Design and Development of Innovative Integrated Technology for Endoscopic Surgeries

Swamy A and Achanta CR

[1]**Swamy A– Chair Mechanical and Industrial Engineering, Emirates College of Technology, UAE.**

[2] **Achanta CR – Consultant Gastroenterologist, KIMS Icon Hospital, India**

Abstract

Compared to open surgery, there are significantly fewer alternatives to control bleeding when it occurs. Endoscopic surgery now includes endoluminal surgery as a crucial part. This article looks at the latest developments in endoscopic surgery, including the use of AI. The use of equipment specifically designed for endoscopic surgery distinguishes it from open surgery. Since endoscopic surgical instruments must be inserted through trocars with a round seal, these devices are usually always designed to resemble tubes and create a gas-tight seal when the instruments are inserted. Due to the limited degrees of freedom, special additional criteria apply when an instrument is inserted through a normal trocar sleeve. One consequence of this is that the suture needles cannot be optimally aligned. The circumstances for inserting endoscopic instruments generally lead to a non-ergonomic operating posture, so that the surgeon is not in the best possible condition to perform his tasks. There are fewer opportunities for the use of ligatures to cut vascular structures than in open surgery.

Keywords: *Endoscopic Surgery, Artificial Intelligence (AI), Gastrointestinal Endoscopy*

DOI Number: 10.14704/nq.2022.20.11.NQ66236 **NeuroQuantology 2022; 20(11): 2389-2398**

1. Introduction

Endoscopy is a rapidly evolving science in which new procedures are continually being developed. The field of gastrointestinal endoscopy has advanced and expanded in recent years, moving from a basic diagnostic technique based on fiberoptic bundles to one that incorporates improved video and computer-assisted imaging, as well as excellent interventional abilities. Even while some of the novel endoscopic procedures will be too sophisticated or costly to adopt by the entire gastroenterology community, others are already making significant strides in treating digestive illnesses. Colon capsule endoscopy, Third eye retroscopes, balloon and spiral enteroscopy, and confocal laser endomicroscopy are just a few of the developing methods and innovations discussed in this chapter to improve diagnostic accuracy in the small colon intestine. They will also explore OTSC devices, a reasonably simple and affordable instrument that can close non - invasively intestinal perforations while also allowing for the removal of cancers that have infiltrated the intestinal wall. In addition, experimental methods such as NOTES will be reviewed, focusing on their potential clinical use in the future[1]. The endoscopic ultrasonography (EUS) technique will also be discussed, which has progressed from being an experimental method to becoming a useful founded diagnostic modality that not only competes with advanced imaging techniques, including such magnetic resonance imaging, as well as being especially helpful in the interventional configuration, primarily in the treatment of pancreatic and hepatobiliary disease.

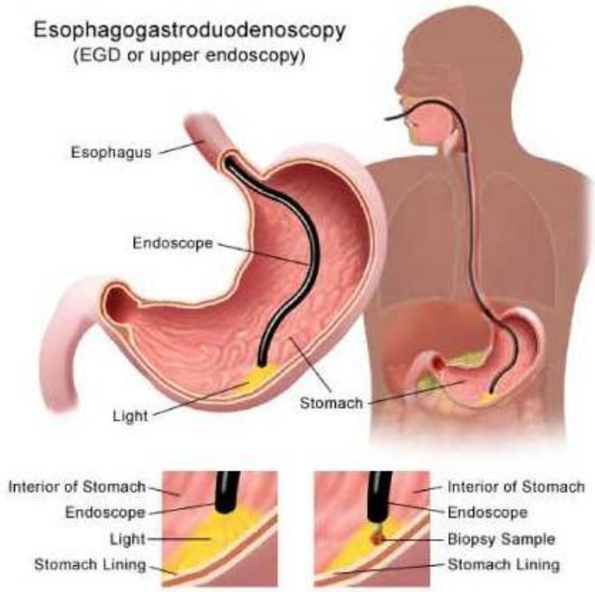

Figure 1: Endoscopic Surgery

The advent of artificial intelligence (AI) technologies based on deep learning methodologies has completely transformed how algorithms are used in the medical industry. Deep learning neural networks are now being trained on many manually annotated datasets, a relatively new development. These datasets may include photographs, such as those captured during normal endoscopy, as well as video recordings. However, photos are not the only data utilized to train AI[2]. It is possible to build artificial intelligence that effectively directs decision-making in endoscopy using sounds and sometimes even laboratory test data from medical health records. The training process is carried out on potent computers with graphic cards specifically designed to form neural networks. A server building is generally where they are kept. The process of training and improving a neural network is time-consuming. To get the best results, a highly trained non - modifiable neural network is then deployed utilizing a computer with limited processing capabilities, comparable to the one present in the endoscopic room. One benefit of such artificial intelligence systems is that their implementation can be carried out in the actual moment due to the real sense that images are most often analyzed at a lower resolution than the image displayed on the investigation screen and therefore necessitate fewer computer resources than the image displayed on the investigation screen. Not only are attempts being made to construct neural networks inside server facilities, rather use the real-world deployment by using cloud-based technologies are being developed.

2. Innovative Integrated Technology in Endoscopic Surgeries

2.1 CT Colonography

A picture of the colon’s interior is created by combining CT scan technology with computerized software to generate a virtual colonoscopy, also referred to as CT colonography or virtual colonoscopy. It is also possible to gain images of other intra-abdominal organs during the procedure. A colonoscopy simulator may be used to create visuals similar to what would be seen during the procedure. An alternative procedure, known as colonoscopy[3], looks directly into the colon with a video-equipped scope introduced and through the anus (windpipe) into the colon.

In most cases, radiologists are responsible for both the performance and interpretation of CT colonography. The procedure is identical to colonoscopy in that the intestine must be cleared of faecal particles before the scan can be performed successfully. Colonoscopy is the only procedure that can be used to discover and remove polyps in the colon simultaneously.

According to recent research, CT colonography is useful in detecting medium to large polyps but is unsuccessful in detecting tiny polyps. Currently, Medicare does not fund the treatment as a first-time diagnostic test.

2.2 High-Definition Scopes/Narrow Band Imaging/Chromoendoscopy

Endoscopic pictures are progressing similarly to how television visuals are improving with new HD television sets every year. Research and development are underway for a new era of endoscopes that will employ HD imaging with amazing precision. Not only does HD offer a crisper visual for the doctor to examine, but it also provides much more knowledge because of the enhanced quality of the image shown on the screen[4].

In combination with endoscopic procedures, chromoendoscopy is a specialized method that allows for better visualization of the "mucosa, or lining, of the intestine". The use of chromoendoscopy may assist the endoscopist in identifying abnormalities that seem to be visible during the endoscopic evaluation, but that may be hard to detect using solely "white light" endoscopic examination.

2.3 Endoscopic Mucosal Resection (EMR)

As the scope goes through the hollow lumen of the gastrointestinal tract, a direct view of the innermost lining of the "gastrointestinal tract" is possible. The mucosa is the term used to describe this inner lining. The mucosa of the gastrointestinal system is the genesis site for many malignancies. Cancers of the colon, oesophagus, and stomach are only a few instances.

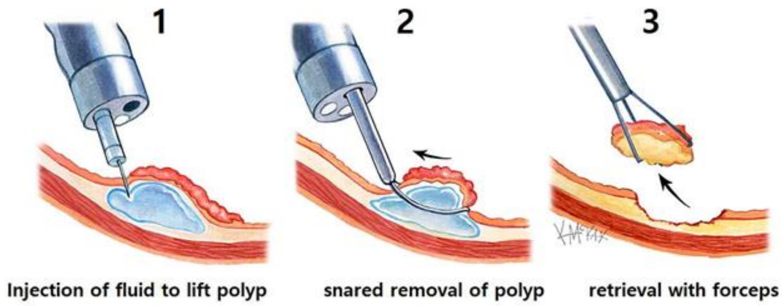

Figure 2: Endoscopic Mucosal Resection (EMR)

Using an endoscope, precancerous alterations and tumours in their early stages may be eliminated, assuming that cancer has not progressed beyond the superficial layers of the gastrointestinal lining. Endoscopic mucosal excision is a procedure that is useful in the removal of these lesions, and it is described below. A needle is introduced via the endoscope[5]. As seen in the image, a liquid solution is inserted beneath the region of concern, thereby "lifting" the aberrant tissue and isolating this from the "deeper intestinal layers". With the use of a snare, the aberrant lesion is extracted, as well as the tissue is then deleted and submitted to pathology for assessment.

2.4 FNA (Fine Needle Aspiration) or EUS (Endoscopic Ultrasound)

Endoscopic ultrasonography is a method that uses sound waves recognized as ultrasound to examine at or through the wall of the gastrointestinal system during an endoscopic operation to diagnose or treat gastrointestinal disorders. It enables clinicians to observe the structure of the human body that is not normally accessible during gastrointestinal endoscopies, like the pancreas, liver, gastrointestinal tract wall, and bile ducts, which are not seen during gastrointestinal endoscopy[6]. A tiny needle may be inserted into such structures under continuous real-time ultrasound monitoring to acquire an aspirate of the tissue. A fine needle aspirate is a term used to describe this method. Using a microscope, the cells recovered from the Fine Needle Aspiration may be spread on a slide and examined for irregularities, such as cancer. Cytology is the term used to describe cell examination.

The capacity to identify and stage malignancies of the gastrointestinal system and analyze the pancreas has been transformed by EUS with FNA technology. The pancreas is yet another organ that can be viewed with EUS technology.

2.5 Natural Orifice Transluminal Endoscopic Surgery (NOTES)

NOTES® is a novel form of hybrid endoscopic/surgical treatment that is now being explored in hospitals and research centres all over the globe. It is a hybrid operation that uses an endoscope and a surgical instrument. NOTES® is the next step forward in developing surgical concepts and endoscopic procedures. Currently, the most common method of accessing the peritoneal cavity is by a surgical incision or puncture of the skin, which allows the insertion of tiny cameras deep into the belly[7]. Laparoscopic surgery is the term used to describe the latter method.

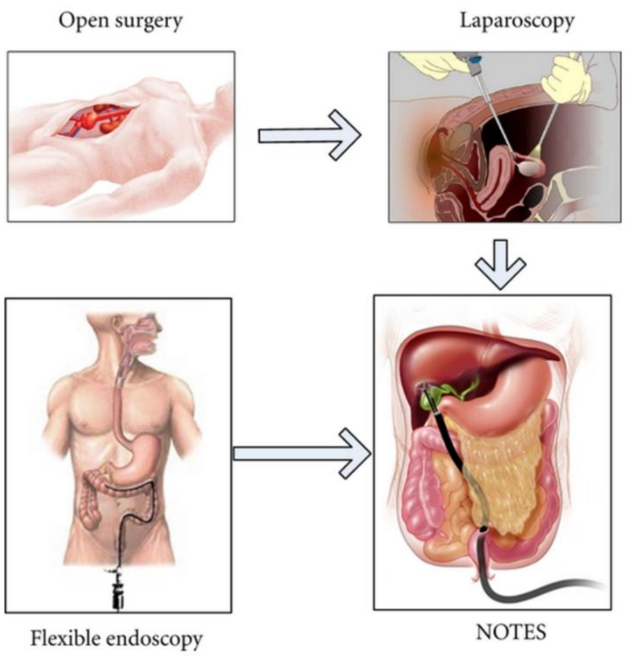

Figure 3: Natural Orifice Transluminal Endoscopic Surgery®

The peritoneal cavity contains parts of the gastrointestinal system routinely examined during endoscopy, like the stomach and colon. Perforation of the gastrointestinal system has long been seen as an unfavourable occurrence in medicine. Nevertheless, interventions with NOTES® are designed to purposely perforate the stomach, colon, or vaginal wall, enabling the operator to enter the peritoneal cavity via a normal bodily orifice. Any peritoneal architecture is theoretically reachable in this context.

3. Application of Artificial Intelligence in Endoscopic Surgeries

Endoscopic artificial intelligence research is now focused on the standardization of endoscopic evaluation, the identification and description of gastrointestinal (GI) disease, and new applications for Artificial intelligence in the field. Stress, weariness, and a lack of prior experience may all impact the functioning of the human brain. Artificial Intelligence technology can compensate for these constraints, minimize interoperator variability, improve the reliability of diagnosis, and reduce the amount of time, cost, and burden associated with endoscopic operations, among other things.

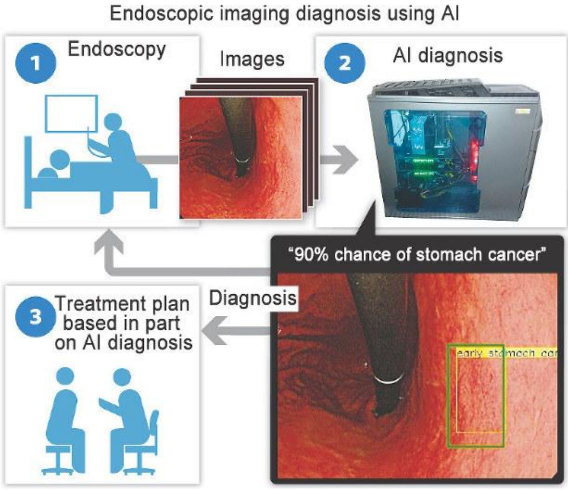

Figure 4: AI in Endoscopy

As shown in figure 4 AI is used in Endoscopic as images are generated as shown in part 2 of the image, diagnosis is made using AI and treatment plan based in part on AI diagnosis is planned.

3.1 Artificial Intelligence in Endoscopic Examination: Cerebro

Then Prof Chiu went into detail about the Cerebro endoscopic examination protocol, which his institution developed in collaboration with the start-up company Endovision. Cerebro is a standardized artificial intelligence-driven protocol for endoscopic investigation that improves testing and monitoring while adhering to standard protocols. Cerebro's clinical studies investigated the effectiveness of using an artificial intelligence-driven support device to check the gastrointestinal system[10]. The artificial intelligence in the protocol has standardized the capture of imagery and time for assessing each of the locations; as a result, if any position is overlooked, the computer will notify the endoscopist of the error immediately. Findings from 100 cases have shown 95 % accuracy and high sensitivity and specificity (95 %), and another 100 patients are now being included in the trial. Cerebro's artificial intelligence may be seen as an assessment thoroughness and quality assurance tool that assures that an endoscopic treatment is completed to the greatest possible standard. It serves as an instance of the kind of collaboration that artificial intelligence might facilitate.

3.2 Artificial Intelligence in Endoscopic Detection: ENDOANGEL

Another artificial intelligence programme used in clinical settings is the ENDOANGEL system, used to identify gastrointestinal pathology. The ENDOANGEL system makes use of deep neural networks as well as perceptual hashing techniques. In recent research, individuals ranging in age from 18 to 75 years were randomly allocated to either the ENDOANGEL system or unaided colonoscopy in a 1:1 ratio. Adenoma detection performance, the primary outcome, was significantly higher in the ENDOANGEL group compared with the control group: 16 % of 355 patients assigned to ENDOANGEL-assisted colonoscopy had a single or multiple adenomas discovered compared with 8 % of 349 patients allocated to regulate colonoscopy.

3.3 Artificial Intelligence in Endoscopic Characterization: EndoBRAIN

EndoBRAIN, a newly authorized artificial intelligence-assisted approach, has been found to considerably increase the specificity and sensitivity of GI neoplasia detection when compared to traditional methods. Around 2017 and 2018, Japanese multicentre research used 69,142 endocytoscopic pictures collected at 520x magnification from patients with colorectal polyps who had endoscopic procedures at five educational institutions throughout the country to train the EndoBRAIN computer system. It was discovered that EndoBRAIN had much greater diagnostic accuracy than the trainees in a retrospective, comparative investigation of EndoBRAIN's diagnostic performance vs 30 endoscopists in the capacity to discriminate neoplasmatic from non-neoplasmatic tumours across all of the outcomes[11]. Compared with the specialists, only the EndoBRAIN's sensitivity and negative predictive accuracy were considerably greater, with all other results equivalent. This technique has now been approved for clinical usage by the Japanese regulatory body. It supports physicians in detecting lesions in the clinical context via a joint effort with other medical professionals.

4. New Advances of Endoscopic Surgeries

Even though the fundamental stage of stretchy endoscopes is comparable to that developed five decades ago, a slew of current technological breakthroughs is becoming accessible to endoscopic practitioners. Self-propelled endoscopes and shape-conforming overtures, among other innovations, may make colonoscopic examinations less complicated. A plethora of novel imaging techniques may make it possible to identify dysplasia and other pathologic entities earlier in their development. Many of these approaches are still under development and are now being tested in clinical studies to evaluate if they are beneficial to patients.

4.1 Self-propelled colonoscopes

Self-propelled endoscopes are being developed to make the procedure of colonoscopic screening as simple as possible. The Aer-O-Scope is a colonoscope autonomous of the operator, self-propelled, and self-navigating. In addition to a reusable rectal implementer, a supply cord, and a scope inserted inside a scanning balloon. The Aer-O-Scope was the subject of a brief pilot study that looked at its proof of concept. In a study of young volunteers (ranging from 18 to 42 years), the device effectively reached the cecum in 82 % of the instances[13]. There were no issues associated with the gadget. Because the gadget does not have a functional channel for treatments, it is solely designed for use in screening situations. The ColonoSight colonoscope is another self-propelled colonoscope that uses air-assisted propulsion in a throwaway device. In order to provide forward force, a pneumatic system creates pressure, and the operator guides the scope using handlesPilot trial results showed that intubation of the cecum was successful in 88 % of patients and took on average 12 minutes, with no device-related problems.

4.2 Controlled partially Automated colonoscope by Computer

The Neo-Guide Endoscopy Device is meant to prevent the creation of loops in the colon by changing the placement tube of an endoscope to fit the structure of the colon. Like traditional colonoscopy, the distal tip of the insertion tube is directed by an actuation control unit. The insertion tube comprises numerous steerable sections coupled to the control unit. The data from the tip orientation and implantation depth set by the physician is utilized to construct a 3-dimensional map of the colon, created using sophisticated computer software.

4.3 Double balloon endoscopy

An examination of the interior of the small intestine was performed under anaesthesia. It is necessary to implant a specific tool consisting of two tubes via the mouth or rectum and through the small intestine. This procedure involves moving an endoscope through a section of the small intestine and inflating the balloon at the tip of the tube to maintain the endoscope in place.. The balloon at the bottom of the endoscope is then deflated, and the endoscope is then transferred to the next section of the small intestine to complete the procedure. This sequence of events is repeated several times as the tubes pass through the entire small intestine.

4.4 Chromoendoscopy

Colour endoscopy identifies modest mucosal abnormalities in the body's mucosa. "Lugol's methylene blue", solution, indigo carmine, as well as Congo red are some of the most often used colourants. A potassium iodide solution containing 2 % to 3 % potassium iodide interacts with "glycogen in keratinized squamous epithelium"[16]. A deep brown stain is produced by normal squamous epithelium. However, dysplasia, inflammation, and cancer do not tint due to the absence of glycogen in the tissue. Squamous cell carcinoma of the oesophagus has been detectable using Lugol's solution, which has also helped detect Barrett's oesophagus.

4.5 Magnification Endoscopy

Magnification endoscopy is a technique in which an endoscope is equipped with a cap that contains a magnifying lens. The mucosa that comes into touch with the lens is enlarged, yet the scope's mobility is not impaired as a result. Changing the scope's magnification may be accomplished by turning a dial on the hand controls. It ranges from 1.5x to 115x. Magnification endoscopy is a method usually used in combination with chromoendoscopy to examine the inside of the body[17]. Comprehensive monitoring is carried out using chromoendoscopy, followed by a targeted evaluation of worrisome lesions in the magnification phase. It has been documented in case series that this combination of examinations may improve the diagnosis of Barrett's oesophagus, "Helicobacter pylori infection, chronic gastritis, gastric dysplasia, including early gastric cancer".

4.6 Confocal fluorescence microendoscopy

Typical endoscopy employs white light to observe a wide surface space with a very poor resolution over a relatively long period. On the other hand, confocal endoscopy tries to view the mucosa and submucosa with subcellular resolution, a method known as optical biopsy, to contrast this. At a magnification of 1000x, the procedure of confocal amplification lowers out-of-focus light from above and below the reference spot by reducing its intensity[18]. Considering that the technique is meant to assess tissue fluorescence, an exogenous fluorophore is often supplied. By changing the focus plane, various tissue depths may be studied, and pictures from diverse depths can be loaded together to form an optical slice of a tissue, hence the phrase "optical biopsy."

4.7 NBI (Narrowband imaging)

Filtered light is utilized in narrow-band endoscopy to increase the "mucosal surface", particularly the system of underlying capillaries, in a selectively visible manner. Narrowband imaging is almost always used in conjunction with high enlargement endoscopy[19]. Both "adenomas and carcinomas" contain a dense system of fundamental capillaries that intensify on narrow-band imaging, resulting in them looking "dark brown against such a blue, green mucosal" backdrop on the imaging modalities used.

5. Conclusion

Endoscopy can use a variety of artificial intelligence systems. This is a broad spectrum with a number of therapeutic applications that could be useful. These include improved identification of lesions, differentiation of lesions based on their mucosal or vascular architecture, hazard assessment before and during treatment, and evaluation of key success indicators. Overall, reducing effort and increasing accuracy are the two main benefits of artificial intelligence-assisted endoscopy. Consequently, the role of artificial intelligence in clinical practise will increase in the not too distant future. Endoscopic identification and more effective AI-assisted endoscopic resection may also soon benefit from artificial intelligence. However, there are still a number of problems that need to be solved. Large-scale clinical applications for artificial intelligence in endoscopy are still largely unexplored. Most of the information provided comes from specialised institutions. False positive detections are still a problem for CADe systems used in current examinations; this problem has not been addressed in many previous studies. It is still unclear whether an arbitrary intervention should be considered a positive finding or a consistent signal across multiple images or seconds should be considered a true positive. Therefore, it is important that artificial intelligence-based systems evaluate keyframes and determine the strength of a signal required for it to be considered a true positive. Furthermore, an efficient framework based on randomised trials should not be seen as an alternative but as necessary to establish the true value of different commercially available technologies. Finally, there are many more applications for artificial intelligence than just photo-analysis. Such deep learning algorithms should incorporate additional relevant data, including medical history or laboratory results, to help the investigator diagnose and treat specific individuals with the highest degree of accuracy and minimal invasiveness.

6. Acknowledgement

The above project is supported by Liwa College of technology [grant approval code IRG-ENG-002-2020].

7. Authors

Dr. Amit Swamy, is presently working as Assistant Professor at Liwa college of technology, Abudhabi Campus, UAE. He has a proven track record of research across various

areas of applied science applications backed by academic publications and patents.

Dr Chalapathi Rao Achanta, is a well experienced and dynamic gastroenterologist and liver specialist with special interest in pancreatic diseases and therapeutic endoscopy including ERCP and endoscopic ultrasound.

REFERENCE

[1] Khor, W. S., Baker, B., Amin, K., Chan, A., Patel, K., & Wong, J. (2016). Augmented and virtual reality in surgery—the digital surgical environment: applications, limitations and legal pitfalls. *Annals of Translational Medicine*, *4*(23), 454–454. https://doi.org/10.21037/atm.2016.12.23

[2] Yock, P. G. (2015). *Biodesign : the process of innovating medical technologies*. Cambridge University Press.

[3] Zhao, M., Vrielink, T. J. C. O., Kogkas, A. A., Runciman, M. S., Elson, D. S., & Mylonas, G. P. (2020). LaryngoTORS: A Novel Cable-Driven Parallel Robotic System for Transoral Laser Phonosurgery. *IEEE Robotics and Automation Letters*, *5*(2), 1516–1523. https://doi.org/10.1109/lra.2020.2969186

[4] Zhao, M., Vrielink, T. J. C. O., Kogkas, A. A., Runciman, M. S., Elson, D. S., & Mylonas, G. P. (2020). LaryngoTORS: A Novel Cable-Driven Parallel Robotic System for Transoral Laser Phonosurgery. *IEEE Robotics and Automation Letters*, *5*(2), 1516–1523. https://doi.org/10.1109/lra.2020.2969186

[5] Mattos, L. S., Acemoglu, A., Geraldes, A., Laborai, A., Schoob, A., Tamadazte, B., Davies, B., Wacogne, B., Pieralli, C., Barbalata, C., Caldwell, D. G., Kundrat, D., Pardo, D., Grant, E., Mora, F., Barresi, G., Peretti, G., Ortiz, J., Rabenorosoa, K., & Tavernier, L. (2021). µRALP and Beyond: Micro-Technologies and Systems for Robot-Assisted Endoscopic Laser Microsurgery. *Frontiers in Robotics and AI*, *8*. https://doi.org/10.3389/frobt.2021.664655

[6] Samar, A. M., Bond, A., & Ranaboldo, C. (2020). Comparison of FreeHand® robot-assisted with human-assisted laparoscopic fundoplication. *Minimally Invasive Therapy & Allied Technologies*, 1–4. https://doi.org/10.1080/13645706.2020.1771373

[7] Tamadazte, B., Renevier, R., Seon, J.-A., Kudryavtsev, A. V., & Andreff, N. (2018). Laser Beam Steering Along Three-Dimensional Paths. *IEEE/ASME Transactions on Mechatronics*, *23*(3), 1148–1158. https://doi.org/10.1109/tmech.2018.2821239

[8] Kundrat, D., Schoob, A., Kahrs, L. A., & Ortmaier, T. (2015). Flexible Robot for Laser Phonomicrosurgery. *Soft Robotics*, 265–271. https://doi.org/10.1007/978-3-662-44506-8_22

[9] Kundrat, D., Schoob, A., Piskon, T., Grasslin, R., Schuler, P. J., Hoffmann, T. K., Kahrs, L. A., & Ortmaier, T. (2019). Toward Assistive Technologies for Focus Adjustment in Teleoperated Robotic Non-Contact Laser Surgery. *IEEE Transactions on Medical Robotics and Bionics*, *1*(3), 145–157. https://doi.org/10.1109/tmrb.2019.2931438

[10] Lang, S., Mattheis, S., Hasskamp, P., Lawson, G., Güldner, C., Mandapathil, M., Schuler, P., Hoffmann, T., Scheithauer, M., & Remacle, M. (2016). A european multicenter study evaluating the flex robotic system in transoral robotic surgery. *The Laryngoscope*, *127*(2), 391–395. https://doi.org/10.1002/lary.26358

[11] Laves, M.-H., Bicker, J., Kahrs, L. A., & Ortmaier, T. (2019). A dataset of laryngeal endoscopic images with comparative study on convolution neural network-based semantic segmentation. *International Journal of Computer Assisted Radiology and Surgery*, *14*(3), 483–492. https://doi.org/10.1007/s11548-018-01910-0

[12] Saadabad, N. A., Moradi, H., & Vossoughi, G. (2019). Dynamic modeling, optimized design, and fabrication of a 2DOF piezo-actuated stick-slip mobile microrobot. *Mechanism and Machine Theory*, *133*, 514–530. https://doi.org/10.1016/j.mechmachtheory.2018.11.025

[13] Ma, G., Ross, W., Tucker, M., & Codd, P. (2020). Characterization of photoablation versus incidence angle in soft tissue laser surgery: an experimental phantom study. *Optical Interactions with Tissue and Cells XXXI*. https://doi.org/10.1117/12.2546229

[14] Bothner, S. A., York, P. A., Song, P. C., & Wood, R. J. (2019). A Compact Laser-Steering End-Effector for Transoral Robotic Surgery. *2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. https://doi.org/10.1109/iros40897.2019.8968255

[15] Mattos, L. S., Dagnino, G., Becattini, G., Dellepiane, M., & Caldwell, D. G. (2011). A virtual scalpel system for computer-assisted laser microsurgery. *2011 IEEE/RSJ International Conference on Intelligent Robots and Systems*. https://doi.org/10.1109/iros.2011.6094574

[16] Mattos, L. S., Deshpande, N., Barresi, G., Guastini, L., & Peretti, G. (2014). A novel computerized surgeon-machine interface for robot-assisted laser phonomicrosurgery. *The Laryngoscope*, *124*(8), 1887–1894. https://doi.org/10.1002/lary.24566

[17] Moccia, S., De Momi, E., Guarnaschelli, M., Savazzi, M., & Laborai, A. (2017). Confident texture-based laryngeal tissue classification for early stage diagnosis support. *Journal of Medical Imaging*, *4*(03), 1. https://doi.org/10.1117/1.jmi.4.3.034502

[18] Fichera, L., Pacchierotti, C., Olivieri, E., Prattichizzo, D., & Mattos, L. S. (2016). Kinesthetic and vibrotactile haptic feedback improves the performance of laser microsurgery. *2016 IEEE Haptics Symposium (HAPTICS)*. https://doi.org/10.1109/haptics.2016.7463156

[19] Mohammadbagherpoor, H., Acemoglu, A., Mattos, L. S., Caldwell, D., Johnson, J. E., Muth, J., & Grant, E. (2019). Closed-Loop Control of a Magnetically Actuated Fiber-Coupled Laser for Computer-Assisted Laser Microsurgery. *2019 19th International Conference on Advanced Robotics (ICAR)*. https://doi.org/10.1109/icar46387.2019.8981584

[20] Ni, X-G., He, S., Xu, Z-G., Gao, L., Lu, N., Yuan, Z., Lai, S-Q., Zhang, Y-M., Yi, J-L., Wang, X-L., Zhang, L., Li, X-Y., & Wang, G-Q. (2010). Endoscopic diagnosis of laryngeal cancer and precancerous lesions by narrow band imaging. *The Journal of Laryngology & Otology*, *125*(3), 288–296. https://doi.org/10.1017/s0022215110002033

[21] O'Brien, K., Boyer, Z. R., Mart, B. G., Brolliar, C. T., Carroll, T. L., & Fichera, L. (2019). Towards Flexible Steerable Instruments for Office-Based Laryngeal Surgery. *2019 Design of Medical Devices Conference*. https://doi.org/10.1115/dmd2019-3309