Introduction

It is reported that over 650,000 neurosurgeries are performed each year across the globe. Stereotactic surgery with robotic assistance applications are becoming increasingly popular. This paper outlines neurosurgical procedures with robot assistance, the current technology, future technology, and the design failures and improvements of robot assistance in stereotactic neurosurgery. The application of robots in surgery has many advantages. Alongside these advantages are the failures that have happened over the last few decades. Proposed are some design improvements for procedural efficiency.

Even though robots have been seen more often within operating rooms in recent years, such as for prostate cancer and cardiac applications, relying on robots to perform neurosurgery has not yet been a well-developed practice. Robots in neurosurgery have been used for critical tasks, such as precision drilling to reach tumor sites in the patient’s brain. There have been advancements and improvements upon older methods of robotic surgery so the systems can be used in multiple organ system applications.

Many benefits are found when comparing robot assisted surgery to standard surgery. While being useful and potentially lifesaving, these robots bring up some important safety risks that are currently being faced with autonomous surgery. Robot-assisted surgery is a complex combination of electrical, mechanical and biomedical engineering brought together in an innovative system.

Robot-Assisted Stereotactic Neurosurgery

Robot assisted neurosurgery has been around for approximately three decades, and is rapidly increasing in popularity. There are many advantages to robot-assisted neurosurgery including being minimally invasive, a shorter operating time, shorter hospital stay, less scarring, less blood loss, faster recovery time, and working on a small scale. Current robots use a variable combination of modules including sensors, imaging systems, data processing, robotic arms, controllers and GPS systems. Many surgical robots include an arm which can hold tools, including endoscopes, blades, precision drills, and retractors. Most systems operate with about six degrees of freedom, where the information gained for this worksite is gained through sensors.

These frames are used in an array of different neurosurgical procedures. A pictorial representation of a robot assist-assisted neurosurgical procedure to excise a brain tumor on a patient with a stereotactic frame is shown in figure 3.

Figure 1: STEREOTACTIC SYSTEM® produced by Elekta

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P_1'(x_1, y_1, z_1) = P_2'(x_2, y_2, z_2) = P_3'(x_3, y_3, z_3) = P_4'(x_4, y_4, z_4)
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These frames are used in an array of different neurosurgical procedures. A pictorial representation of a robot assist-assisted neurosurgical procedure to excise a brain tumor on a patient with a stereotactic frame is shown in figure 3.

Figure 2: Representation of the tomographic section in the three-dimensional coordinate system of the stereotactic frame (Adapted from Brown R A, Nelson J A (2014) The History and Mathematics of the N-Localizer for Stereotactic Neurosurgery, 2013)

Robot assistance applied for neurological procedures offer significant advantages while robots are used for minor yet critical parts of surgery, most neurosurgical procedures require surgeons to perform most parts of the operation. Some well-known robots used for neurological applications are the NeuroMate (shown in figure 4), which is the first FDA approved robot used in neurosurgery, first approved in 1987 and redesigned in 1997, and NeuroArm (shown in figure 5), the first robot that is compatible with an MRI machine, first used in 2008.

Current Robots used in Neurosurgery

While robots have been beneficial, there have been instances in which the robot-assisted system has failed, mistakes have been made, and there are many risks that are taken during surgeries that could yield significantly undesirable effects. One of the most popular surgical robots, Intuitive Surgical’s da Vinci system (shown below in figure 6), has had multiple recalls due to field errors and failures. The latest large scale recall occurred recently (in 2013), where some of the tools were found to stall during surgery due to friction. This problem affected over half (1,386) of the systems sold worldwide, and there were three reported mistakes made in the field due to this problem. Overall, the da Vinci system has had over 250 reported problems, over 70 deaths, and over 175 nonfatal injuries over the past 13 years. These results are not clinically acceptable. Thus, improvements to system design, user interface and user training become essential, rendering the role of the interdisciplinary design team relevant.

In a recent publication by Pruthi et al at the University of North Carolina Chapel Hill, 100 radical cystectomy procedures with robotic assistance was performed. This study came up with 41 postoperative complications in 36 out of the 100 patients, 8% rate of major complications and a 11% rate of required readmission. In an average follow up time of 21 months, 15 patients were found to have had disease recurrence, and 6 patients had died.

Failures Encountered in Robot-Assisted Stereotactic Neurosurgery

Design Improvements and Future Work

Improvements could be made to enhance the overall system for robot assistance to stereotactic neurosurgery. The precision and coordinate GPS systems can be employed to increase accuracy and efficiency. More advanced and user-friendly systems could be made in order to reduce user errors. It is foreseeable that robot assistance will be implemented more often, and become increasingly cost effective. The systems will also be able to perform a wider variety of procedures, including other organs such as cardiac, breast tumor biopsy and ablation, orthopedic surgeries, and minimally invasive intracranial robotic surgery, with a greater number of features that can hold different tools. Future robots can be remote controlled, becoming useful for potential military applications.

Conclusions

Robot assistance applied for neurological procedures offer significant advantages over conventional operations and will help achieve positive outcomes for the patient. Some potential problems still exist with the current system and procedure; however the problems can be solved with thorough design evaluation and refinements. It is expected that innovative engineering solutions of robotics assistance and image guidance in stereotactic neurosurgeries will result in better health care delivery.