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Integration of Imaging in Modern Operating Rooms: Enhancing Surgical Outcomes

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Abstract:

The integration of imaging devices in modern operating rooms has revolutionized surgical practices, enabling surgeons to visualize internal structures in real-time during procedures. Advanced imaging technologies, such as intraoperative ultrasound, fluoroscopy, and computed tomography (CT), provide critical information that aids in precise surgical navigation. These imaging modalities help in identifying anatomical landmarks, assessing the extent of disease, and guiding interventions with greater accuracy. As a result, the potential for complications decreases, and the probability of achieving successful surgical outcomes increases. By allowing for immediate adjustments based on real-time data, these technologies enhance the surgeon's ability to make informed decisions, leading to improved patient safety and reduced recovery times. Furthermore, the adoption of digital imaging systems facilitates better communication and collaboration among surgical teams. Integration with electronic health records (EHR) and surgical planning software ensures that relevant imaging data can be accessed seamlessly throughout the surgical process. The use of 3D imaging and augmented reality in the operating room allows for improved visualization of complex anatomical structures, aiding in the pre-operative planning and intraoperative execution. As the field of surgical imaging continues to evolve, ongoing research and development will further enhance the capabilities of integrated systems, ultimately leading to a more efficient surgical workflow and better outcomes for patients.

Keywords: Integration, Imaging Devices, Operating Rooms, Surgical Outcomes, Real-time Visualization

Introduction:

The integration of imaging devices into modern operating rooms (ORs) represents a paradigm shift in surgical practice, fundamentally altering the approach to both diagnostic and procedural processes. This innovation is driven by the recognition that enhanced visualization during surgery can lead to improved patient outcomes, including reduced complication rates, shorter recovery times, and overall better postoperative results. As healthcare continues to evolve in the 21st century, the ability to leverage advanced imaging technologies has become increasingly critical in the pursuit of precision medicine and personalized surgical interventions [1].

Historically, traditional surgical methods relied heavily on the surgeon's experience and tactile feedback, which while valuable, often lacked the comprehensive visual insights afforded by modern imaging techniques. The introduction of imaging modalities such as intraoperative ultrasound, fluoroscopy, magnetic resonance imaging (MRI), and computed tomography (CT) has transformed the landscape of the OR. These technologies empower surgeons with real-time visual data, enabling them to navigate complex anatomical structures with greater accuracy [2].

The prevalence of minimally invasive surgical techniques has further underscored the importance of imaging devices in contemporary surgical practice. These procedures often employ laparoscopy or robotic-assisted systems, wherein visualization becomes crucial for operative success. Imaging devices provide high-resolution, three-dimensional representations of the surgical field, facilitating precise incisions, careful dissection, and optimized surgical outcomes. Furthermore, with the rise of augmented reality (AR) and artificial intelligence (AI), surgeons are being endowed with unprecedented tools that not only assist in navigation but also enhance decision-making capabilities during surgery [3].

Enhancing surgical outcomes is a multifaceted goal that encompasses several key aspects, notably increased accuracy in tumor resections, improved ability to identify critical structures (such as blood vessels and nerves), and optimized surgical workflows. Each of these factors contributes to a reduced risk of intraoperative and postoperative complications, translating into shorter hospital stays and quicker recovery for patients. For example, studies have shown that the use of intraoperative imaging can lead to a significant decrease in incomplete tumor resections in oncological surgery, thereby directly impacting patient survival rates [4].

Moreover, the integration of imaging devices does not solely benefit the domain of complex surgeries; it also impacts routine procedures across various surgical specialties including orthopedics, cardiology, and neurosurgery. In orthopedic surgeries, intraoperative imaging aids in the precise placement of implants, enhancing joint stability and longevity. In neurosurgery, advanced imaging assists in navigating delicate brain structures, greatly reducing the risks associated with brain surgeries. Thus, the incorporation of imaging technology across surgical specialties not only enhances individual procedural outcomes but also aligns with broader healthcare goals of interdisciplinary collaboration and improved patient-centered care [5].

However, the implementation of these technologies in the OR does not come without challenges. Integrating imaging devices requires significant investment in both equipment and training, and it necessitates a shift in the surgical workflow. Hospitals and surgical centers must consider the logistical implications of introducing new devices, such as the need for additional space, the integration of digital systems, and the training required for surgical teams. Furthermore, there are ethical and regulatory considerations, particularly regarding patient safety and the management of image data [6].

An exploration of the integration of imaging devices into modern operating rooms is thus timely and necessary. It necessitates a comprehensive review of current literature to assess the impact of imaging technology on surgical outcomes while mapping out the future trajectory of surgical innovation. This research aims to synthesize existing knowledge, identify gaps in the literature, and propose an evidence-based framework for the optimal implementation of imaging technologies in surgical practice. Ultimately, this inquiry seeks to contribute to the ongoing dialogue about enhancing surgical outcomes through cutting-edge solutions, thereby advancing the field of surgery and improving patient care in the ever-evolving landscape of healthcare [7].

Types of Imaging Devices Utilized in Operating Rooms

The major types of imaging devices commonly utilized in operating rooms include fluoroscopy, ultrasound, computed tomography (CT), and magnetic resonance imaging (MRI). Each of these technologies has distinct characteristics, benefits, and limitations that underscore their roles in contemporary surgical protocols [3].

Fluoroscopy

Fluoroscopy is a dynamic imaging technique that provides real-time visualization of internal structures using X-rays. This technology is invaluable for a variety of procedures, particularly those involving the gastrointestinal tract, vascular systems, and orthopedic surgeries. In fluoroscopy, continuous X-ray beams are directed toward the area of interest, while a fluorescent screen or digital detector captures the transmitted images. Surgeons rely on fluoroscopy to guide catheter placements in interventional radiology and to assess the dynamics of joint movement or bowel function [8].

Advantages: The primary advantage of fluoroscopy is its ability to provide real-time, continuous imaging, allowing for immediate assessment of changes during surgical procedures. This can significantly enhance the accuracy of interventions such as guided injections or the placement of stents and other devices. Moreover, the portable nature of fluoroscopic units enables their use in various surgical environments [9].

Limitations: Despite its strengths, fluoroscopy is not without drawbacks. The use of ionizing radiation poses risks to both patients and medical staff, necessitating stringent safety protocols and protective measures. Additionally, fluoroscopy may have limited soft tissue contrast capabilities compared to other imaging modalities, making it less effective in visualizing certain anatomical structures [10].

Ultrasound

Ultrasound imaging employs high-frequency sound waves to generate images of internal organs and structures, making it an essential tool in various surgical procedures. Unlike fluoroscopy, ultrasound is non-invasive and does not use ionizing radiation. This imaging technique is commonly used in general surgery, obstetrics, and gynecology, as well as in vascular and cardiac assessments [11].

Advantages: One of the primary advantages of ultrasound is its portability and real-time imaging capabilities, which allow surgeons to make immediate decisions during procedures. Ultrasound can also provide excellent soft tissue contrast, making it effective for guiding needle aspirations and biopsies. The absence of radiation exposure further enhances its safety profile, particularly in sensitive populations such as pregnant women and children [12].

Limitations: However, ultrasound imaging is not without its limitations. Its effectiveness is heavily dependent on the anatomical location of the structures being imaged, as well as the skills of the operator. Additionally, ultrasound waves do not penetrate bone or air-filled structures well, which limits its utility in certain areas, such as in the imaging of brain tumors or lung pathology [11].

Computed Tomography (CT)

CT scanning utilizes a series of X-ray images taken from different angles and processed to create cross-sectional images of the body. In the operating room, CT is primarily used for preoperative planning or intraoperative navigation in complex cases. For instance, in neurosurgery or orthopedic procedures, CT images assist surgeons in visualizing the anatomy in three dimensions, ensuring accurate positioning and planning [13].

Advantages: The most significant benefit of CT imaging is its high resolution and ability to generate detailed cross-sectional images. This precision is vital for planning complex surgical interventions, particularly in trauma cases where anatomical clarity is essential. CT can also rapidly provide images in emergencies, allowing quick diagnosis and response [14].

Limitations: Despite its capabilities, CT imaging comes with considerable disadvantages. The exposure to ionizing radiation is a primary concern, especially given the cumulative effects of repeated imaging. The process of performing a CT scan can also be time-consuming, which can pose challenges in time-sensitive surgical situations. Furthermore, CT's reliance on contrast agents may lead to complications or allergic reactions in some patients [15].

Magnetic Resonance Imaging (MRI)

MRI uses powerful magnets and radio waves to produce detailed images of organs and tissues within the body, making it particularly useful for evaluating soft tissue structures. While traditionally not used in the operating room due to its size and the magnetic field it generates, intraoperative MRI (iMRI) has been developed to provide real-time imaging capabilities during surgery, primarily in neurosurgical and orthopedic applications [12].

Advantages: The major advantage of MRI is its exceptional soft tissue contrast, which allows for detailed visualization of structures such as brain tissue, muscles, and ligaments. iMRI further enhances surgical accuracy by providing immediate feedback, allowing surgeons to identify critical anatomical boundaries and assess the completeness of tumor resection, for instance [14].

Limitations: However, the use of MRI in the OR is limited by several factors. The size and cost of MRI machines can be prohibitive, and the long acquisition times can affect surgical schedules. Additionally, the presence of metal instruments and implants can cause artifacts, complicating image interpretation. Moreover, the requirement for a strong magnetic field makes MRI unsuitable for certain patients with implanted medical devices [16].

Real-Time Imaging: Enhancing Surgical Precision

Real-time imaging refers to the ability to visualize internal structures and physiological processes as they occur, providing immediate feedback during surgical procedures. Unlike traditional imaging techniques, which often require preoperative scans or delayed interpretations, real-time imaging allows surgeons to make informed decisions based on current anatomical and functional data. This capability is facilitated by various imaging modalities, including ultrasound, fluoroscopy, magnetic resonance imaging (MRI), and computed tomography (CT), each offering unique advantages in different surgical contexts [12].

Ultrasound Imaging

Ultrasound is one of the most widely used real-time imaging modalities in surgery. It employs high-frequency sound waves to create images of soft tissues, allowing surgeons to visualize organs, blood vessels, and other structures in real-time. The advantages of ultrasound include its portability, lack of ionizing radiation, and the ability to provide dynamic images of physiological processes. For instance, in laparoscopic surgeries, ultrasound can guide the surgeon in identifying and avoiding critical structures, such as blood vessels and nerves, thereby minimizing the risk of complications [17].

Fluoroscopy

Fluoroscopy is another essential real-time imaging technique, particularly in orthopedic and interventional radiology procedures. It utilizes X-rays to produce live images of the body's internal structures, enabling surgeons to observe the movement of instruments and the positioning of implants during operations. This is particularly beneficial in procedures such as spinal surgery, where precise placement of screws and rods is critical for patient safety and surgical success. Fluoroscopy not only enhances the accuracy of these placements but also allows for immediate adjustments during the procedure, reducing the likelihood of postoperative complications [18].

Magnetic Resonance Imaging (MRI) and Computed Tomography (CT)

While MRI and CT are traditionally used for preoperative planning, advancements in technology have made it possible to utilize these modalities in real-time settings. Intraoperative MRI, for example, provides high-resolution images of the surgical field, allowing for continuous assessment of tumor resection margins in neurosurgery. This capability is crucial in ensuring complete removal of tumors while preserving surrounding healthy tissue. Similarly, intraoperative CT can aid in complex orthopedic surgeries by providing real-time feedback on bone alignment and implant positioning, significantly enhancing surgical precision [19].

Benefits of Real-Time Imaging in Surgery

The integration of real-time imaging into surgical practice offers numerous benefits that collectively enhance surgical precision and improve patient outcomes [17].

Improved Accuracy and Reduced Complications

One of the most significant advantages of real-time imaging is its ability to improve the accuracy of surgical interventions. By providing surgeons with immediate visual feedback, real-time imaging minimizes the chances of errors during critical stages of surgery. For example, in cardiac surgery, real-time imaging allows for the precise navigation of catheters and other instruments, significantly reducing the risk of damaging surrounding tissues and organs. Consequently, this heightened accuracy leads to fewer complications, shorter recovery times, and improved overall patient safety [20].

Enhanced Visualization of Complex Anatomy

Surgical procedures often involve navigating intricate anatomical structures, which can be challenging without adequate visualization. Real-time imaging provides surgeons with a detailed view of these structures, allowing them to make informed decisions during the operation. This is particularly important in procedures such as tumor resections, where the goal is to remove cancerous tissue while sparing healthy tissue. The ability to visualize blood vessels, nerves, and other critical structures in real-time enables surgeons to tailor their approach, reducing the risk of inadvertent damage and improving surgical outcomes [21].

Facilitating Minimally Invasive Techniques

The trend towards minimally invasive surgical techniques has gained momentum in recent years, driven by the desire to reduce patient trauma and promote quicker recovery. Real-time imaging plays a pivotal role in facilitating these techniques. For instance, in laparoscopic surgeries, ultrasound and fluoroscopy can guide the placement of instruments through small incisions, allowing for precise manipulation of tissues without the need for large openings. This not only minimizes scarring but also reduces postoperative pain and the risk of infections, ultimately leading to faster recovery times for patients [22].

Real-Time Decision Making

The dynamic nature of surgical procedures often requires surgeons to make quick decisions based on the evolving situation in the operating room. Real-time imaging provides the necessary information to support these decisions, allowing for immediate adjustments to surgical plans. For example, if unexpected bleeding occurs during surgery, real-time imaging can help surgeons quickly locate the source and address it effectively. This adaptability is crucial in maintaining patient safety and ensuring successful surgical outcomes [23].

Training and Skill Development

Real-time imaging also serves as an invaluable educational tool for surgical training. By providing trainees with immediate visual feedback during procedures, real-time imaging enhances their understanding of anatomy and surgical techniques. This experiential learning fosters the development of essential skills, ultimately producing more competent and confident surgeons. Additionally, the integration of augmented reality (AR) and virtual reality (VR) technologies in conjunction with real-time imaging offers exciting possibilities for simulation-based training, further enhancing the educational experience for surgical residents [24].

Despite the numerous benefits of real-time imaging, challenges remain in its widespread adoption. The cost of advanced imaging technologies can be prohibitive, particularly for smaller healthcare facilities. Additionally, the need for specialized training to interpret and utilize real-time imaging effectively poses another barrier. However, ongoing research and technological advancements are likely to address these challenges, making real-time imaging more accessible and user-friendly [25].

Looking ahead, the future of real-time imaging in surgery appears promising. Innovations such as artificial intelligence (AI) and machine learning are poised to revolutionize the field by enhancing image analysis and providing predictive insights during surgical procedures. Furthermore, the integration of real-time imaging with robotic surgical systems may lead to even greater levels of precision and control in complex operations [26].

Impact on Surgical Outcomes and Patient Safety:

Reducing Complications through Enhanced Visualization

One of the most significant benefits of integrated imaging systems is their ability to reduce surgical complications. Traditional surgical techniques often rely on external imaging methods that may not provide sufficient detail or real-time feedback. In contrast, integrated imaging systems offer surgeons enhanced visualization of the surgical field, allowing them to identify and navigate critical structures with greater accuracy. For instance, in neurosurgery, integrated imaging can help surgeons avoid damaging vital neural pathways, thereby minimizing the risk of postoperative neurological deficits [27].

Moreover, integrated imaging systems facilitate the use of minimally invasive surgical techniques, which have been shown to reduce complications such as infection, bleeding, and prolonged recovery times. By providing real-time imaging during procedures, surgeons can perform operations with smaller incisions, leading to less trauma to surrounding tissues. This is particularly evident in laparoscopic surgeries, where integrated imaging systems enable surgeons to visualize internal organs and structures without the need for large incisions. As a result, patients experience less pain, reduced scarring, and a lower likelihood of complications associated with open surgical procedures [28].

Enhancing Recovery Times

In addition to reducing complications, integrated imaging systems significantly enhance recovery times for patients. The ability to visualize anatomical structures in real-time allows for more efficient surgeries, as surgeons can make informed decisions quickly and accurately. This efficiency translates into shorter operative times, which have been linked to improved postoperative outcomes. Studies have shown that reduced surgical duration correlates with lower rates of complications and faster recovery, as patients are exposed to less anesthesia and surgical stress [29].

Furthermore, integrated imaging systems contribute to more effective postoperative care. By enabling precise assessments of surgical sites through imaging, healthcare providers can monitor healing and identify potential complications early. For instance, in orthopedic surgeries, integrated imaging can be used to assess the alignment of implants, ensuring that any issues are addressed promptly, thus preventing complications such as implant failure or malunion. Early detection of problems allows for timely interventions, which can further enhance recovery and reduce the length of hospital stays [30].

Improving Patient Safety

Patient safety is a paramount concern in surgical care, and integrated imaging systems play a crucial role in enhancing safety protocols. The ability to visualize surgical fields in real-time reduces the likelihood of human error, which is a significant contributor to adverse events in surgery. By providing surgeons with accurate and detailed images, integrated imaging systems minimize the chances of misidentification of anatomical structures and ensure that surgical interventions are performed with precision [31].

Moreover, integrated imaging systems facilitate better communication and collaboration among surgical teams. The sharing of real-time imaging data allows for a more coordinated approach to patient care, as all team members can access the same information simultaneously. This collaborative environment fosters a culture of safety, where team members can actively engage in discussions about surgical strategies and potential risks. As a result, the likelihood of errors due to miscommunication is reduced, further enhancing patient safety [32].

Conclusion:

In conclusion, the integration of imaging devices in modern operating rooms is not merely a technological advancement; it is a significant leap towards more accurate, efficient, and patient-centered surgical practices. By harnessing the capabilities of advanced imaging technologies, we can anticipate a future of surgery that prioritizes safety, efficacy, and enhanced quality of life for patients globally. As we move forward, continued research and innovation will be paramount in maximizing the full potential of these transformative tools within the realm of surgery.

References:

1. Marescaux J, Diana M. Next step in minimally invasive surgery: hybrid image-guided surgery. Journal of Pediatric Surgery. 2015;50(1):30–6. doi: 10.1016/j.jpedsurg.2014.10.022.
2. Hsieh MJ, Wen CT, Fang HY, Wen YW, Lin CC, Chao YK. Learning curve of image-guided video-assisted thoracoscopic surgery for small pulmonary nodules: A prospective analysis of 30 initial patients. Journal of Thoracic and Cardiovascular Surgery. 2017;155(4):1825–32. doi: 10.1016/j.jtcvs.2017.11.079.
3. Terra RM, Andrade JR, Mariani AW, Garcia RG, Succi JE, Soares A, et al. Applications for a hybrid operating room in thoracic surgery: from multidisciplinary procedures to—image-guided video-assisted thoracoscopic surgery. Jornal brasileiro de pneumologia: publicacao oficial da Sociedade Brasileira de Pneumologia e Tisilogia. 2016;42(5):387–90. doi: 10.1590/S1806-37562015000000177.
4. Barstad RM, Fosse E, Vatne K, Andersen K, Tønnessen T-I, Svennevig JL, et al. Intraoperative angiography in minimally invasive direct coronary artery bypass grafting. The Annals of Thoracic Surgery. 1997;64(6):1835–9. doi: 10.1016/s0003-4975(97)01072-2.
5. Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. Ann Intern Med. 2018;169(7):467–73. doi: 10.7326/M18-0850.
6. Field ML, Sammut J, Kuduvalli M, Oo A, Rashid A. Hybrid theatres: nicety or necessity? J R Soc Med. 2009;102(3):92–7. doi: 10.1258/jrsm.2009.080390.
7. Richter PH, Gebhard F, Dehner C, Scola A. Accuracy of computer-assisted iliosacral screw placement using a hybrid operating room. Injury. 2015;47(2):402–7. doi: 10.1016/j.injury.2015.11.023.
8. Hertault A, Sobocinski J, Spear R, Azzaoui R, Delloye M, Fabre D, et al. What should we expect from the hybrid room? J Cardiovasc

Surg. 2017;58(2):264–9. doi: 10.23736/S0021-9509.16.09845-1.

9. Giménez M, Gallix B, Costamagna G, Vauthey JN, Moche M, Wakabayashi G, et al. Definitions of computer-assisted surgery and intervention, image-guided surgery and intervention, hybrid operating room, and guidance systems: strasbourg international consensus study. Annals of surgery open: perspectives of surgical history, education, and clinical approaches. 2020;1(2):e021. doi: 10.1097/as9.0000000000000021.
10. Marescaux J, Diana M. Next step in minimally invasive surgery: hybrid image-guided surgery. Journal of Pediatric Surgery. 2015;50(1):30–6. doi: 10.1016/j.jpedsurg.2014.10.022.
11. Hsieh MJ, Wen CT, Fang HY, Wen YW, Lin CC, Chao YK. Learning curve of image-guided video-assisted thoracoscopic surgery for small pulmonary nodules: A prospective analysis of 30 initial patients. Journal of Thoracic and Cardiovascular Surgery. 2017;155(4):1825–32. doi: 10.1016/j.jtcvs.2017.11.079.
12. Kinoshita T, Yamakawa K, Yoshimura J, Watanabe A, Matsumura Y, Ito K, et al. First clinical experiences of concurrent bleeding control and intracranial pressure monitoring using a hybrid emergency room system in patients with multiple injuries. World Journal of Emergency Surgery. 2018;13:56. doi: 10.1186/s13017-018-0218-x.
13. Yang SM, Ko WC, Lin MW, Hsu HH, Chan CY, Wu IH, et al. Image-guided thoracoscopic surgery with dye localization in a hybrid operating room. Journal of Thoracic Disease. 2016;8:S681–S9. doi: 10.21037/jtd.2016.09.55.
14. Liao CH, Chen WH, Lee CH, Shen SC, Tsuei YS. Treating cerebrovascular diseases in hybrid operating room equipped with a robotic angiographic fluoroscopy system: level of necessity and 5-year experiences. Acta Neurochirurgica. 2019;161(3):611–9. doi: 10.1007/s00701-018-3769-4.
15. Goudeketting SR, Heinen SGH, Unlu C, van den Heuvel DAF, de Vries J, van Strijen MJ, et al. Pros and Cons of 3D Image Fusion in Endovascular Aortic Repair: A Systematic Review and Meta-analysis. Journal of Endovascular Therapy. 2017;24(4):595–603. doi: 10.1177/1526602817708196.
16. Attigah N, Demirel S, Hakimi M, Bruijnen H, Schöffski O, Müller A, et al. Hybrid operating rooms versus conventional operating rooms: Economic comparisons in vascular surgery using the example of endovascular aneurysm repair. Chirurg. 2017;88(7):587–94. doi: 10.1007/s00104-017-0431-2.
17. Vogl TJ, Farshid P, Naguib NN, Zangos S. Thermal ablation therapies in patients with breast cancer liver metastases: a review. Eur Radiol. 2013;23:797–804.
18. Reijnen MM, Zeebregts CJ, Meijerink WJ. Future of operating rooms. Surg Technol Int. 2005;14:21–27.
19. Cirocchi R, Trastulli S, Boselli C, et al. Radiofrequency ablation in the treatment of liver metastases from colorectal cancer. Cochrane Database Syst Rev. 2012;6:CD006317.
20. Bharathan R, Aggarwal R, Darzi A. Operating room of the future. Best Pract Res Clin Obstet Gynaecol. 2013;27:311–322.
21. Chao YK, Fang HY, Wen YW, Hsieh MJ, Wen CT. Intraoperative computed tomography-guided pulmonary tumour localization: A thoracic surgeon’s learning curve. European Journal of Cardio-thoracic Surgery. 2018;55(3):421–6.
22. Steinbauer M, Katsargyris A, Greindl M, Topel I, Verhoeven E. Hybrid operation theatre in vascular surgery: Options and perspectives. Chirurg. 2013;84(12):1030–5. doi: 10.1007/s00104-013-2557-1.
23. Richter PH, Yarboro S, Kraus M, Gebhard F. One year orthopaedic trauma experience using an advanced interdisciplinary hybrid operating room. Injury. 2015;46:S129–S34. doi: 10.1016/S0020-1383(15)30032-2.
24. Schroeder C, Chung JM, Mitchell AB, Dillard TA, Radaelli AG, Schampaert S. Using the Hybrid Operating Room in Thoracic Surgery: A Paradigm Shift. Innovations. 2018;13(5):372–7. doi: 10.1097/IMI.0000000000000531.
25. Elmi-Terander A, Nachabe R, Skulason H, Pedersen K, Soderman M, Racadio J, et al. Feasibility and accuracy of thoracolumbar minimally invasive pedicle screw placement with augmented reality navigation technology. Spine. 2018;43(14):1018–23. doi: 10.1097/BRS.0000000000002502.

26. Kpodonu J. Hybrid cardiovascular suite: The operating room of the future. Journal of Cardiac Surgery. 2010;25(6):704–9. doi: 10.1111/j.1540-8191.2010.01111.x.
27. Lerisson E, Hertault A, Bianchini A, Azzaoui R, Haulon S, Sobocinski J. Value of cone beam volumetric tomography (CBVT) after endovascular exclusion of AAAs. Annals of Vascular Surgery. 2019;60:8.
28. Kageyama H, Yoshimura S, Uchida K, Iida T. Advantages and disadvantages of multi-axis intraoperative angiography unit for percutaneous pedicle screw placement in the lumbar spine. Neurologia Medico-Chirurgica. 2017;57(9):481–8. doi: 10.2176/nmc.oa.2017-0059.
29. Zimmermann A, Eckstein HH. Der gefäßchirurgische Hybrid-Operationssaal–Standard in der invasiven Versorgung von Gefäßkrankheiten. Zeitschrift für Gefäßmedizin. 2014;12(1):16–21.
30. Kopelman Y, Lanzafame RJ, Kopelman D. Trends in evolving technologies in the operating room of the future. *JSLS*. 2013;17(2):171-173. doi:10.4293/108680813X13693422522196
31. Hüfner T, Citak M, Imrecke J, Krettek C, Stübig T. Handling moderner Bildgebung in einem Hightech-Operationssaal [Handling modern imaging procedures in a high-tech operating room]. *Unfallchirurg*. 2012;115(3):220-225. doi:10.1007/s00113-012-2181-4
32. Bernardo A. The Changing Face of Technologically Integrated Neurosurgery: Today's High-Tech Operating Room. *World Neurosurg*. 2017;106:1001-1014. doi:10.1016/j.wneu.2017.06.15