brown, MD[6], John Curotta, MD[7], Kornkiat Snidvongs, MD[8], and Richard J. Harvey, MD[1]

- 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



Laryngoscope 118: November 2008

Transoral Robotic Surgery Using an Image Guidance System

Shaun C. Desai, BA; Chih-Kwang Sung, MD; Eric M. Genden, MD, FACS

Combined TORS and IGS to resect 3 tumors in the parapharyngeal space

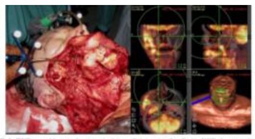
Intraoperative control of resection margins in advanced head and neck cancer using a 3D-navigation system based on PET/CT image fusion

Mathias FEICHTINGER, MD, DMD, Consultant[1], Mauro PAU, MD, Consultant[1], Wolfgang ZEMANN, MD, DMD, Consultant[1], Reingard Maria AIGNER, MD, PhD, Professor, Head[2], Hans KÄRCHER, MD, PhD, Professor, Head[1]

[1]Department of Oral and Maxillofacial Surgery, Medical University of Graz, Austria; [2]Department of Radiology, Division of Nuclear Medicine, Medical University of Graz, Austria

Journal of Cranio-Maxillo-Facial Surgery (2010) **38**, 589–594

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



Application of a Computer-Aided Navigation Technique in Surgery for Recurrent Malignant Infratemporal Fossa Tumors

Rui Guo, MD, Yu Xing Guo, MD, Zhien Feng, PhD, MD, Chuan Bin Guo, PhD, MD

The Journal of Craniofacial Surgery • Volume 26, Number 2, March 2015

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 the drifting of the internal carotid artery."

Japanese Dental Science Review (2018) 54, 139–149

Contents lists available at ScienceDirect

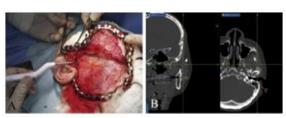
Japanese Dental Science Review

journal homepage: www.elsevier.com/locate/jdsr

Review Article

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

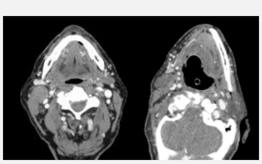
Shintaro Sukegawa[a,*], Takahiro Kanno[a,b], Yoshihiko Furuki[a]



Localize joint during TMJ surgery

FOR TRANS-ORAL SURGERY, PRE-OPERATIVE CT DOES NOT REFLECT THE INTRA-OPERATIVE REALITY

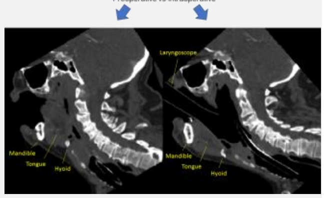
Skull-Registered CT Images of Preoperative vs Intraoperative



Standard Neck CT

Intra-op CT During Laryngoscopy

Axial CT Images



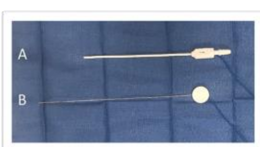
Sagittal CT Images

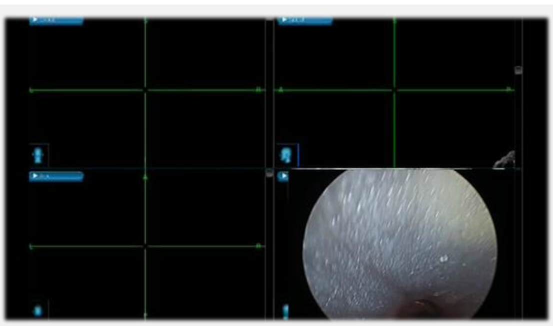
Patient	Pathology	Site	Stage	Procedure
1	Laryngocele	Internal/External Larynx	N/A	Trans-oral CO2 laser excision
2	SCCa	Supraglottic larynx	T1N0	TLM excision
3	SCCa	Base of tongue	T2N0	TLM and open resection, right neck dissection
4	SCCa	Aryepiglottic fold	T3N2c	TLM excision and bilateral neck dissection

PROOF OF CONCEPT: SURGICAL NAVIGATION WITH INTRAOPERATIVE IMAGING TO IMPROVE LOCALIZATION ACCURACY

Paydarfar JA, Wu X, Halter RJ. Initial experience with image-guided surgical navigation in transoral surgery. *Head & Neck*. 2018;1–10

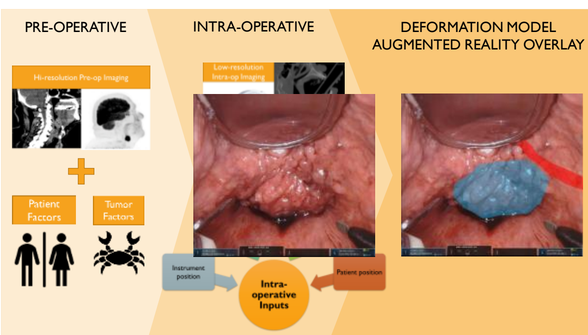
HIGH LEVEL OF REGISTRATION ACCURACY (<= 1 MM)

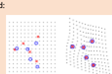
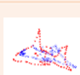
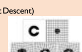


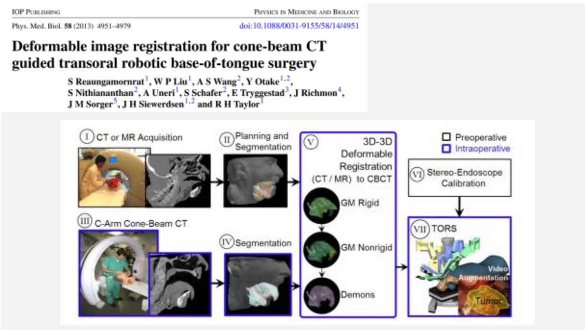


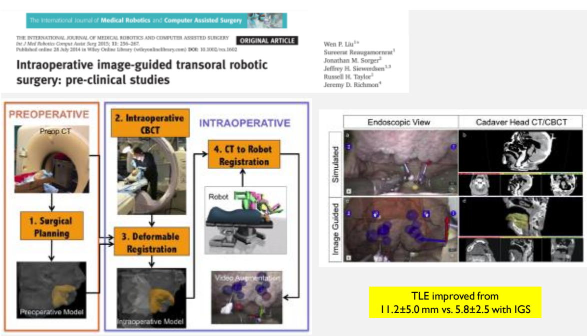
LIMITATIONS IDENTIFIED USING SURGICAL NAVIGATION WITH INTRAOPERATIVE IMAGING

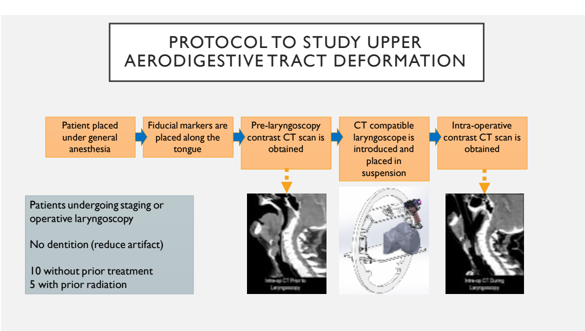
- Intra-operative contrast enhanced CT imaging is required (specialized operating room)
- Optical tracking not as effective; EM tracking accuracy may be affected by metallic instruments
- Tumor delineation with smaller tumors on CT can be difficult
- Repositioning the scope requires:
  - Obtaining new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



Examples of Non-rigid Registration	Pros	Cons
Correspondences/Feature-based: (Thin-Plate Spline)  Donato, G., & Belongie, S.J. (2002). Approximation Methods for Thin Plate Spline Mappings and Principal Warps.	Correspondences align well/exactly; fast	Need to define corresponding features; no physical properties
Probabilistic/Point-set: (Coherent Point Drift)  Myronenko, A., & Song, X.B. (2010). Point Set Registration: Coherent Point Drift. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *32*, 2262-2275.	No need to define corresponding features; excels at overall shape-matching	Struggles with smooth/featureless point-clouds; prior segmentation required; no physical properties
Image/Intensity-based: (Demons, Mutual Information/Gradient Descent)  Pennec, X., Cathier, P., & Ayache, N. (1999). Understanding the "Demon's Algorithm": 3D Non-rigid Registration by Gradient Descent. *MICCAI*.	No need for prior segmentation; Uses image intensity as features	Slow; no physical properties
Physics/Model-based  J. E. Lloyd, I. Stavness, and S. Fels, "ArtiSynth: A Fast Interactive Biomechanical Modeling Toolkit Combining Multibody and Finite Element Simulation," in *Soft Tissue Biomechanical Modeling for Computer Assisted Surgery*, vol. 11, Y. Payan, Ed. Berlin, Heidelberg: Springer Berlin Heidelberg, 2012, pp. 355–394.	Physical properties!	Slow; Prior segmentation/model-building required


IOP Publishing
Physics in Medicine and Biology
Phys. Med. Biol. 58 (2013) 4951–4979
doi:10.1088/0031-9155/58/14/4951
Deformable image registration for cone-beam CT guided transoral robotic base-of-tongue surgery
S Reaungamornrat[1], W P Liu[1], A S Wang[2], Y Otake[1,2], S Nithiananthan[2], A Uneri[1], S Schafer[2], E Tryggestad[3], J Richmon[4], J M Sorger[5], J H Siewerdsen[1,2] and R H Taylor[1]
I CT or MR Acquisition
II Planning and Segmentation
III C-Arm Cone-Beam CT
IV Segmentation
V 3D-3D Deformable Registration (CT / MR) to CBCT
GM Rigid
GM Nonrigid
Demons
Preoperative
Intraoperative
VI Stereo-Endoscope Calibration
VII TORS
Video Augmentation
Tumor

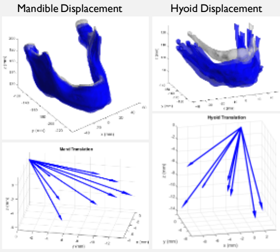

The International Journal of Medical Robotics and Computer Assisted Surgery
ORIGINAL ARTICLE
Intraoperative image-guided transoral robotic surgery: pre-clinical studies
Wen P. Liu
Sureerat Reaungamornrat
Jonathan M. Sorger
Jeffrey H. Siewerdsen
Russell H. Taylor
Jeremy D. Richmon
PREOPERATIVE
Preop CT
1. Surgical Planning
Preoperative Model
2. Intraoperative CBCT
INTRAOPERATIVE
4. CT to Robot Registration
Robot
3. Deformable Registration
Intraoperative Model
Video Augmentation
Endoscopic View
Cadaver Head CT/CBCT
Simulated
Image Guided
TLE improved from
11.2±5.0 mm vs. 5.8±2.5 with IGS


PROTOCOL TO STUDY UPPER AERODIGESTIVE TRACT DEFORMATION
Patient placed under general anesthesia
Fiducial markers are placed along the tongue
Pre-laryngoscopy contrast CT scan is obtained
CT compatible laryngoscope is introduced and placed in suspension
Intra-operative contrast CT scan is obtained
Patients undergoing staging or operative laryngoscopy
No dentition (reduce artifact)
10 without prior treatment
5 with prior radiation

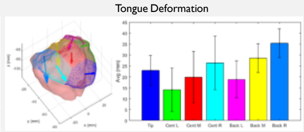
QUANTIFY DEFORMATION DURING LARYNGOSCOPY

Mandible Displacement

Hyoid Displacement



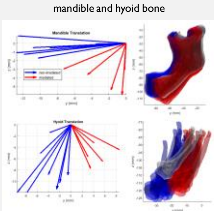
Tongue Deformation



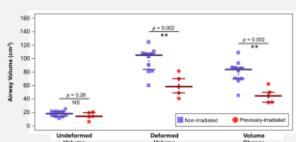
X. Wu, J. A. Paydarfar, and R. J. Halter, "Quantifying Anatomic Deformations During Laryngoscopy," *Ann. Biomed. Eng.*, vol. 46, no. 6, pp. 912–925, 2018.

PRIOR RADIATION SIGNIFICANTLY AFFECTS DEFORMATION

Differences in translation and rotation of mandible and hyoid bone



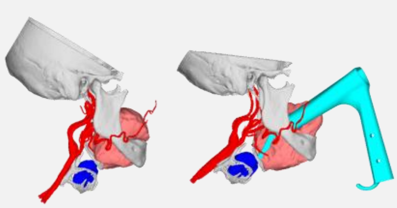
Reduced pharyngeal airway volume

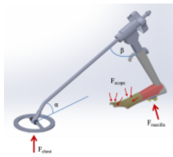


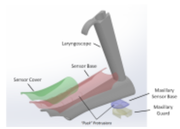
X. Wu, J. Paydarfar, and R. Halter, "Intraoperative deformation during laryngoscopy of irradiated and non-irradiated patients," in *Medical Imaging 2018: Image-Guided Procedures, Robotic Interventions, and Modeling*, 2018, vol. 10576, p. 45.

C. Rees, X. Wu, D. Pastel , R. Halter, J. Paydarfar, "Prior radiation exposure alters airway deformation during laryngoscopy," The Triological Society Sections Meeting, Coronado, CA, Jan. 2019.

VISUALIZE TISSUE AND TUMOR DEFORMATION DURING LARYNGOSCOPY



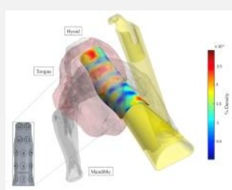




QUANTIFY FORCES GENERATED DURING OPERATIVE LARYNGOSCOPY

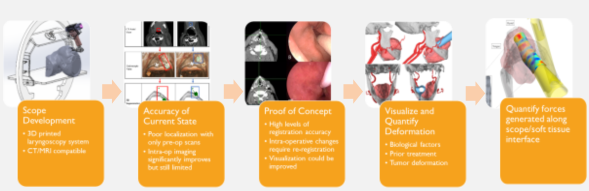
Avg peak force of **50 lbf** recorded on scope!

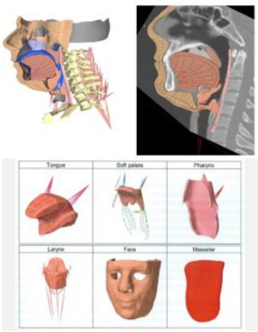
10 lbf on chest!



A. Ponukumati, X. Wu, P. Kahng, J. Skinner, J. Paydarfar, R. Halter, "A System for Characterizing Intraoperative Force Distribution during Operative Laryngoscopy," IEEE Transactions of Biomedical Engineering, Submitted Mar. 2019.

SUMMARY OF WORK COMPLETED TO DATE





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

J. E. Lloyd, I. Stavness, and S. Fels, "ArtiSynth: A Fast Interactive Biomechanical Modeling Toolkit Combining Multibody and Finite Element Simulation," in *Soft Tissue Biomechanical Modeling for Computer Assisted Surgery*, vol. 11, Y. Payan, Ed. Berlin, Heidelberg: Springer Berlin Heidelberg, 2012, pp. 355–394.

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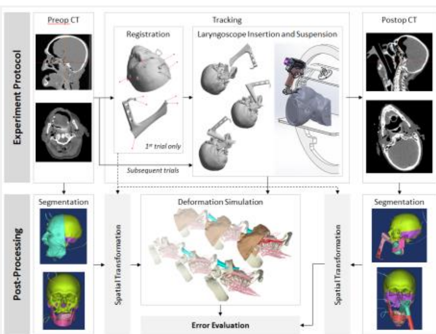
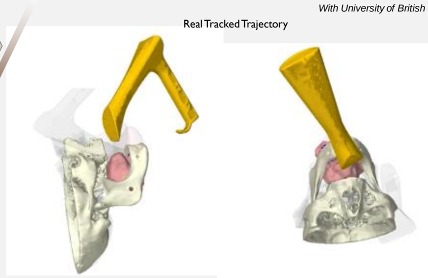


With University of British Columbia

Real Tracked Trajectory



TLE
9.7±3.0mm

FUTURE DIRECTIONS

- Pressure and position data to drive dynamic model 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 model

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