Fluorescence Guided Robotic Surgery
A Literature Review

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Objective

The objective of this literature review is to investigate if the use of fluorescence improves the robotic-guided surgical outcomes for complete tumor excision for patients with malignancies with minimal injury to healthy adjacent tissues.
Fluorescence and DaVinci

Fluorescence

- Fluorescence and its guided robotic approaches have aided in the recognition of vascular anatomy, evaluation of organ and tissue perfusion, visualization of biliary anatomy, identification of lymph nodes, identification of specialized tissue, identification of lesions based on vascular and metabolic pattern, and adequate resection of tumors.
- Use of indicator markers such as Indocyanine Green (ICG), 5-aminolevulinic acid (5-ALA)-induced fluorescence, and protoporphyrins (PpIX).

DaVinci

- Robotic surgery/robotic-assisted surgery is a novel minimally invasive surgical technique.
- The use of robotics began in the early 1980s with the first documented surgery using the Unimation Programmable Universal Manipulation Arm (PUMA) 200 for a brain needle biopsy.
- There have been several iterations and advancements of robotics with the modern-day Da Vinci Si HD and Da Vinci Xi that improved resolution, extended reach, and added the capability of fluorescent imaging.
Design and Methods

- Systematic literature review through the SJSMS library using PubMed, EBSCO, and Google Scholar.
- Literature search criteria included papers newer than 2010, scholarly and peer-reviewed papers, the use of specific fluorescent dye, and articles only published in the English language.
- After the accumulation of adequate articles, each of the articles was equally split among the members to evaluate.
- From there each member did a detailed analysis and literature review of the articles that were assigned to them.
- Finally, all of the literature reviews were combined and formatted to form the research paper.
Procedures in which Fluorescence-Guided Robotic Surgery was used

- Lymphadenectomy
- Colorectal and hepatobiliary surgery
- Laparoscopic adrenalectomy
- Laparoscopic partial nephrectomy
- Colon cancer oncology
- Colon resection
- Phrenic nerve thymectomy
- Tumor ablation in neurosurgery
Clinical Applications

- Indocyanine green (ICG) is a water-soluble dye that fluoresces green when excited by light in the near-infrared spectrum. Due to the non-toxic, nonradioactive properties, and high safety index, it gained Food and Drug Administration (FDA) approval in 1959 for both intravenous and interstitial administration.

- In a 2015 study by The University of Illinois Hospital and Health Sciences System, researchers looked at the ability to recognize the splenic artery and vein during distal pancreatectomy when visualization was blocked by a tumor and/or inflammation. The research showed that identification of major vessels could be difficult in those cases.

- A 10mg dose of ICG was injected. The median time of visualization after injection was 37.5 sec, and lasted for 1–2 min. The authors reported that NIF helped in identifying small communicating arteries between the gastroepiploic artery and the first short gastric artery. It also aided in the recognition of vessels between the small gastric arteries that would have otherwise been unrecognized. One limit of this method was the reduced visualization in obese patients.
Clinical Applications continued..

- Using the same technique in 2016 *Department of Urology, New York University, Langone Medical Center* used ICG for robotic partial nephrectomy, first to potentially allow for the differentiation of renal tumor from normal parenchyma. In this application, it has been hypothesized that normal kidney tissue fluoresces green color, while the tumors commonly remain hypo-fluorescent, thereby aiding tumor excision.

- Secondly, Near-Infrared Fluorescence (NIRF), imaging with ICG has been employed to facilitate selective arterial clamping during robotic partial nephrectomy, allowing for a regional perfusion deficit in the kidney to be readily identified and therefore targeted at a given tumor.

- Impact on functional outcome, that of estimated glomerular filtration rate (eGFR), through decreasing ischemia in normal tissue. NIRF imaging allows the surgeon to confirm the devascularization of a tumor and local area and continued perfusion of normal tissue. This technology provides real-time intraoperative renal angiograms to confirm selective ischemia. In this way, NIRF imaging aids in the confirmation of a bloodless field and may also offset some of the skill- and operator-dependent properties.
Images from Tumor Excision

NIRF imaging with ICG to facilitate optimization of renal tumor localization. Renal mass seen under white light (a) and under NIRF imaging with ICG demonstrating a hypo-fluorescent tumor adjacent to bright green normal renal parenchyma (b)

NIRF imaging with ICG to facilitate selective arterial clamping. Dissection of the secondary, tertiary, or quaternary level arterial branches (a), selective arterial clamping with mini bulldog clamps seen under NIRF imaging with ICG (bright fluorescent green vessels) (b), renal tumor seen under white light (c), and NIRF imaging with ICG (hypo-fluorescent renal tumor confirming ischemia with perfused bright green normal renal parenchyma) (d)

Outcome of the use of Fluorescence & Robotic Surgery

- All of the other surgeries had the following the outcome:
- Avoided ischemia
- Patient’s improvement in short-term follow-up.
- Reduced risk of recurrence and retreatment.
- Minimally invasive successful surgeries.
- High success rate in being able to avoid disruption of any other vessel or organ.
- Other secondary infections were avoided.
- Improvement to the da-vinci machine.
- Used to identify metastasis, with high accuracy rate.
Current Updates

● Currently the use of ICG is still in use for a lot of the procedures that are being performed. As of right now, in terms of improvement, folic acid conjugate is being used to get better imaging sensors. The normal window for ICG in the light spectrum 600 nm –1,350 nm but with blood and water it is minimized to wavelengths of 1,000 nm. Folic acid can reach up to even further wavelengths than that of 1,350 nm as used in a ovarian cancer surgery done by the Oncology Surgery Department in Netherlands. (Center for Devices and Radiological Health)

● Fluorophores, such as IRDye800CW are under clinical investigation in numerous tumor types, such as head and neck, pancreatic, breast, brain cancers and squamous cell carcinomas. (Center for Devices and Radiological Health)
Conclusion

In conclusion, the combination of fluorescence and robotic surgery has come a long way. New findings are published in nearly all surgical specialties regarding the uses of fluorescence imaging. Great implementation is found in assessing perfusion, mapping, and visualizing anatomy. As more targeted agents progress through clinical trials and gain FDA approval, the prevalence of the fluorescence platform will increase. As a progression of time and technological advancement, the discovery of new indicator markers will come along, new procedures will use fluorescence marker, and there will be other robotic surgeries that may not even need these markers.
Bibliography


Acknowledgement

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The Use of Fluorescence to Guide Robotic Surgery for Complete Tumor Excision

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Introduction

Robotic surgery for neural surgery has several unique surgical techniques. The use of fluorescence to guide the early 1990s with the first fluorescent surgery using the Uniscan Photodynamic ProceM Hyperthermia System (1990-1991) became a reliable method. This has been demonstrated to have improved surgical margins of excision in various cases of tumors, evidenced by the use of fluorescence in the early cases of head and neck surgery. The utilization of intraoperative hyperthermia (IOH) has been found to improve surgical margins and reduce recurrence rates. Further, intraoperative hyperthermia is now being used in a variety of surgical procedures to improve surgical outcomes and reduce recurrence rates.

In recent years, the use of intraoperative hyperthermia has expanded for applications in oncology and neurosurgery. Specifically, intraoperative hyperthermia has been used in various centers around the world. However, despite the potential benefits of intraoperative hyperthermia, few studies have investigated the comprehensive use of fluorescence in combination with intraoperative hyperthermia. The combination of fluorescence and intraoperative hyperthermia has been shown to improve surgical outcomes in various cases of tumors. However, there is a need for further investigation of the comprehensive use of fluorescence and intraoperative hyperthermia to fully understand the potential benefits and limitations of this combination.

Results

In the extensive literature research we have done, we have seen that in many procedures, the use of fluorescence with robotic surgery proved to improve successful rates of excisions of tumors. Such procedures seen with this include laryngectomy, cranial base and bony surgery, hypopharyngectomy, hypopharyngeal surgery, colorectal surgery, head and neck surgery, and reconstruction. The use of fluorescence with robotic surgery has been shown to improve surgical outcomes and reduce recurrence rates. The combination of fluorescence and intraoperative hyperthermia has been shown to improve surgical outcomes and reduce recurrence rates.

However, this technology is not without its limitations. Fluorescence dye alone can only penetrate shallow depth of tissue. This low penetration ability of ICG and fluorescent dyes limits its usage in surgery with infiltration, inflammation and abscesses. Another limitation of ICG is that it has very high sensitivity but low specificity of tissue. Because of this reason, ICG is only used for intraoperatively stained lymph nodes to evaluate cancer spreading. With better penetration ability of ICG, fluorescent dye applications of improved dyes will be multiplied. Lastly, the implementation cost of the robotic assistance guiding system requires more investment, and the cost of maintenance of this machine input on the cost of overall robotic assisted surgery to a patient and insurance company.

Conclusion

From analyzing and accumulating data over-two decades surgical techniques of fluorescence and endoscope, we learned that ICG dye is readily and reliably identified of tissues and in vivo tissue, but its applicability is rapidly expanding due to its fluorescent and endoscopic imaging. It is not only minimally invasive but is also more precise than in vivo imaging with the use of fluorescence. Several studies have shown that this technology is also reducing the risk of complications and improving surgical outcomes.

The use of fluorescence with robotic surgery for complete tumor excision is a promising technique that has demonstrated improved surgical outcomes and reduced recurrence rates. Further studies are needed to determine the comprehensive use of fluorescence and intraoperative hyperthermia to fully understand the potential benefits and limitations of this combination.