Sarcouncil Journal of Engineering and Computer Sciences

ISSN(Online): 2945-3585

Volume- 03| Issue- 01| 2024

Review Article **Received:** 22-11-2023 | **Accepted:** 22-12-2023 | **Published:** 28-01-2024

AI and Robotics in Surgical Procedures Enhancing Precision and Outcomes

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Abstract: Objective: The primary objective of this review is to provide a comprehensive summary of major themes within artificial intelligence (AI), with a specific focus on its applications and limitations in the field of surgery. The paper aims to elucidate the key capabilities of AI, facilitating surgeons in comprehending and critically assessing novel AI applications while contributing to the ongoing developments in this evolving domain. ***Summary Background Data*:** Artificial Intelligence (AI) encompasses diverse subfields, each offering potential solutions to clinical challenges. The core subfields explored in this review have found application not only in the medical domain but also in other industries, including autonomous cars, social networks, and deep learning computers. This versatility underscores the broad impact and cross-industry relevance of AI technologies. ***Methods*:** To achieve a comprehensive understanding of artificial intelligence (AI) and its impact on various sectors, a thorough review of AI literature spanning computer science, statistics, and medical sources was undertaken. The goal was to identify pivotal concepts and techniques within AI that drive innovation across diverse industries, with a specific focus on its applications in surgery. Additionally, the review delved into the critical examination of limitations and challenges associated with the practical implementation of AI across these fields. ***Result*:** The review identified four key subfields within Artificial Intelligence (AI): Machine Learning, Artificial Neural Networks, Natural Language Processing, and Computer Vision. These subfields were found to be crucial components with significant relevance to surgical practice. The examination not only outlined their current applications but also provided insights into their potential future contributions, particularly in areas such as big data analytics and clinical decision support systems. The discussion extended to the broader implications of AI for surgeons, emphasizing their pivotal role in advancing technology to enhance clinical effectiveness. In summary, the results highlighted the transformative potential of AI in shaping the landscape of surgical practices and underscored the importance of surgeon involvement in this technological evolution. **Conclusions:** Surgeons emerge as key facilitators for the integration of Artificial Intelligence (AI) into contemporary medical practices. The recommendation is for surgeons to establish collaborative partnerships with data scientists, facilitating the capture of comprehensive data across various phases of patient care. This collaboration aims to provide crucial clinical context, recognizing AI's potential to revolutionize the methodologies of teaching and practicing surgery. The envisioned outcome is a future optimized for the delivery of the highest quality patient care, signifying the transformative impact AI can have on the field of surgery under the guidance and collaboration of skilled medical professionals.

Keywords: AI, Machine Learning, clinical challenges, surgery.

INTRODUCTION

Artificial Intelligence (AI) is broadly characterized as the exploration of algorithms enabling machines to engage in reasoning and cognitive functions, encompassing problem-solving, object and word recognition, and decision-making. Initially relegated to the realm of science fiction, AI has now become a prominent subject in both popular and academic literature. Extensive research has propelled it beyond theoretical boundaries, leading to practical applications like IBM's Watson and Tesla's autopilot.(Hammer, P. C. *et al*., 2015)

Historical narratives, such as the tale of John Henry pitted against a steam-powered hammer, illustrate a longstanding apprehension and fascination with machines. Over time, society has embraced and eagerly anticipated the integration of machines into human workflows, paralleling the transformative impact of the Industrial Revolution. Similarly, AI now elicits both awe and fear, presenting a technology that not only outperforms but also potentially out-thinks its human creators. In the Information Age, mirroring the shifts seen during the Industrial Revolution, there is a noticeable transformation in workflow and productivity, holding promising implications for the field of surgery. However, amidst the excitement surrounding AI, there exists the risk of overlooking its true potential amid the hype. (Rudin C. *et al*., 2014)

Recognizing this, it becomes imperative for surgeons to establish a foundational understanding of AI. This knowledge is crucial for comprehending its potential impact on healthcare and contemplating ways in which surgeons can effectively engage with this technology. This review serves as an introductory guide to AI, spotlighting four core subfields—machine learning, natural language processing, artificial neural networks, and computer vision. The exploration includes discussions on their limitations and anticipates the future implications of AI for surgeons in the evolving landscape of healthcare.

Machine Learning, the first core subfield, empowers machines to learn from data and improve their performance over time. This dynamic capability has led to breakthroughs in various domains, including healthcare. Natural Language Processing (NLP), the second subfield, enables machines to understand and interpret

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DOI- https://doi.org/ 10.5281/zenodo.10578089

human language, facilitating communication between technology and healthcare providers. (National Research Council, 2013)

Artificial Neural Networks (ANNs), the third subfield, draws inspiration from the human brain's neural structure. ANNs excel in pattern recognition and are particularly impactful in image and speech recognition applications. In surgery, this translates to enhanced diagnostic capabilities and improved decision support systems.

Computer Vision, the fourth subfield, equips machines with the ability to interpret and make decisions based on visual data. In the medical realm, this holds immense potential for image-based diagnostics, precision surgery, and real-time procedural assistance. (Jüni, P. *et al*., 2001)

While the prospects of AI in surgery are promising, it is crucial to acknowledge its limitations. The hype surrounding AI often obscures practical challenges, including ethical considerations, data privacy concerns, and potential biases in algorithmic decision-making. Surgeons need to approach AI with a nuanced understanding, recognizing its capabilities while remaining vigilant about its limitations and potential pitfalls.

Looking forward, the integration of AI in surgery offers a paradigm shift. Surgeons, equipped with a foundational understanding of AI, can actively participate in shaping its application in healthcare. Collaboration with data scientists becomes essential to harness the potential of AI while ensuring its alignment with ethical standards and patient well-being. (Hopewell, S. *et al*., 2009)

Subfields in AI:

The foundations of Artificial Intelligence (AI) trace back to a convergence of disciplines, encompassing robotics, philosophy, psychology, linguistics, and statistics. Key strides in computer science, marked by advancements in processing speed and power, have acted as pivotal catalysts, laying the groundwork for the emergence of AI. The widespread adoption of AI across diverse industries is evidenced by a substantial venture capital investment, reaching a staggering $5 billion in 2016 alone.

While AI spans various facets, the current spotlight is on four core subfields, each contributing significantly to the evolving landscape of artificial intelligence: (Murthy, V. H. *et al*., 2004)

Machine Learning:

Definition: Empowers machines to learn and improve from data, unlocking capabilities for autonomous decision-making.

Significance: Enables AI systems to adapt and evolve without explicit programming, making it instrumental in various applications.

Natural Language Processing (NLP):

Definition: Facilitates the interaction between computers and human language, enabling machines to understand, interpret, and respond to human communication.

Significance: Drives advancements in language-based applications, including chatbots, translation services, and voice recognition systems. (Chang, A. M. *et al*., 2007)

Artificial Neural Networks (ANNs):

Definition: Modeled after the human brain's neural structure, ANNs excel in pattern recognition, enabling sophisticated data analysis and interpretation.

Significance: Applied in image and speech recognition, enhancing capabilities in diagnostics and decision support systems.

Computer Vision:

Definition: Equips machines with the ability to interpret and comprehend visual information, replicating human vision capabilities.

Significance: Crucial in applications such as image and video analysis, autonomous vehicles, and medical diagnostics.

These four core subfields represent the forefront of AI research and application, driving innovation and transforming industries across the technological landscape. The convergence of these disciplines propels AI into new realms, fostering advancements that impact diverse aspects of modern life. (Douglas, P. S. *et al*., 1996)

Machine Learning:

Machine Learning (ML) empowers machines to learn and make predictions by discerning patterns. Unlike traditional computer programs with explicitly programmed behaviors, ML allows computers to use partially labeled data (supervised learning) or inherent data structures (unsupervised learning) to make predictions without explicit programming. Supervised learning is beneficial for training ML algorithms to predict known outcomes, while unsupervised learning is valuable for identifying patterns within data. (Wang, X. *et al*., 2017).

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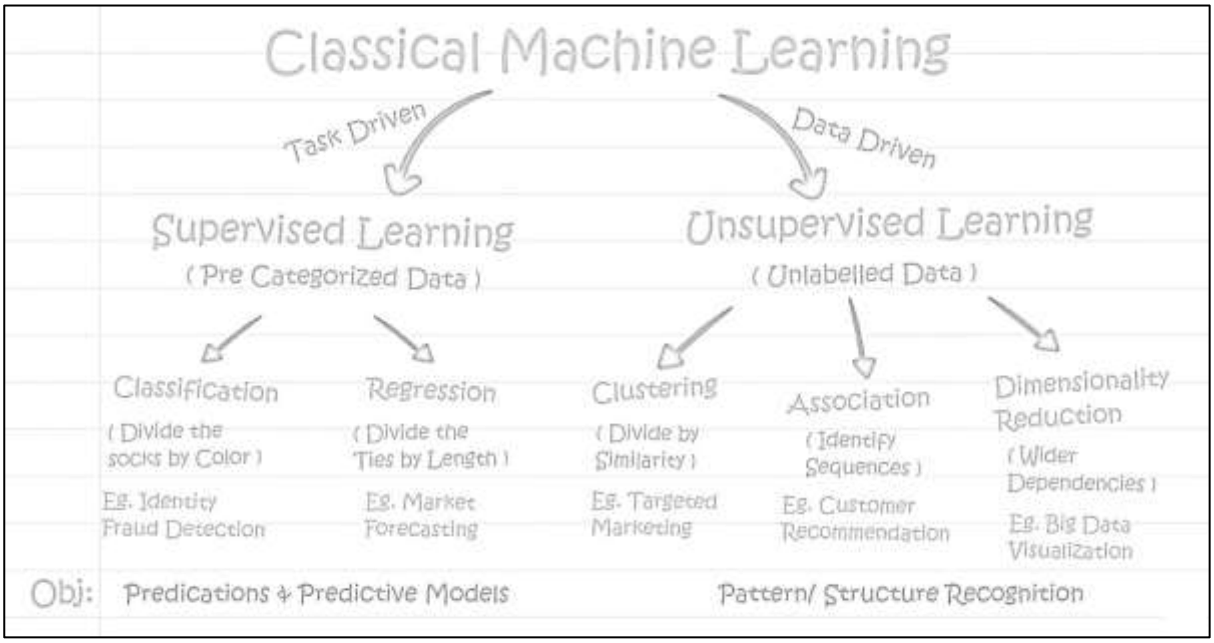

Figure 1: Supervised Learning and Unsupervised Learning

A third category in ML is reinforcement learning, where a program learns from its successes and mistakes while attempting to accomplish tasks. This category, akin to operant conditioning in psychology, is applicable in automated tuning scenarios, such as optimizing the measurement and delivery of insulin in an artificial pancreas system for diabetic patients.

ML excels in uncovering subtle patterns in large datasets, surpassing manual analyses in detecting complex non-linear relationships and multivariate effects. ML has outperformed traditional logistic regression in predicting surgical site infections (SSI) by incorporating non-linear models that utilize diverse data sources.

Moreover, ensemble ML, employing multiple algorithms collaboratively, achieves prediction accuracy levels previously considered unattainable. For instance, ensemble ML, combining random forests, neural networks, and lasso regression, predicted lung cancer staging from International Classification of Diseases (ICD)-9 claims data with exceptional sensitivity, specificity, and accuracy, outperforming clinical guideline-based decision tree approaches. (Oakden-Rayner, L. *et al*., 2020)

Natural Language Processing (NLP):
Natural Language Processing (NLP) focuses on enhancing a computer's understanding of human language, crucial for analyzing extensive content like electronic medical record (EMR) data, especially physicians' narrative documentation. Successful NLP systems go beyond word recognition, incorporating semantics and syntax for human-level language understanding.

NLP allows machines to infer meaning and sentiment from unstructured data, enabling clinicians to input data more naturally. It has been instrumental in large-scale database analyses of EMR to detect adverse events and postoperative complications. Many EMR systems now integrate NLP for tasks such as automated claims coding, enhancing workflow efficiency.

In surgical contexts, NLP has automated the identification of words and phrases in operative reports predicting anastomotic leaks after colorectal resections. The algorithm's ability to self-correct enhances prediction utility as datasets evolve. This application of AI in healthcare, particularly in surgery, highlights the transformative potential of NLP in leveraging unstructured data for enhanced patient care and workflow optimization. (Oakden-Rayner, L. *et al*., 2020)

Artificial Neural Networks:
Artificial Neural Networks (ANNs), a subset of Machine Learning (ML), draw inspiration from biological nervous systems and have become pivotal in numerous AI applications. These networks emulate the processing of signals in layers of computational units known as neurons. The connections between neurons are parameterized through weights that adapt as the network learns different input-output maps, addressing tasks like pattern/image recognition and data classification. Deep learning networks, a more

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advanced form of ANNs with many layers, excel in learning complex and subtle patterns compared to simpler neural networks. (Ribeiro, M. T. *et al*., 2016)

In clinical applications, ANNs have demonstrated significant superiority over traditional risk prediction methods. For instance, an ANN's sensitivity (89%) and specificity (96%) outperformed the APACHE II model's sensitivity (80%) and specificity (85%) in predicting pancreatitis severity six hours after admission. Leveraging clinical variables such as patient history, medications, blood pressure, and length of stay, ANNs, in conjunction with other ML approaches, achieved accurate predictions of in-hospital mortality following open abdominal aortic aneurysm repair, with a sensitivity of 87%, specificity of 96.1%, and accuracy of 95.4%. These results underscore the effectiveness of ANNs in enhancing predictive capabilities and informing clinical decision-making. (Sussillo, D. *et al*., 2013)

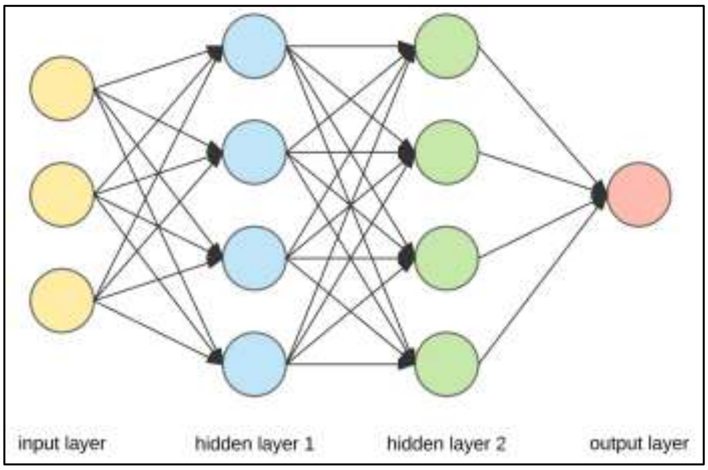

Figure 2: Architecture of Artificial Neural Networks

Computer Vision:
Computer vision pertains to machines comprehending images and videos, showcasing significant progress in achieving human-level capabilities, particularly in object and scene recognition. In healthcare, computer vision plays a crucial role in image acquisition and interpretation, particularly in axial imaging. Applications span computer-aided diagnosis, image-guided surgery, and virtual colonoscopy. Originally rooted in statistical signal processing, the field has transitioned toward more data-intensive Machine Learning (ML) approaches, notably neural networks, with adaptations into novel applications.

Current advancements in computer vision, driven by ML approaches, are directed towards higher-level concepts. This includes image-based analysis of patient cohorts, longitudinal studies, and the inference of subtle conditions like decision-making in surgery. For instance, real-time analysis of laparoscopic videos has demonstrated a 92.8% accuracy in automatically identifying the steps of a sleeve gastrectomy and detecting any missing or unexpected steps. Given the wealth of data in surgical videos—estimated to be 25 times more than that in a high-resolution computed tomography image—there is potential for leveraging predictive video analysis to process extensive surgical data. Although still in its early stages, this work serves as a proof-of-concept, illustrating that Artificial Intelligence (AI) can be harnessed for real-time intraoperative clinical decision support, potentially identifying or predicting adverse events during surgery. (Cabitza, F. *et al*., 2017).

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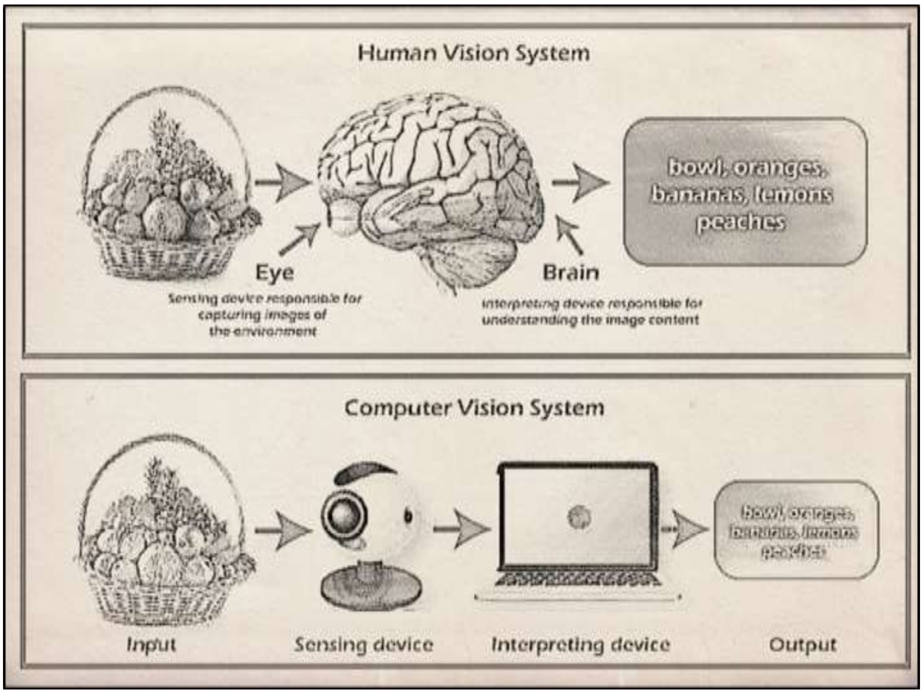

Figure 3: Human and Computer Vision System

Synergy across AI and Other Fields:

The potential of Artificial Intelligence (AI) lies in applications that integrate aspects of each of the aforementioned subfields with other computing elements, such as database management and signal processing. This trend mirrors other recent technological advancements, like mobile phones and cloud computing, emerging from the convergence of rapid advances in both hardware and software. (Sturm, I. *et al*., 2016)

The synergy between fields is vital for expanding the applications of AI. The combination of Natural Language Processing (NLP) and computer vision, as seen in Google Image Search, illustrates how AI can respond to textual queries with relevant images. Neural networks, particularly in deep learning, are now integral to the architecture of various AI systems, enhancing accuracy in translation and image classification.

Clinical applications showcase successful implementations of AI, including deep learning algorithms for classifying skin lesions with accuracy equivalent to dermatologists. Analyses combining NLP and Machine Learning (ML) in postoperative colorectal patients demonstrated improved prediction accuracy for anastomotic leaks, emphasizing the strength of analyzing various data types together. (Tan, S. *et al*., 2015)

Early AI attempts in surgical augmentation focused on simple tasks like suturing, laying the groundwork for more complex AI tasks. For instance, the Smart Tissue Autonomous Robot (STAR) from Johns Hopkins University demonstrated the potential for AI to match or outperform human surgeons in autonomous bowel anastomosis.

While fully autonomous robotic surgery is a distant goal, synergy across fields is poised to accelerate AI's capabilities in augmenting surgical care. AI's clinical potential lies in analyzing combinations of structured and unstructured data, such as Electronic Medical Record (EMR) notes, vitals, laboratory values, and videos, to provide clinical decision support. The unpredictable nature of synergistic reactions between different technologies could lead to revolutionary advancements, as demonstrated by autonomous cars resulting from the combination of advanced robotics, computer vision, and neural networks.

The true potential of AI remains uncertain, and the interaction between different components within AI and other fields might bring unforeseen changes to healthcare delivery. Surgeons play a crucial role in evaluating the quality and applicability of AI advances, ensuring their appropriate translation into the clinical sector. The evolving landscape of AI underscores the importance of interdisciplinary collaboration and ongoing assessment to harness its full potential in the field of surgery. (Pearl, J, 2000)

Limitations of AI:

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Like any emerging technology, Artificial Intelligence (AI) and its subfields can fall prey to unrealistic expectations fueled by media hype, potentially leading to disappointment and disillusionment. AI is not a cure-all solution and has limitations. Instances exist where traditional analytical methods outperform Machine Learning (ML), and the effectiveness of AI hinges on asking the correct scientific questions and having the appropriate data to answer them.

While ML is a potent tool for uncovering subtle patterns in data, there are associated costs and risks. ML excels at detecting patterns and correlations, potentially uncovering new clinical questions or generating hypotheses about surgical diseases and management. However, using ML incorrectly can yield misleading results.

The outputs of AI analyses are constrained by the types and accuracy of available data. Systematic biases in clinical data collection can affect the patterns AI recognizes, particularly impacting under-represented groups due to historic disparities in clinical trial and registry populations. Supervised learning relies on well-labeled data, and poorly labeled data can lead to inaccurate results. An example involving chest x-rays highlights the risk of improperly labeled data, where the AI network identified chest tubes instead of pneumothoraces as intended. (Wang, D. *et al*., 2016)

Interpretability is a significant concern with AI algorithms, especially those utilizing neural networks with a "black box" design. The lack of transparency in how AI discerns patterns poses challenges for human assessment. Accountability, safety, and verifiability of automated analyses are crucial considerations that impact the utility of AI in clinical practice. Efforts to improve interpretability are ongoing, and early input from surgeons in the design phase of AI algorithms could enhance accountability and interpretability in big data analyses.

Despite advances in causal inference, AI currently falls short in determining causal relationships at a level suitable for clinical implementation. Additionally, AI cannot provide automated clinical interpretations, lacking the ability to offer nuanced clinical context. Human physicians play a vital role in critically evaluating AI predictions and interpreting data in clinically meaningful ways. As AI continues to evolve, addressing these limitations and incorporating clinician input will be pivotal for its responsible and effective integration into healthcare practices. (Bahl, M. *et al*., 2018)

Implications for Surgeons:

The initial widespread application of Artificial Intelligence (AI) is likely to involve the computer augmentation of human performance, showcasing its potential in enhancing decision-making. In medical settings, AI has already demonstrated its utility in reducing error rates. For instance, pathologists utilizing AI experienced a significant decrease in the error rate for recognizing cancer-positive lymph nodes. AI can also assist surgeons and radiologists in refining decision-making, as evidenced by a potential 30% reduction in lumpectomy rates for patients with breast needle biopsies initially considered high risk but later found to be benign. (Harvey, C. *et al*., 2016)

Looking ahead, surgeons can expect AI analysis of population and patient-specific data to augment each phase of care. Preoperatively, patients may track relevant metrics through mobile applications and fitness trackers, with automated analysis providing personalized risk scores for operative planning and predicting postoperative care needs. Intraoperatively, real-time analysis of various data types, including operative video, vital signs, and electrosurgical energy usage, can aid in decision-making and prevent adverse events. Integrating pre-, intra-, and post-operative data allows for comprehensive monitoring of recovery and complication prediction, promoting patient-centered care. (Horner, G. N. *et al*., 2017)

AI holds the potential to facilitate knowledge sharing among surgeons globally. Massive datasets comprising operative videos and Electronic Medical Record (EMR) data can be collected, creating a database for evaluating practices and techniques against outcomes. Computer vision in video databases can capture rare cases or anatomy, enabling the aggregation of data across all phases of care. This approach could lead to disruptive innovation, generating and validating evidence-based best practices that significantly enhance the quality of patient care. Surgeons stand to benefit from AI's capabilities not only in improving individual patient outcomes but also in fostering a collaborative, evidence-driven approach to advancing surgical practices. (Ryu, B. *et al*., 2017)

The Surgeon's Role:

With big data analytics anticipated to yield annual healthcare savings of $300 billion to $450 billion

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in the US alone, there is significant economic incentive to incorporate AI and big data into various elements of the healthcare system. Surgeons are well-positioned to drive these innovations actively rather than passively waiting for the technology to become useful.

Recognizing that lack of data can limit AI predictions, surgeons should actively participate in clinical data registries, spanning local, national, or international levels. As data cleaning techniques improve, the linkage of registries can enhance their utility, providing access to diverse clinical, genomic, proteomic, radiographic, and pathologic data. (Allbon, P, 2010)

Surgeons, as key stakeholders in the adoption of AI-based technologies for surgical care, should seek collaborations with data scientists to capture novel forms of clinical data and generate meaningful interpretations. Surgeons possess clinical insights to guide data scientists in asking the right questions with the right data, while engineers contribute automated, computational solutions to data analytics challenges. (National Health and Medical Research Council, 2013)

Technology-driven dissemination of surgical practices can empower every surgeon to enhance global surgical care quality. By pooling surgical experiences similar to efforts in genomics and biobanks, AI could create a "collective surgical consciousness," offering technology-augmented real-time clinical decision support akin to intraoperative GPS-like guidance.

Surgeons contribute value by conveying their understanding of relationships between seemingly simple topics like anatomy and physiology to more complex phenomena such as disease pathophysiology, operative course, or postoperative complications. Transparency and interpretability in algorithms are crucial, demanding accountability for AI predictions and recommendations in the interest of patient safety.

As the conveyors of clinical information to patients, surgeons play a vital role in establishing a patient communication framework to relay AI-accessible data. An understanding of AI is essential for appropriately communicating complex analyses, risk predictions, prognostications, and treatment algorithms to patients within the relevant clinical context.

Collaborating with patients, surgeons should develop and deliver narratives on the optimal utilization of AI in patient care, preventing complications that may arise when external forces mandate technology implementation without fully evaluating potential impacts. If appropriately developed and implemented, AI has the potential to revolutionize the way surgery is taught and practiced, promising a future optimized for the highest quality patient care. (DAA, 2012; Shannon, C. *et al*., 2013)

CONCLUSION:

AI is increasingly integrating into clinical systems, spanning databases to intraoperative video analysis. The distinctive characteristics of surgical practice position surgeons as key contributors to the evolving phase of AI. This next stage emphasizes the creation of evidence-based, real-time clinical decision support, with the overarching goal of optimizing both patient care and surgeon workflow. The collaboration between surgeons and AI holds immense potential for reshaping the landscape of healthcare, ensuring that advancements in technology align seamlessly with the priorities of delivering high-quality patient care.

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Source of support: Nil; **Conflict of interest:** Nil.

Cite this article as:

Chintala, S. "AI and Robotics in Surgical Procedures Enhancing Precision and Outcomes." *Sarcouncil Journal of Engineering and Computer Sciences* 3.1 (2024): pp 8-16.

Publisher: SARC Publisher