

The role of biomedical engineers in enhancing patient care through efficient equipment management

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Abstract

This review explores the future directions and challenges biomedical engineers face as they navigate the rapidly evolving healthcare technology landscape. With the advent of emerging technologies such as artificial intelligence, robotics, and telemedicine, the role of biomedical engineers is expanding beyond traditional equipment management to include innovation, strategic planning, and data analysis. The review highlights the implications of these advancements for biomedical engineers, the challenges in adapting to new equipment and standards, and the evolving expectations of their role in improving patient care. It underscores the need for continuous education and developing new skill sets to effectively manage modern healthcare technology's complexities. The paper concludes by emphasizing biomedical engineers' critical role in integrating these technologies into healthcare systems to enhance patient outcomes.

Keywords: Biomedical Engineering; Emerging Technologies; Artificial Intelligence; Robotics; Telemedicine

1. Introduction

Biomedical engineers play a pivotal role in modern healthcare, bridging the gap between engineering and medicine to ensure that medical technology is effectively utilized in patient care. Their work spans various domains, from designing and developing new medical devices to ensuring the optimal performance of existing equipment. Integrating advanced medical technology into healthcare has significantly enhanced diagnostic and therapeutic capabilities, making the role of biomedical engineers more crucial than ever (Wankar et al., 2020; Yang, Karimi, Kaynak, & Yin, 2021).

Efficient management of medical equipment is a critical aspect of healthcare delivery. Medical devices, from simple diagnostic tools to complex imaging machines, are central to patient care. These devices must function correctly and be readily available to healthcare professionals to ensure accurate diagnosis and treatment. Poorly managed equipment can lead to delays in patient care, misdiagnoses, and even harm, underscoring the need for meticulous attention to equipment management (Dzobo, Adotey, Thomford, & Dzobo, 2020; Li & Carayon, 2021).

This paper explores how biomedical engineers enhance patient care through efficient equipment management. It discusses best practices in installing, maintaining, and repairing medical devices, highlighting how reduced equipment downtime can improve patient outcomes. Additionally, the paper emphasizes the importance of continuous training and professional development for biomedical engineers, ensuring they remain at the forefront of technological

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advancements. The following sections delve into the key responsibilities of biomedical engineers, the impact of their work on patient care, the importance of continuous education, and the challenges and future directions of the field.

2. Key Responsibilities of Biomedical Engineers in Equipment Management

Biomedical engineers are critical in the healthcare industry, particularly medical equipment management. Their expertise ensures that medical devices are properly installed, maintained, and repaired, essential for the smooth operation of healthcare facilities and the delivery of high-quality patient care. These responsibilities are multifaceted and require a deep understanding of engineering principles and clinical applications. In this section, we will explore the key responsibilities of biomedical engineers in equipment management, focusing on the installation and setup of medical devices, routine maintenance and calibration, and troubleshooting and repair.

2.1. Installation and Setup of Medical Devices

The installation and setup of medical devices are among biomedical engineers' first and most crucial responsibilities. This process involves more than just assembling and placing equipment in a healthcare facility. It requires careful planning, coordination, and an understanding of the specific needs of the medical staff using the equipment. During the installation phase, biomedical engineers must ensure that all device components are correctly assembled and that the device is integrated with other systems within the healthcare facility. For example, many medical devices must be connected to hospital networks, including electronic health record (EHR) systems, to ensure seamless data exchange. This integration is vital for maintaining accurate patient records and enabling healthcare providers to make informed decisions based on real-time data (Dwivedi, Mehrotra, & Chandra, 2022).

Moreover, engineers must verify that the installation site meets all requirements, such as electrical power, environmental conditions, and spatial considerations. Some medical devices, like imaging systems or surgical robots, may require specific room modifications to function optimally. Biomedical engineers are responsible for ensuring that these requirements are met and that the device is positioned to maximize its effectiveness while ensuring patients and healthcare providers' safety and comfort.

After installation, engineers conduct rigorous testing to ensure the device functions as intended. This includes running diagnostic tests, verifying that the device meets manufacturer specifications, and ensuring it complies with relevant safety standards and regulations. Only after passing these tests can the device be approved for clinical use. The thoroughness of this process is critical, as any errors or oversights during installation can lead to malfunctions, which could jeopardize patient safety and lead to costly repairs or replacements (Jaleel, Mahmood, Hassan, Bano, & Khurshid, 2020).

2.2. Routine Maintenance and Calibration

Once medical devices are installed and operational, routine maintenance and calibration become the next major responsibility of biomedical engineers. Maintenance is essential to ensure that devices operate efficiently and safely over time. This involves regular inspections, cleaning, part replacements, software updates, and other preventive measures designed to extend the life of the equipment and prevent unexpected failures.

Routine maintenance schedules are typically established based on the manufacturer's recommendations and the specific usage patterns of the device. Biomedical engineers must adhere to these schedules rigorously, as even minor lapses in maintenance can lead to significant issues. For instance, a ventilator that has not been properly maintained might fail during a critical moment, putting a patient's life at risk. To avoid such scenarios, engineers must ensure that all devices are maintained according to the highest standards.

Calibration is another crucial aspect of equipment management that directly impacts the accuracy and reliability of medical devices. Calibration involves adjusting the device's settings to ensure that it provides accurate readings and functions as intended. This is particularly important for diagnostic equipment, such as blood glucose monitors, blood pressure machines, and imaging devices, where precision is critical.

Biomedical engineers use specialized tools and procedures to calibrate medical devices, following manufacturer guidelines and industry standards. Calibration must be performed regularly after any repairs or part replacements to ensure the device remains accurate. Inaccurate equipment can lead to misdiagnoses or incorrect treatment decisions, severely affecting patients. Therefore, engineers must be meticulous in their calibration efforts, documenting each step to ensure traceability and compliance with regulatory requirements (Alsaab & Alsaab, 2023; Demir, Gunduz, Kayikci, & Paksoy, 2023).

2.3. Troubleshooting and Repair

Despite the best efforts to maintain and calibrate equipment, medical devices may still experience malfunctions or breakdowns. When this occurs, biomedical engineers are responsible for troubleshooting and repairing the equipment as quickly and efficiently as possible. This aspect of their role is particularly challenging, as it often involves working under pressure in high-stakes environments where time is of the essence. Troubleshooting is diagnosing the root cause of a problem with a device. Biomedical engineers must have a deep understanding of their equipment and the ability to interpret error codes, read schematics, and use diagnostic tools to identify issues. Troubleshooting can involve hardware and software components, and engineers must be skilled in both areas to effectively resolve problems (Karthick, Ramkumar, Akram, & Kumar, 2021).

Once the issue has been diagnosed, engineers move on to the repair phase. This may involve replacing faulty components, updating software, or making mechanical adjustments to the device. In some cases, repairs can be completed on-site; in others, the equipment may need to be returned to the manufacturer or a specialized repair facility. Biomedical engineers must make quick and accurate decisions about the best course of action to minimize downtime and ensure that the device is returned to service as soon as possible (Ulloa, 2021).

In addition to technical skills, effective communication is essential during troubleshooting and repair. Biomedical engineers must often work closely with healthcare providers to understand the symptoms of the problem and explain the steps they are taking to resolve it. Clear communication helps to manage expectations and ensures that all stakeholders are informed about the status of the equipment. Timely repairs are critical in healthcare settings, where delays can seriously affect patient care. For example, suppose a critical piece of equipment like a defibrillator or an anesthesia machine is out of service. In that case, it can disrupt procedures and put patients at risk. Biomedical engineers must prioritize urgent repairs and have contingency plans to address equipment failures quickly (Nova, Rahman, & Hosen, 2022).

3. Impact of Equipment Management on Patient Care

3.1. Reducing Equipment Downtime and Improving Patient Outcomes

One of the most significant impacts of effective equipment management is the reduction of equipment downtime. Downtime refers to when medical devices are unavailable for use due to maintenance, repair, or other issues. In a healthcare setting, prolonged equipment downtime can have severe consequences, including delays in diagnosis, treatment, and potentially life-saving interventions. For example, consider a scenario where a hospital's MRI machine is out of service for an extended period. This situation could lead to delays in diagnosing critical conditions such as tumors, strokes, or internal injuries. Patients may experience prolonged suffering, and in some cases, their conditions could worsen due to the delay. Effective equipment management ensures that such scenarios are minimized by maintaining devices in optimal working condition and addressing any issues promptly.

Biomedical engineers are crucial in reducing equipment downtime by implementing preventive maintenance programs. These programs involve regular inspections, calibrations, and minor repairs to prevent major breakdowns. By identifying potential issues early, engineers can address them before they lead to significant downtime. This proactive approach extends the lifespan of medical devices. It ensures that they are available when needed, thereby improving patient outcomes.

Moreover, reducing equipment downtime contributes to the overall efficiency of healthcare delivery. When devices are readily available and functional, healthcare providers can perform their duties without unnecessary interruptions. This leads to shorter wait times, faster diagnosis, and timely treatment, contributing to better patient outcomes. In emergencies, where every minute counts, having reliable equipment can be the difference between life and death. Thus, the work of biomedical engineers in minimizing downtime is directly linked to the quality of patient care (Dzobo et al., 2020; Wang & Alexander, 2020).

3.2. Ensuring Safety and Compliance with Medical Standards

Patient safety is paramount in healthcare, and proper medical equipment management is essential to ensuring this safety. Medical devices are subject to stringent regulations and standards to ensure safety. These standards are set by regulatory bodies such as the U.S. Food and Drug Administration (FDA), the International Organization for Standardization (ISO), and other national and international organizations. Biomedical engineers ensure that all medical devices in a healthcare facility comply with these standards (Elahi, 2021).

Compliance with safety standards begins with the correct installation and setup of medical devices. Biomedical engineers must ensure that all devices are installed according to the manufacturer's specifications and integrated into the hospital's systems without compromising safety (Sastri, 2021). For example, radiation devices, such as X-ray machines, must be installed in specially shielded rooms to protect patients and healthcare workers from unnecessary exposure. Engineers must also verify that the device's software is current and includes all necessary safety features, such as alarms and fail-safes (Miclăuș et al., 2020).

In addition to installation, biomedical engineers are responsible for ongoing equipment monitoring to ensure it remains safe. This includes regular safety inspections, calibrations, and testing of safety features. For instance, defibrillators must be tested regularly to ensure they deliver the correct electrical energy to the patient. Any deviation from the required specifications could result in ineffective treatment or harm to the patient. By maintaining rigorous safety protocols, biomedical engineers help prevent such incidents and ensure all equipment functions as intended (Badnjevic, 2023).

Ensuring compliance with medical standards also involves keeping detailed records of all maintenance, repairs, and inspections. These records are essential for demonstrating compliance during audits and inspections by regulatory bodies. They also provide a history of the device's performance, which can be useful in identifying recurring issues or trends that may indicate a need for more frequent maintenance or replacement (Brauer, 2022). By maintaining accurate and up-to-date records, biomedical engineers help healthcare facilities avoid legal and regulatory issues arising from non-compliance. Furthermore, the role of biomedical engineers in ensuring safety and compliance extends to training healthcare staff on the proper use of medical devices. Even the most advanced equipment can pose risks if used incorrectly. Engineers provide training sessions to ensure all users know the device's operation, safety features, and potential risks. This training is crucial for preventing user errors that could compromise patient safety (Aronson, Heneghan, & Ferner, 2020).

3.3. Enhancing the Efficiency of Healthcare Delivery

Efficiency in healthcare delivery is essential for providing high-quality patient care while managing costs. Biomedical engineers' efficient management of medical equipment contributes significantly to this goal. When medical devices are properly maintained and available when needed, healthcare providers can perform their duties more effectively, leading to better patient outcomes and a more streamlined healthcare process.

One way biomedical engineers enhance efficiency is by optimizing the use of medical equipment. This involves ensuring that devices are utilized to their full potential without overloading or allowing them to become underutilized. For example, engineers might schedule their use in a large hospital with multiple imaging devices to ensure that each device is used regularly but not excessively. This helps prevent wear and tear from overuse while ensuring all devices remain in good working order.

Biomedical engineers are often involved in selecting and procuring new medical devices. Their expertise allows them to assess the healthcare facility's needs and recommend equipment to enhance efficiency. This includes evaluating the total cost of ownership, including maintenance and operational costs, to ensure that the device is a worthwhile investment. By selecting the right equipment, engineers help healthcare facilities avoid unnecessary expenses and ensure they have the tools to provide the best possible care (Dzobo et al., 2020).

The efficient management of medical equipment also reduces the likelihood of equipment-related delays in patient care. For example, suppose a ventilator is out of service due to a maintenance issue. In that case, it can disrupt the treatment of critically ill patients. By keeping equipment in good working order and addressing issues promptly, biomedical engineers help to ensure that healthcare providers have the tools they need to deliver care without unnecessary interruptions. This contributes to a smoother workflow within the healthcare facility and a better overall patient experience (Sastri, 2021; Thapa & Camtepe, 2021). Moreover, efficient equipment management can lead to cost savings for healthcare facilities. Well-maintained equipment has a longer lifespan, reducing the need for frequent replacements and the associated costs. Additionally, by preventing equipment failures and the associated downtime, engineers help to avoid the costs of emergency repairs or rental equipment. These savings can be reinvested in other areas of the healthcare facility, further enhancing patient care quality (Karthick et al., 2021).

4. Continuous Training and Professional Development

4.1. Importance of Staying Updated with Technological Advancements

Technological advancements in medical equipment occur rapidly, driven by innovations in materials science, electronics, software, and biotechnology. These advancements result in the development of more sophisticated medical devices, such as advanced imaging systems, robotic surgical tools, and artificial intelligence (AI)-driven diagnostic equipment. For biomedical engineers, staying abreast of these advancements is crucial to maintaining their expertise and ensuring safe and effective management of medical equipment.

One of the primary reasons for continuous learning is the introduction of new technologies that can drastically change how medical devices operate. For instance, integrating AI and machine learning algorithms into diagnostic tools has revolutionized areas such as radiology and pathology. Biomedical engineers must understand how these technologies work, how they are implemented in devices, and how to troubleshoot possible issues. Without continuous learning, an engineer's knowledge can quickly become outdated, compromising their ability to manage modern equipment effectively.

Moreover, staying updated with technological advancements allows biomedical engineers to anticipate and prepare for future trends in healthcare technology. For example, the growing field of telemedicine has led to the development of remote monitoring devices and other technologies that enable healthcare providers to deliver care from a distance. Engineers knowledgeable about these trends can help healthcare organizations adopt and integrate new technologies more smoothly, ultimately improving patient care. In addition, continuous learning enables biomedical engineers to contribute to innovation. By staying informed about the latest developments, engineers can identify gaps in existing technologies and propose new solutions or improvements. This proactive approach not only enhances their careers but also contributes to advancing the healthcare industry (Dwivedi et al., 2022; Nova et al., 2022).

4.2. Role of Certifications and Specialized Training

Certifications and specialized training play a critical role in the professional development of biomedical engineers. These credentials formally recognize an engineer's expertise in specific areas of biomedical engineering and can significantly enhance their career prospects. In a field where technological expertise is paramount, certifications allow engineers to demonstrate their competence and commitment to continuous learning.

Several certifications are available to biomedical engineers, each focusing on different aspects of the field. For example, the Certified Biomedical Equipment Technician (CBET) certification, offered by the Association for the Advancement of Medical Instrumentation (AAMI), is a widely recognized credential that covers the maintenance, repair, and management of medical devices. This certification requires a rigorous exam that tests an engineer's knowledge of various biomedical technologies, safety protocols, and regulatory standards. Holding a CBET certification can open doors to advanced career opportunities and is often a requirement for higher-level positions in healthcare facilities (Kermit & Upendra, 2020).

In addition to general certifications, specialized training programs allow biomedical engineers to gain expertise in specific technologies or areas of practice. For example, training programs focused on imaging technologies, such as MRI or CT scanners, provide engineers with in-depth knowledge of these complex systems. This specialized knowledge is essential for engineers who manage high-tech equipment, enabling them to handle advanced troubleshooting, calibration, and maintenance tasks beyond basic technical skills (Hertz, 2020).

Specialized training is also crucial for staying compliant with regulatory requirements. Medical devices are subject to strict regulations to ensure they are safe. Biomedical engineers must be familiar with these regulations and how they apply to the devices they manage. Training programs often include modules on regulatory compliance, helping engineers understand the legal and safety standards they must adhere to. This knowledge is particularly important in areas where technology and patient safety intersect, such as managing life-support systems or radiation-emitting devices (Sastri, 2021).

Furthermore, certifications and specialized training programs often include continuing education components that require engineers to stay updated with the latest advancements in their field. This ensures that certified professionals maintain their competence over time and continue to provide high-quality service in their roles. Employers also benefit from having certified and well-trained engineers on staff, as it enhances the overall quality of care provided in their facilities (Palomino-Valles, Tokumori-Wong, Castro-Rangel, Raymundo-Ibañez, & Dominguez, 2020).

4.3. The Impact of Training on Biomedical Engineering Practice

The impact of continuous training and professional development on biomedical engineering practice is profound. Engineers who actively engage in ongoing education are better equipped to manage the complexities of modern medical equipment, contribute to the innovation of new technologies, and ensure the highest standards of patient care. One significant impact of continuous training is the ability to reduce equipment downtime and improve reliability. Engineers who are well-trained and up-to-date with the latest technologies are more effective in diagnosing and resolving issues with medical devices. This reduces the time equipment spends out of service, ensuring it is available when needed and minimizing disruptions to patient care (Al-Duais, Mohamed, Jawa, & Sayed-Ahmed, 2022).

Training also enhances the safety and compliance of medical equipment management. Engineers knowledgeable about the latest safety protocols and regulatory requirements are better able to ensure that devices meet all necessary standards. This protects patients from potential harm and shields healthcare facilities from legal and regulatory risks (Gadde & Kalli, 2020). Moreover, continuous training fosters a culture of excellence and innovation within healthcare organizations. Engineers who pursue advanced certifications and specialized training are often more motivated and engaged in their work. This leads to higher job satisfaction, improved performance, and a greater willingness to take on challenging projects. These engineers are also more likely to contribute to developing new technologies and processes, driving innovation within their organizations (Smith & Simpson, 2020).

5. Future Directions and Challenges

5.1. Emerging Technologies and Their Implications for Biomedical Engineers

As technology advances, biomedical engineers are increasingly required to integrate and manage cutting-edge medical devices. Emerging technologies such as artificial intelligence (AI), robotics, and telemedicine are rapidly becoming integral to healthcare delivery. AI-driven diagnostic tools, for example, are revolutionizing how diseases are detected and treated by providing faster and more accurate analyses. Robotics enhances surgical precision, allowing for minimally invasive procedures with quicker recovery times. Additionally, telemedicine has expanded access to healthcare by enabling remote monitoring and consultations, especially in underserved areas.

For biomedical engineers, these technologies represent a significant shift in the types of equipment they must manage and maintain. The complexity of AI and robotics requires engineers to possess traditional technical skills and an understanding of software algorithms and machine learning principles. Telemedicine devices, which rely heavily on data security and network reliability, also demand new cybersecurity and information technology skills. As these technologies evolve, biomedical engineers must adapt to remain effective.

5.2. Challenges in Adapting to New Equipment and Standards

The rapid pace of technological advancement presents several challenges for biomedical engineers. One of the most pressing issues is the need to continuously update their knowledge and skills to keep up with new equipment and standards. As medical devices become more sophisticated, the learning curve associated with their management and maintenance steepens. Engineers must invest time in continuous education and training to stay proficient in the latest technologies. This can be a significant challenge, particularly for those already balancing demanding workloads.

Another challenge lies in the integration of new technologies with existing healthcare infrastructure. Often, new devices must be compatible with older systems, which can lead to compatibility issues and require additional customization. Engineers must ensure that these integrations are seamless to avoid disruptions in patient care. Moreover, introducing new standards and regulations, particularly those related to safety and data privacy, adds another layer of complexity. Biomedical engineers must navigate these regulatory changes while ensuring all devices comply with the latest requirements.

Resource limitations in many healthcare facilities further exacerbate these challenges. Budget constraints may prevent the acquisition of the latest technologies or limit access to specialized training programs. In such environments, engineers must find creative solutions to maintain and optimize existing equipment while preparing to adopt new technologies.

5.3. The Evolving Role of Biomedical Engineers in Healthcare

As healthcare technology advances, the role of biomedical engineers is evolving beyond traditional equipment management. Biomedical engineers are increasingly involved in strategically planning and implementing new

technologies within healthcare facilities. They are expected to work closely with clinicians, IT professionals, and hospital administrators to identify technological solutions to improve patient care and operational efficiency.

In addition to their technical expertise, biomedical engineers act as innovators and problem solvers. They are often called upon to develop new devices or modify existing ones to meet specific clinical needs. This shift towards innovation requires a deeper understanding of the clinical environment and the ability to collaborate with medical professionals to design user-friendly and effective solutions. Furthermore, the emphasis on data-driven healthcare pushes biomedical engineers to engage with big data and analytics. The ability to analyze and interpret data from medical devices is becoming increasingly important, particularly as healthcare moves towards personalized medicine. Biomedical engineers must develop data management and analysis skills to contribute meaningfully to this aspect of healthcare.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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