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REVIEW

Mid-Term Management of Operating Room Equipment: Improving Surgical Quality

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Abstract: This study focuses on the mid-term management theory of equipment lifecycle and systematically examines the impact of operating room instrument management on operational efficiency optimization. The review mainly covers four key aspects: operator training, information technology application, cost control, and quality assurance. The results indicate that mid-term management plays a crucial role in the full lifecycle management of operating room equipment and plays a key role in improving the quality of operating room operations. This management model is undergoing a profound transformation from experience driven to evidence-based practice, and from single control to system integration. Future research should focus on developing standardized evaluation metrics, scalable digital management platforms, and cross institutional data sharing models for optimizing the lifecycle of medical devices.

Keywords: operating room, instrument and equipment, mid-life cycle management theory, operational quality

As a key department with multidisciplinary collaboration and high resource investment within the hospital, the management of instruments and equipment in the operating room is directly related to surgical process efficiency, patient safety, and medical cost control. In 2021, the General Office of the State Council of China issued the "Opinions on Promoting the High-Quality Development of Public Hospitals",[1] which aims to promote the transformation of public hospitals from scale expansion to quality and efficiency improvement, from extensive management to refined management, and strengthen technological and management innovation. At present, the management of operating room equipment mainly faces three severe challenges: firstly, equipment operation is becoming increasingly complex. Taking the Da Vinci surgical robot as an example, its operation instructions exceed 200, which puts higher demands on the technical level of nursing staff; Secondly, the frequency and load of equipment usage continue to increase; Finally, quality control standards are relatively outdated, traditional management models overly rely on empirical judgment, and lack scientific quantitative evaluation mechanisms.

The life cycle theory of medical equipment is currently widely used in the medical industry as a core equipment management model.[2–4] Its connotation is to manage all aspects of medical equipment comprehensively and reasonably, and according to the application for installation and acceptance, operation, use, and maintenance of instruments and equipment, it can be divided into pre -, mid -, and post management. Among them, the mid-term operation and maintenance stage, as the core link of the equipment lifecycle, has a significant impact on perioperative safety, optimized allocation of medical resources, and collaborative efficiency of medical teams in terms of management level,[5] and is closely related to the nursing work in the operating room. In addition, the theory of comprehensive equipment management emphasizes full staff management, so the management of operating room instruments and equipment should not be limited to the hospital equipment department but should also play the management role of nursing staff.

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In this context, the mid-term management of equipment is gradually shifting from passive maintenance to active prevention, and four core systems have been established: operation training, information management, cost optimization, and quality assurance. This review aims to systematically summarize the mid-term management strategies of surgical equipment in the operating room and analyze their practical implications in improving surgical quality, with a focus on training, cost-efficiency, risk management, and digital transformation.

Methodology

This review was conducted by searching peer-reviewed literature published from 2015 to 2024 using databases including PubMed, Web of Science, China National Knowledge Infrastructure, and Google Scholar. Keywords included "operating room equipment", "mid-term management", "surgical quality", and "medical device lifecycle". Priority was given to original studies and systematic reviews related to surgical equipment training, cost control, quality assurance, and information technology. Only English and Chinese articles were included.204 articles were preliminarily identified through keywords, and 131 duplicate articles were removed. After reading the literature titles and abstracts, 58 articles were excluded. After further reading the entire text, 43 articles were ultimately included.

Innovation in Standardized Training System

Training in the operation of surgical instruments is an important link in enhancing the professional capabilities of medical teams and ensuring the safety of surgeries. However, traditional training models seem inadequate in addressing complex clinical situations and sudden emergencies, urgently requiring a systematic reform. This reform is not only about improving operational skills, but also involves the cultivation of psychological qualities and the optimization of multi-disciplinary collaborative abilities, thereby providing comprehensive capability support for operating room nursing staff.

Breakthroughs in the Limitations of Traditional Training Models

Traditional operating room instrument training models often focus on the demonstration of operational procedures, neglecting the training of response capabilities under clinical emergencies. Research by Santos et al[5] indicates that in medical instrument safety incidents, the proportion caused by human error is much higher than that of instrument malfunctions. Through retrospective analysis and accident case tracking, it was found that incidents caused by improper operations or excessive psychological stress accounted for up to 60% among nursing staff and anesthesiologists using instruments, revealing a "skill-situation" disconnection in traditional training. On the other hand, this also highlights the importance of psychological resilience training in instrument management. Notably, in the operating room of Nanchang First Hospital in Jiangxi Province, Wan Qian et al[6] implemented a step-by-step training program and studied its application effects in the collaboration of thoracoscopic lung resection surgery in cardiothoracic surgery. The results showed that step-by-step teaching not only enhances the self-learning ability, operational accuracy, and instrument cleaning and maintenance skills of specialized nurses but also reduces the time for instrument assembly, positively impacting the operational efficiency of the operating room. However, its single-discipline orientation reveals inadequacies when facing multidisciplinary combined surgeries. In light of this, it is recommended to formulate standardized instrument operation training plans and introduce real simulation scenarios into the training to strengthen operational skills and improve psychological quality, effectively reducing the occurrence of human errors.

Technical Integration of Information Technology Training Tools

With the deepening development of medical informatization, the widespread application of QR code technology is gradually transforming the working model of operating room nursing staff. The study by Lifang Ma et al[7] pointed out that after using QR code electronic manuals for equipment management and training in the operating room, nursing staff had more positive evaluations on the use and operation of the equipment, and the time to find the equipment was significantly shortened, demonstrating the advantages compared to traditional training methods and confirming the practicality of QR code electronic manuals in optimizing equipment management and enhancing the effects of nursing training. Similarly, Shao Junfa[8] converted the training videos of electrosurgical instruments into QR codes and made them waterproof, pasting them on the free area of the instrument operation interface, and combined WeChat group for

learning and reporting. The results showed that the self-elimination rate of electrosurgical instrument failures in the experimental group was significantly higher than that in the control group ($\chi2=12.126$, $P<0.01$), effectively improving the operation level and fault handling ability of operating room nursing staff on electrosurgical instruments. The research by Chen Jun et al[9] further demonstrated the application of QR code recognition technology in precise equipment management, by storing equipment information in QR codes for management, and comparing the qualification rate and punctuality of equipment maintenance before and after application. The results showed: the qualification rate of operating room equipment maintenance increased from 67.35% before application to 94.90% ($\chi2=24.288$, $P<0.001$), and the punctuality rate increased from 76.53% to 93.88% ($\chi2=11.696$, $P<0.001$). However, relying solely on static QR code encoding technology makes it difficult to carry the dynamically updated clinical knowledge base, and the lack of adaptability of unidirectional information output mode to human-computer interaction further hinders the training effect.

Furthermore, virtual reality (VR) and augmented reality (AR) technologies are increasingly being applied to the training of complex devices, guiding instrument assembly through a three-dimensional visualization interface, significantly improving surgical efficiency. Currently, VR and AR technologies have achieved results in the standardized training of neurosurgery residents,[10] but caution is needed regarding the new risks that technology dependence might bring, such as the degradation of traditional operational skills. Additionally, the absence of tactile feedback systems may also lead to distortion in force perception, potentially causing unnecessary tissue damage during surgery. In the future, a mixed reality solution of "mechanical sensors + visual compensation" can be adopted: integrating micro-piezoelectric elements into force feedback gloves to capture operational force in real-time; simultaneously superimposing tissue deformation threshold prompts through the AR interface.

Construction of the Information Management System

Information management is an essential support for improving the operational quality of modern operating rooms, with its core being the establishment of a scientific and intelligent management system to achieve precise, standardized, and efficient instrument management. Currently, the informatization of operating room management has gradually become the development trend of mid-term instrument management.

Decision-making System for Intelligent Maintenance

With the rapid development of information technology, the management of operating room instruments is gradually transitioning from a traditional experience-driven model to a data-driven model. The core of this transformation lies in constructing an intelligent decision support system that covers the entire lifecycle of the instruments, thereby achieving real-time monitoring of the usage status of the instruments and comprehensive traceability of management information. Research by Sergeeva et al[11] indicates that through the means of information management, the traceability of instrument management can be significantly improved. This transformation is not only reflected in the improvement of management efficiency but also in the level of intelligent decision support. By building an intelligent decision support system that covers the entire lifecycle of the instruments, operating room managers can make scientific decisions based on real-time data, thereby effectively enhancing management efficacy. However, there are still some issues in existing research, such as the phenomenon of data islands between different systems, and the lack of standardization in the practical application of information management. Future research should focus more on how to build a more efficient and scalable information management system through technology integration and process optimization.

Total productive maintenance management (TnPM), as an advanced management system derived from the concept of total productive maintenance, is focused on reducing equipment failure rates, cutting operational costs and improving operational efficiency by controlling the entire lifecycle of the equipment. The TnPM system emphasizes the cooperation between equipment operators and managers, using scientific maintenance planning, standardized operating procedures, and real-time monitoring technology to maximize the utilization of the equipment.[12] Practice in laparoscopic equipment management by Wang Meng et al[13] has shown that the TnPM system can significantly improve equipment operation accuracy and reduce failure rates. The successful application of this system lies not only in its scientific maintenance planning and standardized operating procedures but also in the cooperative mechanism between equipment operators and managers. However, it is still necessary to solve the standardization issue of equipment data collection and the

sustainability issue of personnel training in order to fully exploit the potential of the TnPM system in practical applications.

The Full Process Traceability System of UDI Technology

Unique Device Identification (UDI) is an identification assigned to a device throughout its life cycle, possessing both uniqueness and traceability.[14] The UDI system architecture proposed by Natalia A. Wilson et al[15] tracks the entire life cycle of the device from procurement to operation and disposal by assigning a unique code to each device. This system can not only track the care information of patients during the use of the device, evaluate the condition of the device, provide data support for the iterative upgrade of the device, but also provide patients with detailed information on the devices used, effectively ensuring patient safety. Chen Beibei et al[16] relying on the national UDI system construction, created a medical consumables intelligent management solution based on UDI through software function design and management process optimization. This solution has realized the entire process management of medical consumables from production to use through the utilization of UDI and has built an intelligent management model of "one code connectivity, full-process scanning, precise tracing". Research results show that this management model has significantly improved the level of refined management of medical consumables, providing reference and learning for the application of UDI in medical institutions. Although the implementation of the UDI system helps bridge the management gap and enhances the health system's support in ensuring the safety and effectiveness of patients' use of devices. However, the comprehensive promotion of the UDI system still faces some challenges, such as the uniformity of coding standards, the cost of system implementation, and issues related to data privacy protection. Future research should pay more attention to how to solve these problems in practical applications, so as to promote the further popularization of the UDI system.

Inventory-Taking System of RFID Technology

Radio frequency identification (RFID) technology uses radio signals to achieve target identification and non-contact data reading and writing,[17] which has significant advantages in improving the accuracy of surgical instrument management. Lazzaro's team[18] developed an intelligent inventory system that embeds micro-RFID tags in surgical sponges and combines them with an automated system to achieve real-time and accurate counting of sponge numbers during surgery, ensuring 100% accuracy in tracking surgical residues. Zhang Fukang's team[19] used ultra-high frequency RFID technology to completely transform and shield the layout of the original warehouse in the operating room, and built an intelligent management system for operating room consumables based on RFID. This system covers four major functional modules: product warehousing, usage recording, inventory monitoring, and querying, and achieves the entire process management and traceability of high-value consumables. The research results show that after the application of the system, the incidence of adverse events in consumable management dropped to 2.9%, significantly lower than the 8.8% before the application ($\chi 2=31.601, P<0.001$), effectively promoting the refinement, standardization, and intelligent management process of high-value consumables in hospitals. The application of RFID technology also has some limitations, such as high tag costs and signal interference. Future research should focus more on how to further improve the application effect of RFID technology in operating room management through technological improvements and cost control.

Intelligent Scheduling System of AI Technology

The application of AI technology is innovating the risk management mode of medical devices. Runarsson[20] developed a surgery scheduling model based on neural network and probability constraints, which aims to solve the complex uncertainty factors involved in the surgery arrangement, such as operation duration, operation interval, surgeons' schedule, operating room occupation, ward capacity and expected number of patients, etc. The study optimized the surgery scheduling through a mixed integer programming method to achieve the optimal configuration of the daily plan of the operating room. Zhou Jing et al[21] also proposed a similar surgery scheduling optimization model. This study starts with the practical problem of "uneven resource utilization" faced by hospital operating rooms, and explores the method of building an intelligent surgical scheduling platform. The multi-stage surgical scheduling model constructed by this intelligent surgical scheduling platform supports medical teams to conduct two rounds of "grabbing orders", which can

fully utilize the spare resources in the operating room, improve the utilization rate of golden time, and reduce the average number of overtime operating rooms per day.

The Development Trend of the Information Management System

In summary, the synergy between information data and manual management is a key strategy for improving the operational efficiency of operating rooms. Through the application of informatization measures, the precision and traceability of operating room equipment management can be significantly enhanced, thereby providing strong support for the improvement of operating room operational quality. However, the comprehensive promotion of informatization management still faces some challenges, such as technology standardization, cost control, and data privacy protection. Future research should focus more on how to build a more efficient and scalable informatization management system through technology integration and process optimization. In addition, manual management still has an irreplaceable role in operating room operations. For example, the collaboration between equipment operators and managers, as well as standardized operating procedures and maintenance planning, are important guarantees for ensuring the efficient operation of equipment. Therefore, future operating room management should pay more attention to the organic combination of informatization means and manual management, and achieve a comprehensive improvement in the quality of operating room operations through the synergy between technology and management.

The Transformation of Economic Management Model and Value Creation

With the rapid development of medical technology and the increasing complexity of operating room equipment management, traditional economic management models have gradually revealed their limitations. The economic management of operating room instruments should not be limited to the control of procurement costs, but should focus on the systematic assessment and optimization of the entire lifecycle of the instruments.

Limitations and Breakthrough Directions of Traditional Management Model

The traditional economic management of surgical room instruments often focuses on the control of procurement costs,[22] overlooking potential losses in the use, maintenance, and disposal of the instruments. Zhou Mingshan[23] emphasizes that the traditional instrument management model lacks a clear economic and target responsibility system, making it difficult to effectively control the entire lifecycle cost of the instruments. The total lifecycle cost of the instruments not only includes purchase expenses but should also cover operation and maintenance, upkeep, depreciation, and residual value recovery. Therefore, establishing an economic management model centered on the entire lifecycle cost is imperative. Liu Huiying[24] adopts the SPD model for refined management and operation of medical consumables. SPD mode refers to Supply Processing&Distribution, where Supply represents supply, Processing represents processing (or organization), and Distribution represents distribution. It is a supply chain optimization service that uses logistics information technology as a tool to centralize and integrate the supply, inventory, processing, and distribution of hospital materials (drugs, medical consumables), in order to improve the efficiency of medical material management and reduce costs. In this mode, the medical consumables supply chain is composed of an external supply chain and an internal supply chain that intersect. In the selection and procurement, acceptance and warehousing, storage and distribution, use and settlement of medical consumables, a refined management chain is established through logistics, information flow, and fund flow to connect medical consumables suppliers, instrument departments, clinical receiving departments, and patients. The SPD mode implements management of the entire process of medical consumables from purchase to final use consumption, truly achieving the goal of managing both materials and accounts, effectively eliminating the occurrence of adverse phenomena in extensive management, strengthening the sense of responsibility of departments and links, establishing a good management concept, and laying a solid management foundation for the sustainable and healthy development of the hospital.

The Application and Value Enhancement of RTLS

With the in-depth development of information technology, real-time positioning system (RTLS) is becoming an important tool for economical management of operating room devices. The research of Jason C. Troutner's team[25]

shows that the RTLS system can significantly improve the tracking efficiency and distribution timeliness of surgical instruments, thereby reducing the risk of infections and economic waste caused by improper instrument management. In the practice of Massachusetts General Hospital, the application of the RTLS system increased the quality compliance rate of instruments from 88.9% to 94.5%, and saved $17,350 in instrument management costs annually, not only effectively improving the efficiency of instrument management, but also optimizing the cost-effectiveness of the endoscopic sterilization process. The value of RTLS is not only reflected in cost savings, but more importantly, in its optimization of work efficiency. The research of YEOH C's team[26] shows that the deployment of RTLS system in operating rooms can monitor patient flow in real time, reduce the time nurses spend looking for instruments, and thus enhance their work efficiency. In addition, the combination of RTLS with mobile terminals also provides anesthesiologists with more efficient communication and data collection tools, further optimizing perioperative processes.[27] However, the widespread application of RTLS still faces challenges such as high technical costs and complex system integration. In the future, further exploration of its applicability in hospitals of different sizes is needed.

Innovation and Application of Data-Driven Decision System

Data-driven decision support systems are becoming a new impetus for economic management of operating room instruments. The study by Altalabi et al[28] shows that by applying stochastic dynamic programming to optimize the replacement strategy of medical instruments and based on predictions of the instrument's entire lifecycle status, usage demands, and maintenance costs, the hospital's economic cost can be significantly reduced, and operational efficiency enhanced. This model makes scientific decisions on the timing of replacement by predicting the instrument's entire lifecycle status, usage demands, and maintenance costs, avoiding resource waste caused by the arbitrariness of replacement timing in traditional models. Crosby L[29] and others also applied stochastic dynamic programming to optimize the replacement strategy of medical instruments, shortening the instrument processing time and operating room preparation time, reducing the medical costs for both patients and hospitals. Domestic scholar Hu Haiyang and others[30] further explored the application of dynamic programming theory in preventive maintenance and procurement update management of medical instruments. They pointed out that the dynamic programming model can achieve the goals of minimizing instrument operation consumption, maximizing operational efficiency, and scientifically managing. However, existing research is mostly focused on the construction of theoretical models, and practical applications still need to solve issues such as the completeness of data acquisition and dynamic adjustment of model parameters. In the future, artificial intelligence technology can be combined to develop more intelligent decision support systems to enhance the precision and efficiency of economic management.

Sharing and Value Creation of Medical Device Resources Under the Framework of Medical Consortium

Under the framework of the "Medical Consortium", medical equipment sharing has become an important model for improving resource allocation efficiency. At present, equipment sharing within the medical consortium is mainly realized through the technology sharing network dominated by core institutions, and the member units improve the utilization efficiency of large-scale equipment through information sharing and collaboration.[31] Zhang Le et al[32] took Hospital A as an example to explore how to build a sustainable equipment sharing resource center with the help of Internet of Things technology, and summarized the standardized process of building such a resource center in hospitals. They emphasized that breaking down departmental barriers and realizing the "de-departmentalization" of equipment ownership are the keys to the success of the sharing model. However, there are still some problems in the existing sharing model, such as the imperfection of the resource sharing mechanism, and the imbalance of benefit distribution among member units. In the future, it is necessary to further explore how to achieve dynamic optimization of resource sharing through data visualization and intelligent management platforms. In addition, it is also necessary to establish a more flexible benefit distribution mechanism to mobilize the enthusiasm of member units to participate in sharing, so as to truly maximize the benefits of resources.

Improvement and Promotion of Quality Control System

The quality management of operating room instruments is undergoing a transition from passive response to active prevention. In this process, the role of nursing staff in risk early warning and continuous quality optimization is becoming increasingly prominent. How to effectively implement quality control to ensure the safe and stable operation of instruments and achieve ideal surgical results is an important test of the capabilities of nursing staff and their management.

Risk Management: From Passive Response to Active Prevention

The theory of risk management originated from the field of enterprise management in the early 20th century, with its core principle being the systematic identification, assessment, and control of risks to minimize their impact on organizational objectives. In the management of surgical instruments in operating rooms, the application of risk management strategies is of significant importance. By early identifying and intervening in potential risks during the use of instruments, the rate of instrument failure can be effectively reduced, ensuring the smooth progress of surgeries.[33]

In recent years, scholars at home and abroad have conducted extensive research on risk management of operating room instruments. The team of Huang Fengyu[34] applied effective risk management strategies such as risk assessment, identification, and control in the study of Da Vinci robot management, prospectively identified high-risk links, and formulated corresponding measures to reduce the incidence of risks, achieving standardized management of instruments and ensuring that the operating room can obtain safe and effective Da Vinci robot surgical instruments in a timely manner to ensure the smooth progress of surgery. Li Jianmin et al[35] started from the perspective of risk management, divided hospital medical equipment management into groups according to clinical diagnosis and treatment needs, and established an information feedback mechanism to record instrument user information in detail, achieve tracking and traceability. This measure can quickly respond to and solve problems when they arise, effectively reduce the occurrence of instrument failures and adverse events in patients, improve the quality of instrument management, and ensure patient safety. The study of Yang Yidong[36] further explored the value of risk management in hospital medical device management. The results showed that after the implementation of risk management, the improvement of instrument management quality in the experimental group was significantly higher than that in the control group, and the incidence of instrument risk events was significantly lower than that in the control group ($P<0.05$). The study pointed out that risk management effectively controls risks and reduces their impact on instrument management by analyzing the possible risk factors in instrument management and formulating corresponding management systems, norms, and processes.

Despite the significant effectiveness of risk management in operating room instrument management, there are still many challenges faced in its implementation. For example, how to achieve comprehensive risk assessment under limited resources, and how to timely update risk control measures in complex and ever-changing clinical environments, both require further research and exploration.

Internal Control: From Individual Management to System Optimization

Internal control, as a systematic management method, its core lies in establishing a scientific control mechanism, which can achieve comprehensive and all-encompassing control over the entire process of instrument management in operating rooms.

In the 1990s, the American Anti-Fraudulent Financial Reporting Committee (COSO) issued the "Internal Control—Integrated Framework" report, which authoritatively defined internal control and proposed five major elements, including control environment, risk assessment, control activities, information communication, and monitoring. At the beginning of the 21st century, COSO released the "Enterprise Risk Management—Integrated Framework" marking the evolution of the internal control concept, emphasizing the importance of enterprise-wide risk identification and management, and the synergy between risk management and the internal control framework.[37,38] The internal control elements of operating room quality control align with the five major elements of the COSO framework. Yu Shuang et al[39] optimized the internal control process of operating room instruments based on the COSO internal control framework, significantly improving the standardization and precision of operating room instrument management, effectively reducing the risk of

instrument use, and enhancing surgical efficiency and patient satisfaction. However, there are still some issues in its implementation process, such as overly complex control processes and poor information communication. Future research can further explore how to simplify control processes while maintaining control effects and improving management efficiency.

Continuous Improvement: From Local Optimization to Overall Enhancement

Continuous Quality Improvement is a management approach centered on data-driven methods and the involvement of all members. Its application in operating room instrument management not only achieves optimization of local management but also promotes a comprehensive enhancement of the entire management system. Continuous Quality Improvement emphasizes the concept of full participation and end-to-end quality management. By innovatively applying quality improvement methods, it significantly optimizes management efficiency. Commonly used management tools include Quality Control Circles and the PDCA cycle.

Mi Shuli[40] and her team implemented Quality Control Circle activities in their hospital, focusing on the theme of "sterilization qualification rate and intact rate of operating room instruments." They implemented a system where specific individuals were responsible for detailed division of labor management of operating room instruments, improving the management system and strengthening supervision, and regularly carrying out learning, reporting, and summarizing. This measure not only optimized management effectiveness, ensuring the sterilization qualification rate and intact rate of surgical instruments, but also improved the satisfaction of doctors using them. Ji Xiaoman[41] combined the PDCA cycle with the "Five-S Method" and applied it to the management of operating room instruments, conducting regular assessments and implementing continuous improvements. Practice has shown that this method helps standardize the management of operating room instruments, ensuring the instrument intact rate and terminal disinfection rate, and extending the lifespan of the instruments. The study by Xia Shuyan[42] also shows that the implementation of the Quality Control Circle significantly reduced the failure rate of operating room instruments, enhancing team cohesion and management enthusiasm.

Evaluation System: From Single Index to Multi-Dimensional Assessment

The quality evaluation system of medical devices is shifting from a single safety index to multi-dimensional efficacy assessments. The team of Weng YiYi[43] strengthened the use management and quality control of medical devices in tertiary general hospitals. They used expert consultation, literature analysis, questionnaire survey, and gray multi-level evaluation methods comprehensively, established a medical device quality management evaluation index system, and allocated index weights, eventually forming a three-level hierarchical structure model that covers the entire life cycle management practice of medical devices. The research results show that in the evaluation of medical device quality control management in 2018 in six tertiary medical institutions, the procurement quality score is relatively high, while the use quality score is low. This indicates that the evaluation index system can be effectively applied to the quality control management assessment of medical devices in tertiary general hospitals. Wu WeiMin and his colleagues[44] constructed a similar medical device use quality evaluation index system in Guangxi Province. Through literature research and special group discussions, they initially formulated an evaluation index system for Guangxi medical institutions, then used the Delphi method for screening, and the expert scoring method to determine the weights of each level of indicators, ultimately establishing an evaluation system containing 12 first-level indicators, 32 second-level indicators, and 44 third-level indicators. This study also constructed a set of scientific, reasonable, and easy-to-operate medical device use quality evaluation systems. Although the existing evaluation system has played an important role in the quality management of medical devices, there are still some problems in its application process. For example, whether the design of evaluation indicators comprehensively covers all aspects of medical device management, whether the evaluation methods are scientific and reasonable, etc., all need further research and exploration.

Development Trends of Quality Control System

Based on the above research, the improvement and enhancement of the quality control system for operating room instruments in the future can start from the following aspects. Firstly, strengthen the systematic nature of risk

management: Based on existing research, further improve risk assessment and control processes, construct a multi-level, multi-dimensional risk management system to ensure that risks can be timely identified and effectively controlled. Secondly, optimize internal control processes: Based on the COSO framework, combined with the actual situation of operating room instrument management, further optimize internal control processes to enhance the standardization and precision of management. Additionally, construct a scientific evaluation system: On the basis of the existing evaluation index system, further improve evaluation indices and methods, build a multi-dimensional, dynamic evaluation system to provide a scientific basis for the quality management of operating room instruments.

Summary

Currently, the mid-term management of operating room instruments and equipment plays a crucial role in improving the quality of operating room operations. This management model is undergoing a profound transformation from experience driven to evidence-based practice, and from single control to system integration. The management of medical equipment in the operating room has certain practical significance (see Table 1).

However, there are still gaps in the long-term mechanisms of technical application, economic efficiency, and quality control in the mid-term management of medical equipment in operating rooms, which hinders the improvement of operating room operation quality. In terms of technical application, VR/AR training lacks interdisciplinary integration, cross system data fragmentation hinders full process traceability, and the application of information tools presents an isolated state; In terms of economic efficiency evaluation, there is an excessive reliance on theoretical deduction of the

Table 1 Systematic Analysis Framework for Mid-Term Management of Operating Room Medical Equipment

Dimension	Core Definition	Representative Technology/ Method	Key Research/ Findings	Core Advantages	Existing Limitations	Practical Significance
Training System Innovation	Enhancing instrument competency through contextualized and technology-driven approaches	Stepwise training[6] VR/AR technology[10] QR code manuals[7–9]	Human errors account for 60% of device incidents[5] Ladder teaching shortens assembly time and improves accuracy[6] The qualification rate of QR code maintenance has increased by 27.55%[9]	High-fidelity simulation improves crisis response Rapid knowledge access via digital tools 3D visualization shortens learning curves	Limited multidisciplinary adaptability[6] VR lacks haptic feedback[10] Static QR codes hinder knowledge updates[7]	Administrators: Establish cross-specialty simulation centers Teams: Engage in stress scenario drills Policymakers: Develop psychological resilience certification standards
Information Management Upgrade	Enabling end-to-end traceability and data-driven decisions via intelligent systems	UDI systems[15,16] RFID inventory[18,19] AI scheduling[20,21]	UDI improves the level of refined management[16] The RFID management event rate decreased by 5.9% (P<0.001)[19] AI scheduling improves the utilization of spare resources[21]	Full lifecycle traceability Real-time inventory monitoring Optimal OR resource allocation	System fragmentation[16,19] High RFID tag costs[18] Black-box AI algorithms[20]	Administrators: Build IoMT data integration platforms Teams: Standardize UDI scanning protocols Policymakers: Unify coding and privacy regulations
Economic Control Optimization	Maximizing resource value through lifecycle cost assessment and sharing models	RTLS tracking[25–27] Dynamic programming[28–30] Medical consortium sharing[31,32]	RTLS saves $17350 annually and increases compliance rate by 5.6%[26] Dynamic programming reduces economic costs[28] Sharing improves the utilization rate of large equipment[31]	Reduced idle resource costs Evidence-based replacement decisions Cost-sharing through collaboration	Accumulation of consumables[24] Complex RTLS integration[25] Unbalanced benefit distribution[32]	Administrators: Prioritize RTLS for high-value devices Policymakers: Design benefit-sharing contracts Teams: Contribute cost data collection
Quality Control Enhancement	Ensuring device safety/efficacy via risk prevention and continuous improvement	COSO framework[39] QCC/PDCA[40–42] Multidimensional evaluation[43,44]	The incidence of device risk events decreased (P<0.05)[36] Aseptic qualification rate of surgical instruments[40] The evaluation system exposes weaknesses in its use[43]	Proactive risk mitigation Staff-driven quality improvement Comprehensive performance monitoring	Resource-intensive assessments[34] Disconnected evaluation metrics[43] Sustainability challenges[40]	Administrators: Implement risk-stratified control Teams: Adopt role-integrated QC indicators Policymakers: Link reimbursement to QC outcomes

full life cycle cost, and there is a real-time interruption in the collection of clinical data. The verification of the benefits of technological investment is limited to individual cases; In terms of the long-term mechanism of quality control, there is an imbalance between the consumption of clinical risk management resources and clinical feasibility, evaluation indicators are detached from job time, and continuous quality improvement relies on administrative drive. These issues further constrain the improvement of operating room operation quality.

Outlook

Nursing staff, as the front-line subject of equipment use, are not only practitioners of management innovation, but also drivers of technological innovation. Future research should focus on developing standardized evaluation metrics, scalable digital management platforms, and cross institutional data sharing models for optimizing the lifecycle of medical devices. By establishing a standardized training system, intelligent management platform, lean cost control mode, and dynamic quality control mechanism, we aim to improve the operational quality of the operating room; It is also necessary to further adhere to patient safety as the center and nursing profession as the leading role, establish a balance between technological innovation and humanistic care, and ultimately achieve the synergistic improvement of equipment management quality and nursing professional value.

Disclosure

The authors report no conflicts of interest in this work.

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