International Journal of Engineering Applied Sciences and Technology, 2023
Vol. 8, Issue 04, ISSN No. 2455-2143, Pages 163-170
Published Online August 2023 in IJEAST (http://www.ijeast.com)
DOI:10.33564/IJEAST.2023.v08i04.022

THE PARALLEL BETWEEN ARTIFICIAL INTELLIGENCE AND NEUROSURGERY

Maleah Crawford
Department of Biology
St. Joseph's Convent, San Fernando, San Fernando,
Trinidad and Tobago

Abstract- **The prowess of neurosurgeons emerges from decades of holistic training centered on technical skills, phasic clinical data collection, decision making, care and recovery. Modern research has opened a discussion regarding a remarkable surge in the importance of artificial intelligence (AI) in neurosurgery and its foundational procedures. AI has proven itself to be an invaluable asset in neurosurgery by complementing the aforementioned expertise of neurosurgeons to provide exceptional patient care throughout the pre-operative, intra-operative and post-operative stages of neurosurgery by enhancing diagnostic and prognostic outcomes in clinical treatment and mitigating the pressures associated with manual decision making taken on by neurosurgeons to improve patient outcomes. AI also contributes to the production, processing and storage of clinical and experimental data and has been observed to decrease risks associated with neuroanaesthesiology. The implementation of AI in neurosurgery can globalize high-quality healthcare with central focus on developing nations and thereby reduce the costs associated with surgical procedures. Additionally, mutualism between AI and neurosurgery can be facilitated, where both fields lead neurosurgeons and AI engineers into further exploration and more complex procedures to possibly re-define traditional methods in AI and neurosurgery and ultimately solve healthcare-related global issues. The aim of this review is to explore the capacity of AI in aspects of neurosurgery and investigate the significance of its contributions with regards to the capabilities of human workers.**

Keywords: **neurosurgery; neurological surgery; artificial intelligence; machine learning; deep learning; nervous system; diagnosis; prognosis**
Abbreviations: AI- Artificial Intelligence, ML- Machine Learning, DL- Deep Learning, BCI- Brain-Computer Interface

I. INTRODUCTION

Through one scope, the field of artificial intelligence can be perceived as derived from neuroscience. The former can be defined as the theory and development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages. Considering this delineation, it is evident that any pioneer in the development of artificial intelligence was required to possess dexterity in the recreating the mechanisms of human intellect. Similarly, neuroscience and artificial intelligence have been observed to co-operate in the advancement of human self-comprehension through phenomena such as AI renditions of our working memory and visual processing, AI analysis of large neuroscience datasets, and computational psychiatry. Another interpretation of the relationship between AI and neuroscience suggests that AI appears to revisit its roots as machine learning engineers apply their proficiency to neuroscience research. They do so as a means of fueling the aforementioned self-comprehension that is crucial for human beings to possess in this incessantly digitizing world. While these neoteric discoveries have aided both genres of study tremendously, both the medical and artificial intelligence realms can benefit from further fortification of the relationship between artificial intelligence and neurosurgical practice by investigating how artificial cognition can repair authentic cognition.

II. PRINCIPLES OF NEUROSURGERY AND ARTIFICIAL INTELLIGENCE

Neurosurgery

Neurological surgery is a discipline concerned with the diagnosis and treatment of nervous system disorders. A neurosurgeon assesses, diagnoses, and treats conditions that affect the body's nervous system, which includes the brain, spinal cord and spinal column, and all the nerves that extend from the spinal cord. A neurosurgeon is skilled in several surgical techniques, including open surgery, minimally invasive surgery, endoscopic surgery, microsurgery, endovascular surgery and chronic pain interventional procedures. Neurosurgeons are also thoroughly trained to perform tests needed to diagnose and treat neurological conditions. Machines used to effectuate these tests include: CT (computed tomography) scans, MRI (magnetic resonance imaging) scans, PET (positron emission tomography) scans, Magneto encephalography (MEG), and Electroencephalograms (EEG). Due to the complexity of the field of medicine, and more specifically, specialized medical procedures such as neurosurgery, neurosurgeons undergo one of the longest training periods of any medical specialty with extensive training before becoming licensed to perform any surgical procedures involving the nervous system.

Artificial Intelligence

Artificial Intelligence is a technology that allows machines and computer applications to mimic human intelligence, learning from experience by means of iterative processing and algorithmic training. AI systems operate by combining large sets of data with intelligent, heuristic processing algorithms to learn from patterns and features in the data that they analyze. Each time an AI system runs a round of data processing, it tests and measures its own performance and develops additional expertise. AI systems work without taking breaks, allowing them to run through hundreds, thousands, or even millions of tasks extremely quickly, learning a great deal in very little time, and becoming extremely capable at whatever it's being trained to accomplish.

AI science aims to build computer systems capable of modeling human behavior so that they can apply human-like thinking processes to solve complex problems. To accomplish this objective, AI systems utilize a series of techniques and processes.

The disciplines which compose the field of AI are as follows:

A) Machine Learning – An application of AI that lets computer systems, programs, or applications learn automatically and develop better results based on experience, all without being programmed to do so. Machine Learning allows AI to find patterns in data, uncover insights, and improve the results of whatever task the system has been set out to achieve.

Machine Learning works under the basis of Neural Networks. Neural networks analyze data sets repeatedly to find associations and interpret meaning from undefined data. They operate like networks of neurons in the human brain, allowing AI systems to accept large data sets, uncover patterns amongst the data, and answer questions about it.

B) Deep Learning - A type of machine learning that allows AI to learn and improve by processing data. Deep Learning uses artificial neural networks which mimic biological neural networks in the human brain to process information, find connections between the data, and come up with inferences, or results based on positive and negative reinforcement.

C) Cognitive Computing – An important component of AI systems designed to imitate the interactions between humans and machines, allowing computer models to mimic the functions of the human brain works when performing complex tasks such as analyzing text, speech, or images.

D) Natural Language Processing – This is a critical piece of the AI process which allows computers to recognize, analyze, interpret, and truly understand human language. Natural Language Processing is essential for any AI-driven system that interacts with humans in some way, either via text or spoken inputs.

E) Computer Vision - One of the prolific uses of AI technologies is the ability to review and interpret the content of an image via pattern recognition and deep learning. Computer Vision allows AI systems to identify components of visual data.

AI systems also use a vast array of different technologies to enable them to apply human-like thinking processes to solve complex problems. The technology required by AI includes larger, more accessible data sets, graphical processing units, intelligent data processing, and application programming interfaces.

III. NEUROSCIENCE AND NEURAL NETWORKS

Neuroscience is any or all of the sciences, such as neurochemistry and experimental psychology, which deal with the structure or function of the nervous system and brain. From this field, the most crucial element of the bond between human cognition and computational cognition was derived—it is the realm of artificial neural networks. A neural network is a series of algorithms which recognize the underlying relationships in a data set through a process modeled after the function of the human brain with respect to organic neurons. Neural networks with several process layers are known as "deep" networks and are used for deep learning algorithms.

According to computational neuroscientist Dr. David Sussillo, artificial neural networks have proved useful for studying the brain. If such a system can produce a pattern of neural activity that resembles the pattern that is recorded from the brain, scientists can examine the way in which the system generates its output and make subsequent inferences about how the brain performs the same action. This approach can be applied to any cognitive task of interest to neuroscientists, including processing an image. Susillo says, "If you can train a neural network to do it, then perhaps you can understand how that network functions, and then use that to understand the biological data."

International Journal of Engineering Applied Sciences and Technology, 2023
Vol. 8, Issue 04, ISSN No. 2455-2143, Pages 163-170
Published Online August 2023 in IJEAST (http://www.ijeast.com)
DOI:10.33564/IJEAST.2023.v08i04.022

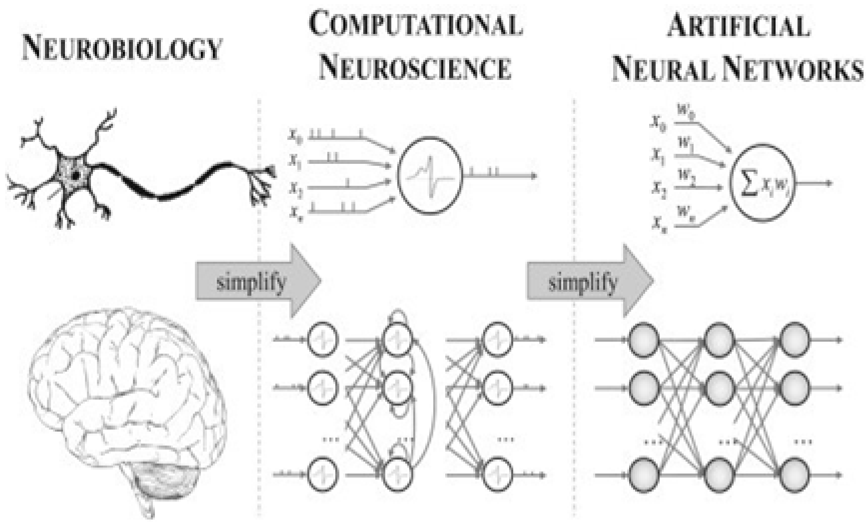

Figure 1.0: The Relationship between Neuroscience and Artificial Neural Networks Simplified.

Image Produced by Hargun Bhalla

Neural networks aid computers in making intelligent decisions with limited human assistance through learning and modeling the relationships between input and output data that are nonlinear and complex. An example of such a decision is medical diagnosis by medical image classification. Neural networks are the basis of machine learning (ML).

Machine learning is a subfield of artificial intelligence, which is broadly defined as the capability of a machine to imitate intelligent human behavior. It was defined in the 1950s by AI pioneer Arthur Samuel as “the field of study that gives computers the ability to learn without explicitly being programmed.”Artificial intelligence systems are used to perform complex tasks in a way that is similar to how humans solve problems.

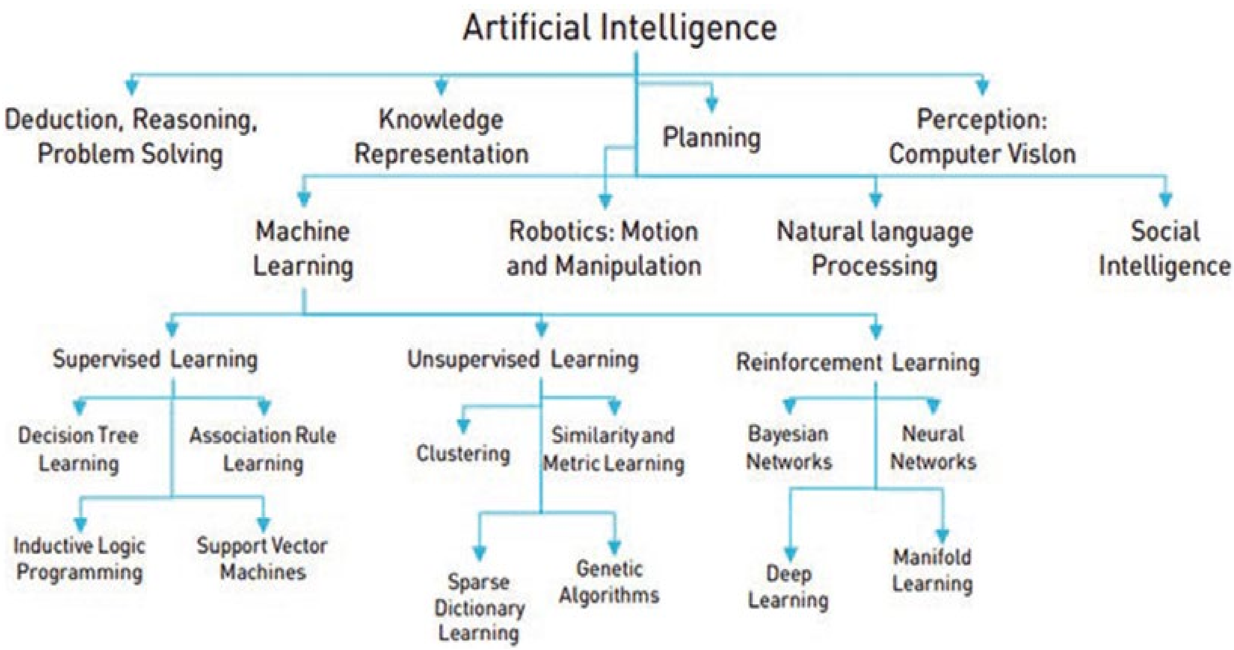

Figure 2.0: A Simplified Artificial Intelligence System Model

Image produced by Saranya Vasanthamani using BioRender

International Journal of Engineering Applied Sciences and Technology, 2023
Vol. 8, Issue 04, ISSN No. 2455-2143, Pages 163-170
Published Online August 2023 in IJEAST (http://www.ijeast.com)
DOI:10.33564/IJEAST.2023.v08i04.022

IV. AI MECHANICS IN THE PHASES OF NEUROSURGERY

The extensive training and experience under a neurosurgeon's belt allows them to engage in manual decision making to determine specific methods needed to facilitate successful surgeries. AI can help curb the vulnerability of human cognitive capacity by handling such information automatically in addition to reducing time taken to determine prognoses and procedures. This accelerates the initiation of treatment and care, thereby cutting costs and reducing labour. The more time that is saved pre-operatively signifies the more time spent ensuring that the intra-operative elements of surgery are successful. Since reducing door-to-needle times improves the prognosis, this can narrow delays in delivering emergency treatments for conditions such as traumatic brain injury which is most common amongst athletes.

As brain imaging acquisition is a notoriously slow process, neurosurgeons implement rapid-sequence MRI of the brain which has been used for a long time in the evaluation of ventricular shunt catheters due to its ability to quickly evaluate intracranial fluid. AI can be used to accelerate brain imaging acquisition and interpretation which can be essential in assisting clinicians to improve the accuracy of their diagnosis.

Additionally, artificial intelligence can automatically classify the type of epilepsy experienced by a patient. According to Dr. Shania Kennedy at Health IT Analytics, a study performed in 2020 found that a network inference technique could be used to analyze Electroencefalography (EEG) electrodes to detect a seizure and pinpoint its location in real time. Most seizures are perceived to occur when a strong, hyper-synchronized firing of a cluster of neurons suddenly interrupts normal brain activity. If a patient is hooked up to an EEG during a seizure, this abnormal brain activity can be measured and presented as spike-and-wave discharges. However, temporal EEG signals can make it more difficult to detect a seizure. The researchers developed a network inference technique to study the relationships between EEG nodes to address this. According to the study, their method allows them to detect seizures and pinpoint their locations with significantly more accuracy and fewer resources than conventional approaches.

Pre-Operative Planning

In pre-operative planning, AI algorithms have been used for automatic tumour segmentation, epileptogenic zone localization, and selecting appropriate candidates for epileptic surgery. Classification of epilepsy and tumour can be subjective, therefore causing differences in the decision-making of neurosurgeons. However, since AI algorithms are robust and use computation, statistics, and strict methods, their use in these processes can eliminate the subjective interpretation of the data and thereby diagnose conditions requiring neurosurgical procedures. More imperative but time-consuming steps in pre-op planning are efficient identification of glioma tissue and AI has been observed to outperform physicians in this task.

Intra-Operative Planning

Unlike human clinicians, AI is capable of managing multiply variables simultaneously, allowing for more accuracy and specificity when planning treatment. This signifies that AI may also propagate higher accuracy in diagnoses. An example of this in the intra-operative phase of neurosurgery is the label-free optical imaging workflow to automatically predict diagnosis in near real-time developed by Hollon and partners.

According to their study, their tumour diagnosis methods can predict the diagnosis of tumours in under 150 seconds compared to conventional methods performed by human operators, which may take up to 30 minutes.

Their diagnosis method yielded 95% accuracy, proving slightly more efficient that conventional methods which propose an accuracy of 94%.

Post-Operative Planning

Telemedicine, powered by artificial intelligence, is widely accepted by patients and healthcare workers and can improve patient outcomes during postoperative care. This phenomenon includes postoperative video conferencing, which is deemed most convenient and comfortable for patients post-surgery. This replaces in-person checkups and routine monitoring and reduces costs associated with patient and professional travel. It also allows correspondents residing in geographically restricted areas to receive high-quality care from a distance.

ML-based algorithms have been observed to be effective in trajectory planning. According to Dr. Simon Williams, work by Dolz et al. investigated the use of deep learning algorithms on MRI to accurately detect local organs at risk for patients undergoing radio surgery— they found that their automated system was able to accurately segment the brainstem in patients with CNS tumours, and was significantly more time efficient than traditional means. Havaei et al. demonstrated the use of a convolutional neural network that was 30 times faster, as well as being more accurate than state-of-the-art segmentation platforms.

As demonstrated, AI algorithms can prove advantageous in the phases of neurosurgery, before, during, and after the various neurosurgerical procedures.

V. AI CATALYSING FURTHER NEUROSURGICAL RESEARCH

International Journal of Engineering Applied Sciences and Technology, 2023
Vol. 8, Issue 04, ISSN No. 2455-2143, Pages 163-170
Published Online August 2023 in IJEAST (http://www.ijeast.com)
DOI:10.33564/IJEAST.2023.v08i04.022

As previously mentioned, artificial neural networks are valuable tools that can help human beings to comprehend the complexity of the nervous system. The implementation of AI and brain-computer interface (BCI) in surgical research has already seen great feats such as the amelioration of motor functions in able-bodied individuals and the restoration of motor abilities in paralysis patients. Prosthetic arms, for instance, can see a new bout of motor privileges. Robotic arms can be controlled by signals from the scalp using EEG in patients with spinal cord trauma. Computer vision connected to display figures allows temporary operators to monitor progress in the motion of someone with a robotic arm so they can deduce information from real-time adjustment of the patient. AI and ML have given data a voice which can guide medical practitioners in making better decisions. Furthermore, AI can build and test hypotheses while also analyzing clinical and experimental data, mostly qualitative. It can also process and store this data in a very short period of time whilst forming memory networks to process this type of information within a shorter duration the next time it is encountered. This allows freer schedules for clinical researchers with higher accuracy of results by means of minimizing human error and the various biases.

AI has already seen vast potential in neuroanaesthesiology.

The aims of neuroanaesthesia are to maintain an adequate cerebral perfusion pressure (CPP), maintain a stable intracranial pressure (ICP), create optimal surgical conditions, ensure an adequately anesthetized patient, and enable rapid return to consciousness to allow effective post-operation neurological assessment. The application of AI has seen incredible results in anesthesiology. In each phase of neurosurgery, pre-op, intra-op, and post-op, it is able to perform a myriad of tasks by means of highly specialized techniques. AI has catalysed a revolution within the realm of anesthesia, called Anesthesia 4.0. However, investigations of clinical impacts and external validations with regards to ethics and socio-economic notions are needed to authorize the usage of this model in daily practice.

Therefore, additional research will be vital to better comprehend the ethical, cultural, and societal implications of integrating AI into clinical workflows, including AI assistance in general healthcare.

Most modern research surrounding AI usage to improve depth of anesthesia focused on use of the Bispectral Index (BIS) or electroencephalography to evaluate anesthetic depth. It is crucial to investigate these methods of measurement due to previous literature suggesting that low BIS and burst-suppression on electroencephalography during anesthesia may be associated with poorer surgical outcomes. Twenty-six Open-A papers were found that pertain to control systems for the automatic delivery of anesthesia. Automated delivery of anesthesia also requires a determination of the depth of anesthesia by a machine, so measurements or substitute markers of anesthetic depth are necessary. It is this arena in which Machine Learning (ML) algorithms become increasingly vital. Therefore, to facilitate controlled delivery, the modalities used to obtain an approximate depth of anesthesia must be improved.

VI. AI GLOBALIZING TREATMENT AND RESOURCES

A large portion of citizens in developing countries is dealt limited access to basic commodities such as food and water, so they undoubtedly face restrictions with regards to neurosurgical service. Neurosurgical procedures are typically unsuccessful in these regions due to lack of advanced diagnostic equipment and trained neurosurgeons in developing countries. Disparities in healthcare have not been mitigated, even with an increased capacity of medical training to meet the demands of patients in developing countries. This was especially evident in the response to the COVID-19 pandemic in the developing world and the consequent waiting period for vaccines and relief services. This issue was incredibly alarming considering that approximately 80% of the world's population resides in developing territories.

However, young machine learning engineers are taking initiatives to improve service and healthcare in third-world nations using AI. An example of this is the NurLabs Initiative, an early cancer diagnostics system. Research from the National Cancer Institute shows that liquid biopsies (biomarker tests) can complement current standard-of-care screening. Liquid biopsy holds tremendous potential to transform the diagnosis and treatment paradigm for cancer. The first generation of liquid biopsies currently rely on biomarkers found in later stages. In contrast, our platform examines the couriers carrying cargo between cells, a living process in all stages. Cancer cells produce 10x more couriers than normal cells, making this biomarker easier to detect in early-stage cancers. NurLabs is a patent-pending materials science and bioinformatics approach to detect cancer early when it's most treatable. They "bring a fresh perspective to an old problem."

Decentralization of healthcare is crucial in the developing world in order to minimize the effects of urbanization. Delivery of surgical interventions for patients wherever they are located can not only decentralize resources, but it can also minimize risks and costs associated with patient transfer. There is a clear global disparity in the availability of neurosurgical care, which can result in preventable disease, disability, and death. These issues can be consequences of long travel due to residence outside of urban centers, lack of trained neurosurgeons, and financial strain. Robotic surgery with the aid of AI can be used to facilitate patient management and surgical operation during times of increased demand on the healthcare systems such as pandemics. However, it is not necessary for this form of surgery to remain restricted to exceptional circumstances. It can be extended to deliver high-quality surgical procedures to rural and less accessible areas.

AI is able to help dissipate the socio-economic disparities that place barriers between certain demographics and high-quality healthcare by detecting and logging need by geographical location, aiding low-staffed regions by performing small aids for neurosurgeons, helping the general economy by processing and storing large amounts of clinical data, and using statistical analysis to regulate success probabilities. Furthermore, AI will reap many benefits through the promotion of AI in the training of skilled workers. AI-guided research programs in the developing world originally taught by foreign instructors in person will reduce travel costs of human resources, minimize BRAINDRAIN, and thereby introduce gold mines of additional invaluable knowledge into these economies. Education has already observed artificial intelligence as an extremely beneficial device.

VII. THE CHALLENGES ASSOCIATED WITH AI IN NEUROSURGERY

While there are many benefits to using AI in neurosurgery, there are also disadvantages. Most risks associated with this notion are related to the reliability of AI in neurosurgery. Errors in diagnoses, scans and surgery caused by system malfunctions are not the only consequences. Prompts to replace healthcare workers can emerge when AI systems prove to be more efficient.

Many workers, including clinicians, question whether their qualifications will still be considered valid as society welcome artificial intelligence into the workforce

According to Pew Research, about half (48%) of experts surveyed felt that robots and digital agents will displace a significant number of blue- and white-collar jobs. Their concern is that this will increase income inequality and create a mass of virtually unemployable people. The other half (52%) expect robotics and AI to create more jobs than they take. This latter half believes that while AI will replace humans, these experts have faith in human ingenuity to create new jobs, industries, and new ways of making a living—much like at the dawn of the Industrial Revolution. Another example supporting this notion is the reaction to Amazon’s replacement of human shelving employees with hundreds of thousands of robots which are noted to complete the task with greater speed. While AI-guided labour can spark concern and skepticism, the introduction of advanced technology into the workplace foresees collaboration between human and computational cognition. This notion is especially relevant to medical practitioners.

The satisfaction of patients with these new developments must be the primary concern as medical practitioners welcome computational intelligence into the clinic. Studies show that neurosurgeons and their patients are generally receptive to these progressions in the event that surgeons are ultimately in control of neurosurgical procedures while being aided by AI systems. It can therefore be deduced that neurosurgeons can harness the prowess of AI algorithms to extend their expertise without being challenged by replacement.

Another challenge facing AI in neurosurgery is the cost. However, the aforementioned benefits can change surgery in all fields for the better, far outweighing any primary expenses.

Finally, technological security can be vulnerable. It is possible that the clinical data based on human neural mechanics stored within these machines can be accessed and used by individuals with ulterior motives.

One way of curbing limitations to the collaboration between AI and neurosurgery is by facilitating more research on potential and previous successes, ethical implications, and other medical research criteria.

VIII. CONCLUSION

Considering the similarity in the foundation between AI and neurosurgery, both interdisciplinary fields can benefit tremendously from the exchange of research and methods. More importantly, machine learning engineers and neurosurgeons may foster previously overlooked relationships between their respective arenas. As computation makes itself a prerequisite in ancillary courses for Neuroscience programs, it can be assumed that an increasing number of computer science minors will emerge in the neuroscience field. This means that the incorporation of advanced technology in general neuroscience will begin during undergraduate medical studies.

AI has displayed the ability to improve surgeons' skills in the pre-, intra- and postoperative areas of neurosurgery and make neurosurgical procedures accessible worldwide. The precision and accuracy introduced by these machines will also allow for higher success rates within surgery as AI machines can use built-in statistical analysis prowess to deduce the probability of success and thereby propose alternative methods to raise the probability. Furthermore, artificial intelligence systems have already appeared to make generous contributions to neuroanaesthesiology. Future applications of AI in neurosurgery demand more research, funding, and cross-disciplinary cooperation, all while observing ethical principles and careful regulation.

IX. REFERENCES:

[1]. Arthur S., Maciej H. (2021). Neurosurgical robots and ethical challenges to medicine, Ethics in Science and Environmental Politics, 10.3354/esep00197, 21, (pp. 25-30).

International Journal of Engineering Applied Sciences and Technology, 2023
Vol. 8, Issue 04, ISSN No. 2455-2143, Pages 163-170
Published Online August 2023 in IJEAST (http://www.ijeast.com)
DOI:10.33564/IJEAST.2023.v08i04.022

[2]. Anand R., Travis D., Zhenyu L., et al. (2010). Use of an artificial neural network to predict head injury outcome, (pp. 585–590).

[3]. Aria J., Alejandro S., Joshua B., Robert S. (2022). Robotics in Cerebrovascular and Endovascular Neurosurgery, Introduction to Robotics in Minimally Invasive Neurosurgery, (pp. 122-147).

[4]. Bardram E., Bossen C. (2020).The spatial dimension of collaboration at a hospital. CSCW. 2005, (pp. 131–160).

[5]. Garg,B. et al. (2020). Robotic spine surgery: Ushering in a new era. Journal of Clinical Orthopaedics and Trauma, 11, (pp. 753–760).

[6]. Bohl A., Oppenlander E., Spetzler R. (2016). A prospective cohort evaluation of a robotic, auto-navigating operating microscope., (pp. 25-30).

[7]. Chang K. et al.(2018). Residual convolutional neural network for the determination of IDH status in low- and high-grade gliomas from MR Imaging. Clin Cancer Res. 24, (pp. 1073–1081).

[8]. Changsheng L. et al. (2018). , Nicolas A Skull-Mounted Robot with a Compact and Lightweight Parallel Mechanism for Positioning in Minimally Invasive Neurosurgery, Annals of Biomedical Engineering, 10.1007/s10439-018-2037-3, 46, 10, (pp. 1465-1478)

[9]. Lanfranco R., Castellanos E., Desai P. et al. (2004). Cureus 8. (pp. 660-662).

[10]. Domagoj D. et al. (2021). 44th International Convention on Information, Communication and Electronic Technology (MIPRO), 10.23919/MIPRO52101.2021.9596804, (pp. 1185-1190).

[11]. Gal A. and Cagle PT. (2005). The 100-year anniversary of the description of the frozen section procedure. JAMA. (pp. 3135–3137).

[12]. Hector J. (2016). Pediatric neurosurgery telemedicine clinics: a model to provide care to geographically underserved areas of the United States and its territories. (pp.753–757).

[13]. Hollon c. et al. (2020). Near real-time intraoperative brain tumor diagnosis using stimulated raman histology and deep neural networks. Nat Med. (pp. 52-58).

[14]. Laura T. et al. (2019). Stereotactic brain biopsy: evaluation of robot-assisted procedure in 60 patients, Acta Neurochirurgica, 10.1007/s00701-019-03808-5, 161, 3, (pp. 545-552).

[15]. Mayank G. et al. (2020). Neurointerventional Robotics: Challenges and Opportunities, Clinical Neuroradiology, 10.1007/s00062-020-00913-2, 30, 2, (pp. 203-208).

[16]. Mohammadreza D. et al. (2018). Analysis, optimization and prototyping of a parallel RCM mechanism of a surgical robot for craniotomy surgery, Industrial Robot: An International Journal, 10.1108/IR-08-2017-0144, 45.

[17]. Mosa M., Yoo I., Sheets L. A systematic review of healthcare applications for smartphones. BMC Med Inform Decis Mak. (pp. 12-67).

[18]. Novis D. and Zarbo R. (1997). Interinstitutional comparison of frozen section turnaround time. A college of American Pathologists Q-Probes study of 32868 frozen sections in 700 hospitals. Arch Pathol Lab Med. (pp. 559–567).

[19]. Radius P. et al. (2018). Design and Implementation of Respiration Rate Measurement System Using an Information Filter on an Embedded Device, Sensors, 10.3390/s18124208.

[20]. Reider-Demer M. et al. (2018). Prospective and retrospective study of videoconference telemedicine follow-up after elective neurosurgery: results of a pilot program. (pp. 497–501).

[21]. Anthony L. et al. (2020). Robotic surgery: a current perspective. (pp.14–21)

[22]. Mario S. (2022). “Neurosurgeon: What They Do, Specialties & Training.” Cleveland Clinic, Date Accessed: 22nd July, 2022. my.clevelandclinic.org/health/articles/22364-neurosurgeon

[23]. Shitong F.et al. (2020). 3-Dimensional printing templates guiding versus free hand technique for cervical lateral mass screw fixation: A prospective study, Journal of Clinical Neuroscience, 10.1016/j.jocn.2020.04.008

[24]. Sorayouth C. et al. (2019). Surgical Robotic Technology for Developing an Endonasal Endoscopic Transsphenoidal Surgery (EETS) Robotic System, The Open Neurology Journal, 10.2174/1874205X01913010096, 13, 1.

[25]. Suhas U. et al (2022). Robot-assisted frontofacial correction in very young children with craniofacial dysostosis syndromes: a technical note and early functional outcome, Neurosurgical Focus, 10.3171/2021.10.FOCUS21515, 52, 1.

[26]. Taku S. et al. (2021). Early Developments, Current Systems, and Future Directions, Neurosurgical Robotics, 10.1007/978-1-0716-0993-4.

[27]. Wenqiang L. et al. (2022). Preoperative management and postoperative complications associated with transoral decompression for the upper cervical spine, BMC Musculoskeletal Disorders, 10.1186/s12891-022-05081-7, 23, 1.

[28]. Weston R. et al. (2018). Automating neurosurgical tumor resection surgery: Volumetric laser ablation

of cadaveric porcine brain with integrated surface mapping, Lasers in Surgery and Medicine. (pp. 1017-1024).

[29]. Yu J. et al. (2017). Noninvasive IDH1 mutation estimation based on a quantitative radiomics approach for grade II glioma. Eur Radiol. (pp. 3509-3522).

[30]. Yue C. et al. (2018). Stereotactic Systems for MRI-Guided Neurosurgeries: A State-of-the-Art Review, Annals of Biomedical Engineering, 10.1007/s10439-018-02158-0

[31]. Z. I. Bibi F., et al. (2022). A Brief Insight on Magnetic Resonance Conditional Neurosurgery Robots, Annals of Biomedical Engineering, 10.1007/s10439-021-02891-z, 50, 2.

[32]. Van Bavel J (2013) The world population explosion: causes, backgrounds and pro-jections for

[33]. Van Bavel J (2013) The world population explosion: causes, backgrounds and pro-jections for

[34]. Lanfranco AR, Castellanos AE, Desai JP, et al. (2004) Robotic surgery: a current perspective.

[35]. Lanfranco AR, Castellanos AE, Desai JP, et al. (2004) Robotic surgery: a current perspective.

[36]. Shimizu S, Kuroda H, Mochizuki T, et al. (2020) Ergonomics-based positioning of the operating

[37]. Shimizu S, Kuroda H, Mochizuki T, et al. (2020) Ergonomics-based positioning of the operating