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Review Article

The Technological Advancement for Planning, Navigation and Robotic Assistance for Skull Base Surgery

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Abstract

An image-guided robot system for skull-base surgery facilitates the planning of surgical station and navigation, and determination of the path be taken by the removal tool, which follows the robotic manipulator. This study focuses on the development of an integrated system for robotics, navigation, and planning assistance using an image-guided robot system for skull-base drilling. The mechanism is effective in providing access to neurosurgical interventions; for example, in the case of tumor resection. The motivation for this study is to identify how surgeons can use robots to maintain and improve safety and prevent accidental damage to critical neurovascular structures that might occur during the drilling process. Data obtained from a systematic and formative review of existing research, as well as evaluation of current experimental studies, will be used to determine the effectiveness and success rate of image-guided robotic surgery.

Keywords: Image-guided surgery; Navigation System; Robotic assistance; Skull-base drilling

Introduction

Recently, Robots have shown effectiveness in assisting surgeons in performing various bone milling and drilling procedures [1]. One of the common examples is the commercial systems used for replacement and joint repair surgeries within Vitro feasibility, as in the case of mastoidectomy [2,3]. While performing the procedure, the robot follows a path guided by the CT image, which has registered the physical anatomy of the surgical site in the operating room that is, in turn, transferred to the robot [4]. In the field of cranial and neurosurgery, there has also been advanced technological innovation [5]. For example, the introduction of neuro-endoscopy, modern neuroimaging, operating microscope, stereotactic surgery image-guided surgery, and technologically demanding implants has contributed to the advancement and also challenging the human dexterity limits [6]. Robotic-assisted surgery in skull-based drilling is motivated by image-guided surgery, and its suitability is enhanced due to the critical nature of adjacent anatomy, complex anatomical components, and static nature of the skull [7]. Complications in the craniotomies for the brain tumors that occur in the deep posterior, middle, and anterior cranial fossae results in the need for complicated removal of the bone for complete tumor resection [8].

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Methods

The literature review performed on Cochrane, Medline, and PubMed databases as well as specialist journals on skull-base drilling and robotic surgery. Some of the keywords used for the search included robotic surgery, image-guided procedure, cranial base surgery, and skull base robotics. The study did not use any selection criterion; all articles with relevant information on the research topic were reviewed, which provided a broad scope. However, articles concerning augmented reality, simulation, and navigation were excluded from the analysis since they were not considered as techniques for skull base robotics.

Results

The studies revealed that using image-guided robotic assistance for skull base surgery minimized complications and adverse events of hand surgery [9]. Surgeons can comfortably control the tool motion using different mechanics, including foot pedal or joysticks, which increases precision [10]. Compared to surgeries without robotic assistance, the setup time for image-guided skull base surgery was relatively long, but with improved accuracy [11]. For instance, when used on patients undergoing endoscopic skull base surgery, none of the individuals developed side effects such as synechia or acute sinusitis [12,13] (Table 1).

Discussion

Although there has been continuous development in the field of robotics, no robot is currently used routinely in skull base surgery [16]. Many researchers have focused their studies on developing approaches such as the da Vinci robot that provides access to skull base; however, none of the proposed solutions have been viable for use on living subjects due to the invasive nature of the procedures [17].

Nevertheless, skull base robotic surgery is state of the art for most pathologies, and it is of high importance in carrying out borderline interventions for neck and head surgeries as well as managing skull base defects that might occur after transnasal surgery [18].

Author name (s)	Year of development	Robot name	Type of Instrument	Type of control	Safety
Bumm, et al. [14]	2005	Evolution 1	Endoscope	Joystick	Guides surgical operations by flexibly inspecting gastrointestinal tract and biological duct.
Xia, et al. [5]	2008	None	Endoscope or Drill	Co-manipulation	Drill the head's skull and also make larger incisions. They are also used to drill away bones during surgery.
Wurm, et al. [15]	2005	A-73	Operating channels, drill, and endoscope	Joystick	Cooling convectional tools helping in surgery or spine, head, and extremities near soft tissues.
Mattheis, et al. [12]	2019	None	Endoscope	Foot pedal	Record video and take pictures during surgery. It also controls suctioning at lower intestinal endoscopy.

Table 1: Showing innovationin integratedrobotic assistance system in skull base surgery.

Since the approval of the da Vinci Surgical System by the Food and Drug Administration, there has been an increase in transoral surgical modalities for neck and head tumors [19,20]. Flexible robotic systems have also been optimized for use in transoral surgery [21]. However, despite the improvement of these systems, the da Vinci Robots cannot be used in skull base surgery due to the size of the machines, especially for use in endonasal surgery [18].

Xia et al. suggested the use of a cooperatively-controlled robotic system due to its feasibility in a clinical setting [5]. The experiments showed that the controlled robot system minimizes the placement and dimension error, improving accuracy in the machining process [22]. Implementation of the prototype in a clinical setting requires engineering effort and high investment, which has been a hindrance to its usage [23,24]. However, robotic surgery in skull base drilling would have been beneficial as well as in endoscopic guiding systems [25]. Methods such as the 4-hand technique, which is part of the implementation for the skull base surgery routine, could also be used with the endoscopic guiding systems [21]. Various prototypes, including Nimsky et al., with their Evolution 1 robotic system, have been developed, but the information on their clinical application is missing [14].

The study identified various barriers to the successful implementation of robotics in surgery, which included inadequate knowledge of the operative technique by the robotic engineers [9]. This challenge is caused by the difficulty of surgeons to express their needs, hence resulting in the limitation of current robots in terms of their machine/man control, controls, and active perception [26]. Therefore, to overcome these challenges, there is a need for collaboration between the surgeons and surgical robot laboratories to help engineers understand the physical properties and the anatomy of the tissues that the robot will be in contact with [16]. Engineers must also develop innovative designs and architecture with miniaturizing components, adapted to work cooperatively in the operative procedures, and interfaces that facilitate safety and meet the surgical environment requirements [20,27,28].

Unanswered Questions

Some of the missing components identified while performing this study are the issue of ergonomy [29]. With the existing commercial robots, there is a gap in how they will be suited to meet the usability needs of the surgeons and the rate of the learning curve for the tested robots [30,31]. The research was also limited to skull base surgery; therefore, it does not provide conclusive information on how other mechanisms such as endoscope surgery have improved the image-guided procedures using robotic guidance system [14].

Conclusion

Robot-assisted skull base surgery is an important technique that enhances the capacities of the surgeons and also saves on time. Therefore, there is a need to develop a dedicated robot with strict specifications on the operation procedure in terms of safety, ergonomy, and dimensions. The different experimental protocol has shown promising progress in the development of robotic assistance skull base surgery and other cases such as lamina papyracea, optic nerve, and internal carotid artery. Robotics are necessary for helping with the extension of indications of the anterior skull base surgery; however, the complications with existing prototypes, as discussed in the literature, present a challenge to its successful implementation. Robotic based surgeries are effective, and they should be optimized to have advanced control units to improve usability and safety. Surgical robots should provide a programmable digital platform that allows integration with preoperative 3D planning data from MRI or CT scans. This process enables familiarization of the robot with surgical aims, determination of landmarks, and identification of the surgical corridor. This safety measure reduces unwanted complications and tissue damage.

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