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Implementation of Deep Learning Application for Emergency Maintenance of Medical Linear Accelerator

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Abstract

The purpose of this work is to improve the quality of medical services, to acquire financial benefits for hospitals, and to achieve beneficial social consequences. These are the goals and the motivations that are driving this work. Using the framework of deep learning, it studies the composition of medical linear accelerators, as well as their working principle, acceptance, and the routine quality assurance (QA) and quality control (QC) procedures. Additionally, it examines the acceptability of these applications. This article focuses on the acceptance items and detection procedures of accelerators, as well as common technological failures and solutions. In addition to providing a summary of emergency maintenance experience and analyzing the usual technical failures of medical electronic linear accelerators, it also provides an analysis of the common technical failures and solutions. Given that Chinese radiation institutions are already utilizing medical accelerators, the authors of this study analyze the relevant development state of medical electron linear accelerators as well as the future development trends of these accelerators. This is done in light of the fact that medical accelerators are currently being utilized by Chinese radiation institutes today. It provides further explanation on the unified implementation and refinement of its usage standards, in addition to providing information regarding conventional quality assurance and quality control. The findings provide a theoretical basis as well as a practical significance for the continued development of linear accelerators for use in medical applications in the future.

Keywords: Deep Learning, Emergency Maintenance, Medical Linear Accelerator, Quality Control.

Introduction

In the context of deep learning, radiation therapy plays a pivotal role in tumor treatment. With the advancement of science and technology, various advanced radiotherapy techniques have appeared (1). However, the development of various advanced radiotherapy techniques is inseparable from the support of radiotherapy equipment. Advanced radiotherapy techniques are only on paper without corresponding radiotherapy equipment (2). With the increasing incidence of tumors, radiation therapy, one of the three major tumor treatment methods, is also developing rapidly. Medical electron linear accelerators, as the main equipment for radiotherapy, have also undergone several generations of updates (3). The development of various new technologies in tumor radiation therapy has put forward higher requirements for medical linear accelerators. As the final execution equipment of radiotherapy, accelerators shoulder a major mission. How to ensure the accurate execution of the treatment plan, how to ensure the accuracy of the patient's treatment location, absorbed dose, and dose distribution in vivo has become the key issues, which have a series of strict requirements for the function, accuracy, control and dose detection of medical electron linear accelerator. Unbalanced differences between doctors and patients in China, and the burden of treatment machines in radiotherapy units are heavier. This requires the accelerator to have good stability and maintain a high startup rate. These all require a complete set of quality assurance and quality control measures, which are strictly implemented by professionals (4). Only in this way can the accelerator be in good working condition, provide high-quality medical services, win economic benefits for the hospital, and achieve good social benefits. Medical electron

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linear accelerators are high-value and high-tech products and belong to large-scale medical equipment. It has the characteristics of complex structure, high precision, a huge system, and expensive equipment. Therefore, correct maintenance, repair, and management are essential to the good operation of the accelerator (5).

Medical linear accelerators (linacs) are essential tools in radiation therapy for cancer treatment. It is crucial to ensure that these machines are well-maintained to provide accurate and safe treatment for patients. However, emergencies can occur that require immediate maintenance to prevent downtime and ensure patient safety. This literature review examines various emergency maintenance schemes for medical linear accelerators.

Medical linear accelerators have been thoroughly studied by researchers in the field of deep learning. Zaripova *et al.*, (2) developed a novel and versatile electron and X-ray medical linear accelerator. The accelerator possesses the capability to adjust energy levels within the range of 2 to 9 MeV through the utilization of a solitary RF pulse. This accelerator employs a robust traveling-wave acceleration structure with a substantial capability for energy and power, allowing for the development of novel adaptive cargo inspection techniques and the precise characteristics of substantial energy and current variations required for computed tomography. By employing strong radio frequency (RF) and water-cooling systems, it is possible to achieve an average beam power of up to 15 kW, with the potential to increase it to 57 kW at 6 MeV. This may make the accelerator suitable for applications that involve electron beam irradiation. Yazdani and Nickfarjam (6) state that X-band medical linear accelerators possess a substantial shunt impedance and electric field intensity. Despite its tube length of 37 cm, the linear accelerator is capable of accelerating the electron beam to a magnitude more than 6 MeV and generating a beam current reaching 90 mA. When the electron gun is in the continuous emission area, the measured transmittance typically falls within the range of around 30% to 40%. The depth dose ratio percentage for depths of 10 and 20 cm is roughly 0.572, which confirms that the energy of the photon beam is approximately 6 MeV. The maximum measured dose rate was 820 cGy/min at a distance of 80 cm from the radiation source. The object lacks the typical quality standards for symmetry, and its flatness exceeds the standard due to the characteristics of a filterless beam that is flat. The penumbra is not steep enough when compared to commercial equipment. Nevertheless, this issue can be resolved by improving the additional equipment. Lee *et al.*, (7) presented a new approach to measure the linear attenuation coefficient of medical linear accelerators in their study. The linear attenuation coefficients of four samples with different chemical contents were determined at a γ-ray energy of 6 MeV. A solitary ionization chamber is utilized as a detector to capture the gamma-ray beam that traverses the sample under investigation. Measurements show that taking into account specific elements in the impurities results in a slight but noticeable change in determining the overall absorption coefficient. Determining the concentration of low atomic weight components in a specimen is especially important. When examining the composition of medium and heavy chemical elements, the influence of light elements can be ignored. Using a 6 MeV gamma radiation helps reduce errors in determining the absorption coefficient. They demonstrate reduced energy reliance within the specific gamma-ray energy range in contrast to the low-energy region. In the low-energy zone, the presence of heavy components will lead to a significant impact from the shell effect.

Kwon *et al.*, (8) examined the inputs employed in constructing prototypes of linear accelerators for radiation therapy systems. The technique will improve the accessibility of radiation therapy, therefore boosting the effectiveness of cancer treatment. Research suggests that the introduction of new technologies should be handled on a case-by-case basis to prevent any unintended disruptions to existing healthcare systems, especially in terms of the current personnel, infrastructure, and socioeconomic factors. The initial results of the study suggest that linear-based facilities in low- and middle-income countries had periods of inactivity caused by issues with the multi-leaf collimator and vacuum pump, as well as unstable power supply. Moreover, there exists a significant correlation of 9 between the per capita Gross National Product (GNP) and the per capita number of linear accelerators. Sukma *et al.*, (9) researched a linac-coordinated cancer therapy platform that provided cancer services using various available devices. The results showed that the main factors affecting the performance of the linac were 76.29% failure loss, 9.59% setup loss, and 8.80% idling rate. Total Productive Maintenance (TPM) is a maintenance strategy that focuses on the overall health of equipment and its usage to improve overall equipment effectiveness (O.E.E.). In the context of a linear accelerator synergy platform for cancer therapy, TPM can help maintain the accuracy and reliability of the system, improving patient outcomes. The implementation of TPM includes regular preventative maintenance, root cause analysis of equipment failures, and cross-functional teamwork between maintenance and operations personnel. It can also involve continuous improvement through data analysis and the identification and implementation of best practices. Dalai *et al.*, (10) studied composite materials for medical linear accelerators by evaluating static permittivity, optical permittivity, expansion factor, and average relaxation time. The results indicated that the composite had a maximum dielectric constant of 223 at 100 Hz.

Predictive maintenance is a proactive approach to equipment maintenance, which involves using data and analytics to anticipate when equipment is likely to fail, and then taking preventive measures to minimize downtime and maintenance costs. In healthcare, predictive maintenance can be particularly useful in maintaining medical linear accelerators, which are critical devices used to treat cancer and other medical conditions. A model for predictive maintenance of medical linear accelerators can help healthcare providers identify potential issues before they become major problems, allowing them to schedule maintenance or repairs more efficiently and effectively (11).

Predictive maintenance is a preventive maintenance strategy that uses data, statistical algorithms, and machine learning techniques to predict equipment failure before it occurs. In healthcare, predictive maintenance can help to identify potential issues with medical equipment before they become major problems, ensuring that patients receive the care they need when they need it. A survey of healthcare professionals found that predictive maintenance can improve patient outcomes, reduce equipment downtime, and save costs. To implement predictive maintenance in healthcare, it is important to have a robust data collection and analysis process, as well as to establish clear protocols for equipment maintenance and repair (12).

Descriptive time series analysis can be used for downtime prediction of a linear accelerator, specifically for a medical application. A group of researchers conducted such analysis on maintenance data and developed a mathematical model to predict downtime at different time ranges. The model used multiple linear regression, a common statistical approach to modelling time series data. They collected maintenance data from the accelerator, including disease codes and the number of times the accelerator was shut down for maintenance. Through their analysis, they were able to successfully predict downtime at specific time intervals, which could help in better planning maintenance schedules and reducing downtime (13).

Artificial Intelligence (AI) can be used to improve maintenance, supervise machine failures, and support repairs. AI-based predictive maintenance can identify machine failures before they occur, allowing preventive maintenance to be performed before a major breakdown. AI can also monitor machine performance and generate alerts when a failure occurs. AI-based diagnostics can help identify the root cause of the failure and recommend repairs. AI can also support repair by providing real-time information and diagnostic data to the technician, enabling more efficient and cost-effective repairs. AI-based maintenance management can streamline maintenance operations, optimize resource allocation, and reduce downtime (14).

The authors introduced a technique (15) that utilizes stacked long short-term memory (LSTM) neural networks to forecast the performance of machines. These networks are capable of capturing and understanding long-term patterns in the data. The authors utilized this technique to forecast the performance of machines in a clinical environment, and their findings demonstrated that the LSTM model surpassed other models in terms of accuracy and resilience.

Authors presents a method (16) for identifying failure modes and trends in linac maintenance logs using topic modelling. Linac, also known as linear accelerator, is a medical device used for radiation therapy. Topic modelling is a technique used to identify latent topics within a collection of documents, and in this study, it was applied to identify common issues and trends in the maintenance logs of linac machines. The article shows how topic modelling can be a useful tool in identifying patterns and issues in the maintenance records of complex medical equipment.

Authors focuses on analyzing the performance of maintenance in industrial applications with the integration of Industry 4.0 technologies (17). The article employs a bibliometric performance analysis to assess the research output on the topic and a systematic literature review to provide a comprehensive overview of the recent developments and trends in the field.

Materials and Methods

Procedure for Determination of Absorbed Dose of Photon Rays in Medical Linear Accelerators Under Deep Learning

In radiotherapy, the accuracy of the absorbed dose of photon rays in medical accelerators is crucial (18). Accurate dosing not only reduces damage to normal tissue but also ensures that tumors receive the exact prescribed dose, improving tumor control and reducing the likelihood of normal tissue complications. The 27th report of the International Commission on Radiation Units and Testing pointed out that the total dose error in radiotherapy should be controlled by 3%. Therefore, the dose error caused by each link in the treatment needs to be strictly controlled (19). Calibration and measurement of absorbed dose is the first step in the entire therapeutic chain. Standardized absorbed dose measurement standards can obtain not only accurate dose measurement results but also have important clinical significance. The measurement process is shown in Figure 1.

In Figure 1, an accurate measurement of the absorbed dose must be done with the aid of a dosimeter (20). But in fact, except for the calorimeter, which can directly measure the absorbed energy, other dosimeters cannot be used to measure the absorbed energy directly. Usually, the detector measures the ionizing charge generated by the ionizing radiation, which is calculated from the average ionization energy of the air and converted into the energy deposited by the ionization box, that is, the absorbed dose. Therefore, if these dosimeters are to be used to measure the absorbed dose of radiation, the response of these dosimeters to the absorbed dose must be compared with that of a dosimeter with a known dose-response. This process is called dosimeter calibration. Therefore, before using a dosimeter for field measurements, it must be calibrated, and the correlation coefficient used to obtain the absorbed dose determined. Dosimeters with known dose responses are kept in the National Standards Laboratory.

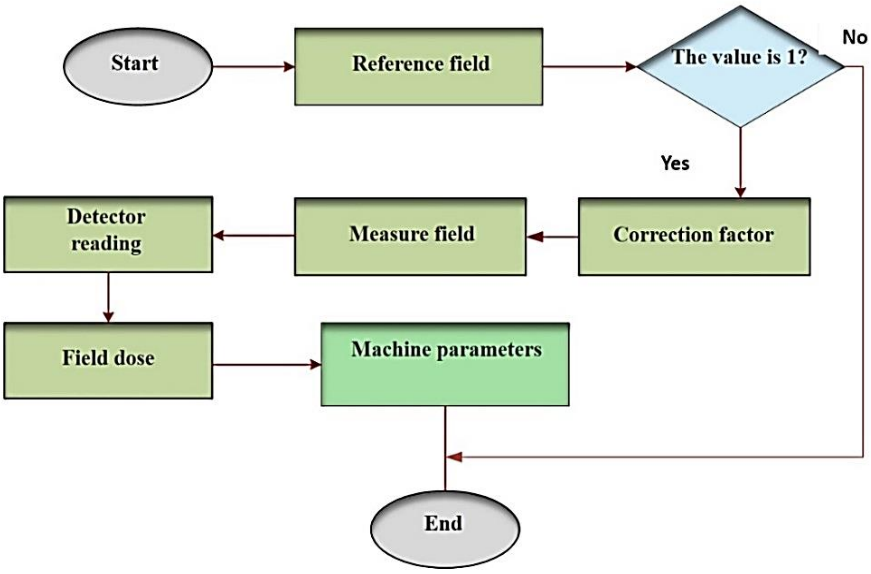

Figure 1: Flow Chart of Absorbed Dose of Photon Rays in Medical Accelerators

Therefore, the calibration work should be completed by the national first-level standard laboratory, such as the Chinese Academy of Metrology and the National Institute of Standards and Technology in the United States as the national metrology supervision department. Various countries and relevant international organizations have produced relevant measurement procedures to standardize and unify the measurement methods of absorbed dose, including measurement instruments used for measurement, measurement conditions, calculation formulas, and relevant calibration coefficients. It is assumed that the ionization chamber is placed in a medium and irradiated with photon rays of given energy (21, 22). Then, the absorbed dose D_{air} in the air cavity is given by Eq. [1]:

$$D_{\text{air}} = M \cdot N_{\text{gas}} \cdot P_{\text{ion}} \quad [1]$$

In Eq. [1], D_{air} is the measured ionization charge, N_{gas} is the gas cavity gas calibration factor, and P_{ion} is the composite effect correction factor of the ionization chamber (23). The absorbed dose of the medium can be calculated by cavity theory, as shown in Eq. [2]:

$$D_{\text{med}} = D_{\text{air}} \cdot (\bar{L}/\rho)_{\text{air}}^{\text{med}} \cdot P_{\text{repl}} \cdot P_{\text{wall}} \quad [2]$$

In Eq. [2], P_{repl} is the replacement factor, which is used to correct the disturbance of the electron and photon fluence after the introduction of the air cavity into the medium; the P_{wall} factor is used to correct the material of the ionization chamber wall and the material of the measurement medium Disturbances that are not caused. The calculation of the absorbed dose in high-energy photon rays in water is shown in Eqs. [3] and [4]:

$$N_{\text{D,air}} = N_{\text{k}}(1-g)k_{\text{m}}k_{\text{att}} \quad [3]$$

$$\text{or } N_{\text{D,air}} = N_{\text{x}}\frac{W}{e}k_{\text{m}}k_{\text{att}} \quad [4]$$

In Eqs. [3] and [4], $N_{\text{D,air}}$ is the calibration factor for the absorbed dose in the cavity of the ionization chamber, N_{k} is the calibration factor for the air kerma, and g is the energy share of the secondary electrons lost in the form of radiation in the air, k_{m} is the air equivalent correction factor of the ionization chamber material, k_{att} is the correction factor of the ionization chamber for ray absorption and scattering, and $\frac{W}{e}$ is the average ionization energy of air (8, 9). The calculation of the absorbed dose at the effective measurement point of the ionization chamber in the water phantom is shown in Eq. [5]:

$$D_{\text{w}} = M_Q N_{\text{D,air}} s_{w,\text{air}} P_{\text{u}} P_{\text{cel}} \quad [5]$$

In Eq. [5], M_Q is the reading of the dosimeter after temperature and air pressure correction, $N_{\text{D,air}}$ is the stopping power ratio of water to air, P_{u} is the ion chamber disturbance correction factor, and P_{cel} is the ion chamber incomplete air equivalent correction factor. The values of P_{u} and P_{cel} under different ionization coefficients are shown in Table 1.

Table 1: Value Table of P_{u} and P_{cel}

Coefficient	1	2	3	4	5	6
P_{u}	3.14	4.87	5.12	6.12	7.31	8.14
P_{cel}	1.12	3.51	4.16	7.14	9.12	11.32

In Table 1, extrapolation is required under standard conditions to obtain the point dose outside the reference field. The dose measured under standard conditions is transferred to other non-reference fields through the ionization chamber measurement output factor (24). The calculation of the portal dose is shown in Eq. [6]:

$$D_{w,Q_{\text{mall}}}^{\gamma_{\text{sall}}} = D_{w,Q_{\text{wf}}}^{f_{\text{ref}}} s_{\text{c,p}} \quad [6]$$

In Eq. [6], f_{ref} represents the conventional reference field in the dosimetry specification, γ_{sall} represents the small size field, and $s_{\text{c,p}}$ is the total scatter factor (25). Q_{wf} is the ratio of the non-standard field to the standard wide beam. The total scatters, and output factors are calculated, as shown in Eqs. [7] and [8]:

$$S_{c,p}(r) = \frac{D_{w,Q_r}^{fr}}{D_{w,Q_{ref}}^{fref}} \quad [7]$$

$$\text{OF} = \frac{M_{w,Q_r}^{fr}}{M_{r:Q_{ref}}^{fref}} \quad [8]$$

In Eqs. [7] and [8], $S_{c,p}(r)$ is the total scatter factor, OF is the output factor, f_{ref} represents the conventional reference field in the dosimetry specification, $s_{\text{c,p}}$ is the total scattering factor (26). According to the water absorbed dose equation. under the condition of the broad beam, the calculation of $D_{\text{w},Q}$ is shown in Eq. [9]:

$$D_{w,Q} = M_Q N_{D,w,Q_0} k_{Q,Q_0} \quad [9]$$

In Eq. [9], $D_{w,Q}$ is the reading of the dosimeter in the field; M_Q represents the total correction factor, and N_{D,w,Q_0} describes the difference in the dose-response of the detector in the reference field (27). The total scatter factor and output factor is calculated, as shown in Eq. [10]:

$$s_{c,p}(r) = \text{OF} \cdot \frac{k^{f_r}_{Q_r,Q_{Q_0}}}{k_{Q_r,f_{ref},Q_0}} \quad [10]$$

In Eq. [10], if the charged particle balance condition is satisfied, the impact of the field size on the change of the ray quality is small. In this case, the difference between the output factor and the total scatter factor is usually negligible. However, in the case of small fields, the laterally charged particles cannot reach equilibrium, resulting in a large difference between the output factor and $s_{c,p}$. Current measurement methods in a small field and non-standard portal dosimetry can meet the reference level requirement of absorbed dose accuracy within ± 3% of the accuracy of total dosimetry (28, 29).

Establishment of deep learning medical linear accelerator model

The mechanical precision of the medical electron linear accelerator determines the accuracy of the position in the patient treatment (30), and the basic structure is shown in Figure 2.

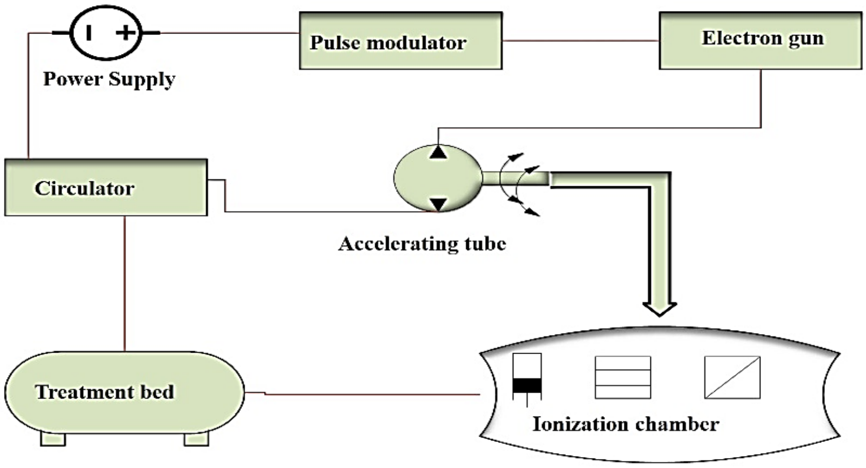

Figure 2: Structure Diagram of Medical Linear Accelerator

In Figure 2, a medical linear accelerator is generally mainly composed of an accelerating tube, a microwave power source, a microwave transmission, an electron injection, a pulse modulation, a beam, a vacuum, a constant temperature water cooling, a power distribution control system, and an accelerator rack. It consists of a computer system, a treatment head and bed, dose monitoring, a safety interlock, an optical simulation, and an additional system (31). Electrons are trained by deep learning to enter the accelerator tube. In the beginning, the electron speed is lower, so the spacing is smaller. As the speed of the electrons increases, the distance between them is slowly increased, and after the wave speed quickly reaches the speed of light, the distance can remain the same. The speed of waves also approximates the speed of light propagation. Linear accelerators that accelerate electrons in this way are called deep learning electron accelerators. The schematic diagram of deep learning electron acceleration is shown in Figure 3.

In Figure 3, the deep learning electron accelerator uses standing wave acceleration. The accelerating tube consists of a series of mutually coupled resonator chains. The resonator chain has various structures, such as side-coupled standing-wave acceleration structure, coaxial-coupled standing-wave acceleration structure, and axis-coupled standing-wave acceleration structure (32). At present, edge-coupled standing wave acceleration structures are often used. In this configuration, half of the accelerating cavity is virtually always zero electric field, acting as a coupling. The transmission of microwave power is called a coupled cavity. Acceleration is called the acceleration cavity. The acceleration principle is to adjust the phase and speed of the reflected wave of the microwave in the accelerating tube appropriately to generate a standing wave accelerating electric field.

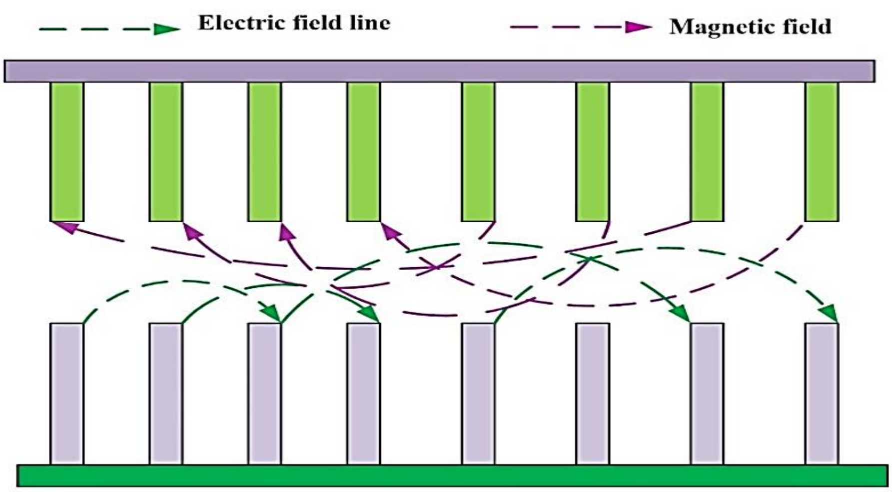

Figure 3: Schematic Diagram of Acceleration of Electrons Accelerated by Deep Learning

Results

Deep Learning Medical Linear Accelerator Performance Test Results

Relative to the calibration principle, the dosimeter, and the ionization chamber are placed at the equidistant centre to receive the same dose of irradiation at the same time. The experimental data is read out with a thermoluminescence dosimeter for analysis. The dose detection results are shown in Figure 4.

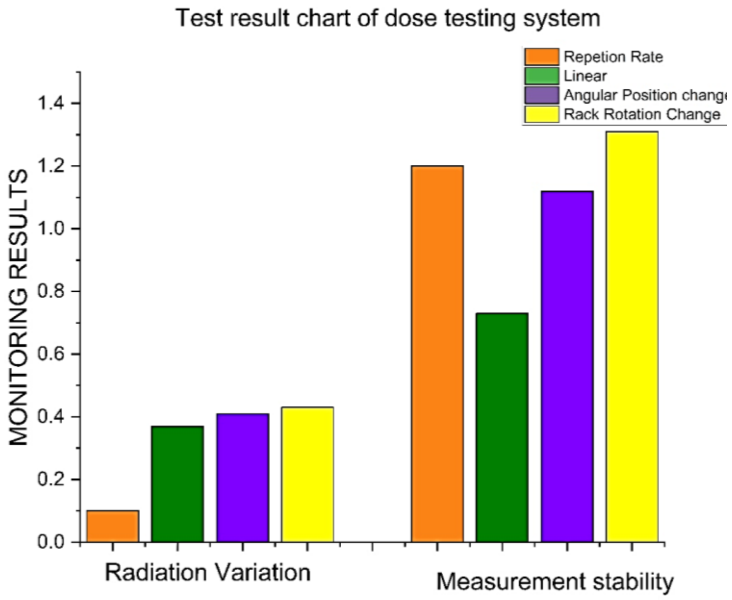

Figure 4: Result Graph of Dose Detection System Testing

In Figure 4, the repeatability of the front and rear irradiation fields in the dose detection system is 0.08%, the linearity is 0.36%, the daily stability is 1.08%, and the weekly stability is 1.29%, and the stability after high-dose irradiation is 0.74%. These indicators are all within the standard detection range. The deeply absorbed dose distribution is shown in Figure 5.

In Figure 5, the incident electron energy and half-width are the key parameters in the simulation that affect the calculated results. In previous studies, the simulation of medical linacs mainly relied on tuning these two parameters to determine the optimal parameters for the incident electrons. In Figure 5, the absorbed dose decreases slowly as the depth data increases. At a depth of 50 mm, the absorbed dose of the agent with an average rate of change of 26 is only 100%. The absorbed dose of the two agents with an average rate of change of 15 and 18 could reach 150%. However, as the incident field becomes larger, the difference gradually becomes larger. Therefore, when searching for the optimal incident parameters of incident electrons in the mode, the off-axis ratio curve obtained only by adjusting the incident electron energy and half-height width cannot be well-matched with the measurement results.

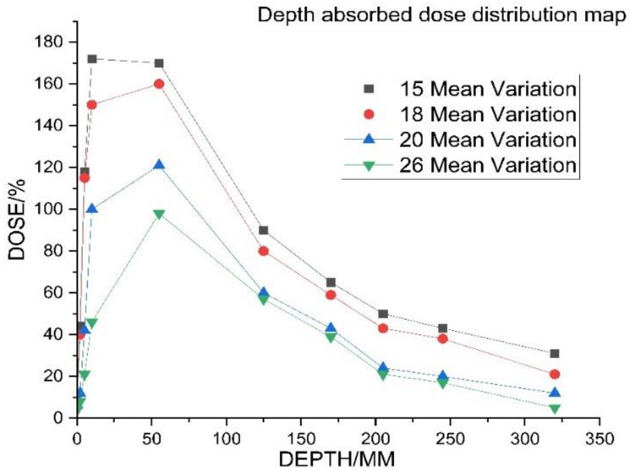

Figure 5: Distribution of Deeply Absorbed Dose

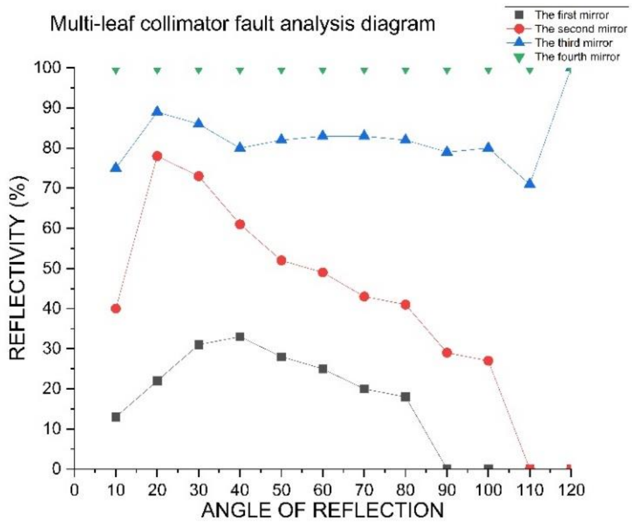

Figure 6: Failure Analysis Diagram Of The Multi-Leaf Collimator

Analysis and Research on Common Faults and Treatment Methods of Medical Accelerators

The common failures of medical electron linear accelerators can be summarized into several categories: multi-leaf collimator failure, beam system failure, operation control system failure, vacuum inflation system and constant temperature water circulation system failure, mechanical failure, etc. Some faults can be repaired independently under the guidance of the manufacturer. The common faults and processing methods are analyzed and studied combined with the operation and control of the deep learning medical linear accelerator model. The failure analysis diagram of the multi-leaf collimator is shown in Figure 6.

In Figure 6, the optical path of the multi-leaf collimator is divided into projection and reflection optical paths. In a multi-page collimator, the reflectivity of the first mirror is only 20% on average. The average reflectivity of the second mirror and the third mirror can reach 60% and 80%, respectively. The average reflectivity of the fourth mirror can always be maintained at the level of 100%. The projected light path refers to the light source provided by the long-life halogen bulb in the handpiece. The light it emits goes through the lens 10% to the first mirror. The light is reflected in the second mirror. Among them, 35% of the light is reflected in the polyester film transparent mirror. Then, the light is reflected in the reference reflection point and the blade reflection point of the frame of the multi-leaf collimator. After they receive the light, they reflect the light back to the polyester film mirror. The polyester film mirror sends the received light through the second mirror to the mirror in front of the camera lens to enter the camera. The second mirror is a beam splitter. When the relevant components in the optical path fail, a phenomenon like the reflection point failure will occur. For example, the brightness of the projection bulb decreases, resulting in a decrease in the brightness of the reflection point. A drop in the reflectivity of any four-sided mirrors can cause a drop in the reflectivity of the reflective point. The beam system is the core part of the accelerator, and the failure analysis is shown in Figure 7.

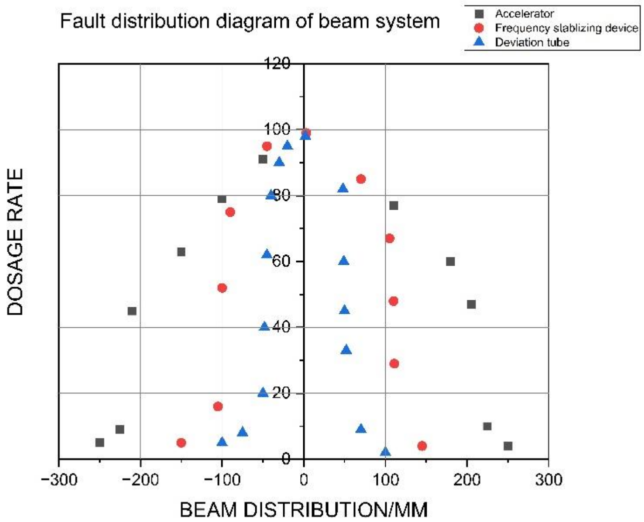

Figure 7: Failure analysis diagram of the beam system

In Figure 7, a reduced dose or zero dose rate, will result in asymmetric beam distributions. Among them, when the beam distribution is 100mm, the dose value of the frequency stabilization device can reach 80. When the beam distribution is 200mm, only the accelerator dose value can be stabilized at around 60, and the dose value of the rest of the devices is 0. According to different models, the error code page is different, but the maintenance principle is basically the same. Solution: take the medical linear accelerator as an example. When the dose rate drops or is very low or even zero, the accelerator will report the dose rate chain. Generally, this situation is mostly due to the failure of the frequency stabilization device, which deviates from the natural frequency of the accelerator tube. If there is no hardware failure, it can be solved by adjusting the automatic frequency control. Press the beam output key during electric adjustment, and observe the dose rate change while adjusting. Finally, the automatic frequency control is adjusted to stop at a steady state of the dose rate. The operation control system is the most frequently used in the treatment, and the failure rate is also high. The specific fault is shown in Figure 8.

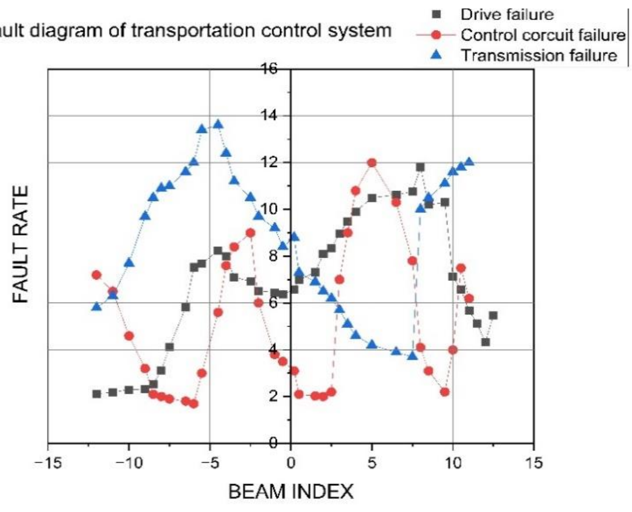

Figure 8: Fault Diagram of the Operation Control System

In Figure 8, the operation control system is generally classified into drive, control circuit, and transmission failure. Among them, when the beam index is 5, the failure probability of the control circuit is 8%. With a beam index of 10, the probability of driver failure is 12%. As the beam index increases, when the beam index is 12, the transmission failure probability value tends to be stable. Drive faults are mostly motor or power failures, control circuit faults are mostly chain faults, and transmission faults are mostly mechanical faults, which will be described in detail in Mechanical Faults. According to the machine parts, it is roughly divided into rack operation control failure, radiation head operation control failure, etc. When an operation control failure occurs, if the relay operates normally, it is basically a problem with the drive motor and power supply. Measure whether the motor is normal. If the motor is damaged, replace the motor. If the motor is normal, the fault is on the power supply circuit, and measure whether the motor power supply voltage exists. If the voltage is normal, measure whether the current is enough. Generally, the power supply is unstable, and the power supply or power output board can be replaced. Most of the vacuum power source faults are ion pump faults. The fault diagram is shown in Figure 9.

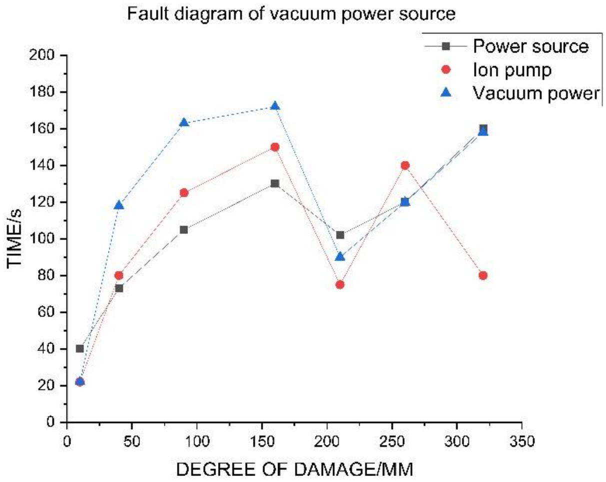

Figure 9: Fault Diagram of Vacuum Power Source

In Figure 9, one of the failures of the vacuum power supply is that the ion pump itself is damaged or its performance is degraded, rendering the vacuum system ineffective. Among them, the greater the damage to the vacuum power supply, the longer the system repair time required. When the damage degree is 50mm, the average repair time required by the system is the 70s. When the damage degree is 100mm, the average repair time required by the system is 150s. After the damage reaches 300mm, the average repair time of the system tends to be stable. In the experiment, firstly, check whether the power supply of the ion pump is normal. If the power supply is normal and the ion pump does not work, the ion pump is likely to be broken, and the ion pump needs to be replaced. If the ion pump is working, but when the vacuum reaches a certain level and can no longer go up, the aging performance of the ion pump also needs to be replaced. The other is the power failure of the ion pump, measuring the abnormal voltage of the ion pump, repairing the power supply circuit of the ion pump, and making the power supply of the ion pump normal after the fault is found and solved.

Discussion

By analyzing the common faults and treatment methods of medical accelerators, the performance test results of medical linear accelerators are obtained. In the dose detection system, the repeatability of the front and rear irradiation fields is 0.08%, the linearity is 0.36%, the daily stability is 1.08%, and the weekly stability is 1.29%. The experimental results are consistent with previous studies. Kutsaev *et al.*, 2021 (27) studied the interaction data of photonuclear reactions and neutron capture during the treatment of cancer patients with photon beams in a medical linear accelerator. The linear dose rate is measured using spectroscopy after treatment. Radionuclides are identified linearly for each. According to the gamma-ray spectrometric survey, most of the nuclides are short-lived nuclides with a half-life of 100 days. The dose rates for the three linacs obtained directly in front of the crosshair ranged from 0.113 to 0.129. The maximum and minimum dose rates measured over the weekend are 0.097 and 0.092, respectively. Compared with the data on weekdays, the difference in the data measured on Saturday and Sunday is not significant. Most of the detected radionuclides had half-lives of less than 100 days, and the dose rate declined rapidly. Radiation effects on workers are minimal when equipment ≤10 Hz is moved after it has been turned off for at least 10 minutes. Ige *et al.*, 2021 (26) obtained a set of data for patient treatment through the commissioning of a medical linear accelerator. Firstly, they present measurements of beam current data during medical linear commissioning, performing dosimetric characterization of 6, 10, and 15 MeV photon beams and 6, 9, 12, and 16 MeV electron beams. Later, based on imported ant indicators such as percent depth dose, depth dose profile, symmetry, flatness, quality index, output factor, and treatment planning system commissioning, the experimental plan and treatment of 8 locations are comprehensively and safely computed through tomography scans. Finally, study compared the calculated dose at the determined location with the measured data validated by the number of terminals at each station. The results show that after 84 light spots of different schemes are tested, 83 light spots meet the standard. Only one spot in the 15 MeV photon beam failed. This indicates that the adjustments for dose and field flatness and symmetry are within the tolerances given by the Varian precession magnetometer. The investigated spectral lines are compliant and available at all available electron and photon energies.

This approach completely outmatches traditional reactive maintenance in effectively predicting an upcoming problem by sensor data analysis and enables proactive intervention to prevent emergencies that would naturally affect patient care. This new application of deep learning in a hospital setting holds a lot of promise for huge strides in machine uptime and treatment accuracy. The hospitals may have fewer emergencies, less downtime, and a lesser maintenance cost. It enables healthcare systems via equipment availability, possibly enhancing patient capacity. Patients receive treatment from an optimally performing system that allows for better accuracy and outcomes. This system will keep life-saving radiation working by means of intelligent, data-driven maintenance. Deep learning can be used in predicting the need for maintenance of a medical linac. This approach shifts attention from responding to repairs only after they occur to the active identification of problems before they become emergencies. Potential outcomes include fewer urgent situations and increased equipment uptime. It thereby pushes AI beyond traditional data analysis and opens its application in this field toward further improvement in the working of critical medical equipment.

Medical linear accelerators are expected to be able to provide very reliable operation to the patient. A malfunctioning device may affect the delivery of the radiation field, either negatively impacting healthy tissue or diminishing treatment effectiveness. Therefore, the focus of this research on predictive maintenance using deep learning is to avert such issues and help safeguard patients during radiotherapy. Deep learning methods are suggested for the complex maintenance of equipment, prediction of failures, and performance optimization of the same equipment. This integration assures enhanced precision during treatment, minimized periods of inactivity, and decreased expenses related to maintenance. Further research outlines the role of interdisciplinary collaboration and continuous education in developing radiation technologies. It gives a perspective on where intelligent radiotherapy systems are heading in the future; therefore, it sets the stage for future developments in the maintenance and operation of medical accelerators.

Conclusion

The Chinese Medical Electron Linear Accelerator was a newly installed equipment. Its radiation protection performance indicators all meet the corresponding international electrical safety requirements and meet the requirements of general international standards. Due to the complex structure of the equipment, wear and aging, environmental factors, fault maintenance, etc., these reasons affect the performance of the radiation field and affect the positioning of the target area and dangerous organs in the patient's radiation therapy plan. In order to ensure the accuracy of the treatment, the daily maintenance and safety guarantee of the accelerator is particularly important. In the context of deep learning, advances in radiotherapy techniques are discussed in conjunction with the development of medical electron linear accelerators. Depending on the model of the medical accelerator, the radiotherapy programs that that model can carry out are further discussed. The results show that medical linacs have high requirements for infrastructure and maintenance, and the staffing level of accelerators is high, especially the high life cycle cost of medical linacs. In future clinical treatment, clinicians should continue to learn and update the professional knowledge system. The engineering and technical personnel of medical accelerators shall participate in the research and development of updated radiotherapy technology and equipment. This is the bridge's responsibility between radiotherapy equipment manufacturers and radiotherapy units. With the advancement of computer manufacturing technology and manufacturing process, as well as the development of deep learning technology, the artificial system of radiation therapy has become more intelligent, and the treatment precision and accuracy are higher. Intelligent radiotherapy robots will be an ideal prospect for future radiotherapy.

Abbreviations

AI: Artificial Intelligence
GNP: Gross National Product
LSTM: Long Short-Term Memory
MeV: Mega Electron-Volts
OEE: Overall Equipment Effectiveness
TPM: Total Productive Maintenance
QA: Quality Assurance
QC: Quality Control

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Conflict of Interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

Ethics Approval

Not applicable.

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