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Virtual Reality (VR) Space for Radiation Oncology Education and Collaborative learning

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Abstract

Background: Current gold standard for clinical training is on actual Linear Accelerators (LINAC) machines, recordings of the actual procedure, videos clips and word of mouth. Current training practices lack the element of immersion, convenience and flexibility. These trainings are not always interactive and may not always represent actual use case scenarios. Immersive experiences by interacting with LINAC machines in a safe and controlled virtual environment is highly desirable. Current real world radiation treatment training often requires a radiation bunker and actual equipment that is not always accessible in the clinical setting. Oncologist's time is extremely precious and radiation bunkers are hard to come by due to heavy demands in specialty clinics. Moreover, scarcity of Linear Accelerator (LIANC) due to its multi-million dollar capital cost makes the accessibility even worse. To solve the logistical, economical and resource issues, virtual reality (VR) radiation treatment will offer a solution that will also improve the clinical outcomes by preparing Oncologists in the virtual environment anywhere and anytime. We are introducing a virtual reality (VR) space for Radiation trainees, so that they can use it anywhere and anytime to practice and refine their radiation treatment skills. Moreover, an immersive space for collaborative learning and sharing their knowledge

Methods: Trainees were invited to the VR space and went through the pre-assessment questionnaire and then guided through series of videos and digital contents and then subjected to post-assessment randomized questionnaire

Findings: Trainees (n=32) reported significant improvement in their learning. For future work we can compare to traditional methods. A number of trainees were new to VR technology and also new to Radiation Oncology.

Interpretation: Our research revealed that incorporating virtual reality (VR) as a tool for elucidating Radiation Oncology concepts resulted in an immediate and notable enhancement in trainees' proficiency. Moreover, those who were educated through VR demonstrated a more profound understanding of Radiation Oncology, including a wider array of potential treatment strategies, all within a user-friendly setting.

Key Words: Radiation Oncology, Virtual reality, Immersive experience, Linear Accelerator

Introduction

In the United States, every year there are over five hundred thousand patients referred to external beam radiotherapy clinics for treatment of a wide variety of cancers [1]. There are over two thousand clinics ranging from large players such as the MD Anderson Cancer Center and Memorial Sloan Kettering Cancer Center to small regional hospitals treating the local patient population [2]. These patients are treated on medical linear accelerators (LINAC) manufactured by companies such as Varian and Elekta. Radiation therapy requires highly trained medical personal and is often constrained by the availability and high cost of the LINACs and the auxiliary equipment. The demand for LINACs and the radiation bunkers is high. These resources are not readily available for training the medical personal before the procedure to hone their skills. Virtual simulation of the radiation therapy can offer a viable cost-effective alternative to training the medical personal anywhere and anytime.

Creating a VR space for education for the radiation therapy treatment (RTT) is very appealing to multiple stakeholders through cost effectiveness, reduced dependency on expensive equipment, and the convenience of training anywhere and anytime. All these elements cover the practical aspect of VR in RTT. By bringing the immersion piece through creating a best experience for the user is highly desirable not only for the trainee but also for the patient and the provider because it drives for best clinical outcomes for the patient and reduced burden on the healthcare system. To be able to practice procedures, effects, approaches, and alternatives in VR for any medical procedure likely will increase comfort of mind for patients as well as positive procedural outcomes [3]. Radiotherapy is delivered in a shielded bunker during which time the patient only has an intercom to communicate with the radiation therapists.

Radiation therapy delivery with precision is extremely important to destroy the cancerous tumors while minimizing the damage to the surrounding tissues. The most common errors that occur during radiation delivery are exposing the wrong target and/or delivery of an incorrect amount of radiation. A number of these factors contribute to emotional stress for the patient. Studies have shown that patients who have gone through the patient education programs providing them with more information about the upcoming radiation procedure experienced significantly less emotional distress. The physiological information, patient's behavior, and social information is important to monitor and refine the care management strategies. Often, patients going through radiation therapy are referred to specialty care such as dermatologists, psychologists, dietitians, and social workers to navigate through their journey. The journey is complex and variable and with the use of digital technologies, we hope to make the journey easier.

Every patient is different, and they respond differently to the radiation treatment and post-treatment regimen. Personalizing care with digital technology, education and training, has shown some promise in improving clinical outcomes [4]. Digital technologies can enable better integration with hospital systems, data sharing, storage, and use of artificial intelligence to guide the patient and the clinician for optimum outcomes.

Methods

We built a VR space for radiation oncology using the online Spatial VR tool. The idea is to build a training module for allowing trainees to obtain a basic understanding of Oncology, diagnostics, treatment options, patient journey, and challenges of cancer care, opportunities and financial burden of the disease. The VR space is designed to provide trainees with an immersive learning experience in the field of radiation oncology. The assessment plan is aimed at evaluating the effectiveness of VR space in achieving its learning outcomes. In the future, we aim to take the trainees through the 3-D environment and to determine if VR space will help participants to work in a fully 3D environment with a virtual LIANC they can interact with. The following are the components of the assessment plan:

1. Pre-assessment: Before trainees navigate the VR space, a pre-assessment will be conducted to establish the baseline knowledge and skills of the trainees in the field of radiation oncology, diagnostics modalities and various treatment options. The pre-assessment will include a quiz that covers the basic concepts of Oncology, radiation therapy and LINACs.

2. VR Space Experience: The VR space experience will be the core of the assessment plan. The trainees navigate through various contents to enhance their knowledge and get familiar with the basic Oncology physiology, disease progressing and possible diagnostics and treatment options. Then, the VR space is designed to immerse the trainees with deep dive into radiation Oncology, LINAC and how is it used to deliver therapy including patient setup and treatment planning. Since this is a multiple player collaborative learning environment, trainees will have the opportunity to interact with other trainees and the instructor if he/she is there with them.

3. Post-assessment: After navigating the VR space and going through the contents and interaction experience, a post-assessment will be conducted to measure the learning outcomes. The post-assessment will include a quiz that covers the same concepts as the pre-assessment. To minimize order bias of the questions between the pre- and post-tests, questions and answer sequence are randomized. Data is collected from the pre-assessment and post-assessment quiz per user and then analyzed for improvement scores as the trainees go through self-managed VR training videos and contents.

Results

We have followed sound systems engineering practices to evaluate a VR space for radiation treatment therapy system. The advancements in VR technology has helped us create a cost-effective alternative where we can train trainees faster and reduce time to competency. The data we gathered as part of the pre-assessment and post-assessment seems to indicate that the VR based education experience is effective and offers convenience so that trainees can engage on their own pace anywhere and anytime. The data is very limited but we got significant data from 32 participants to prove the hypothesis. Data from 32 participants is statistically significant to draw some conclusions on the effective of the VR based education. Figure 1 below shows the landing area of the VR space where trainees can start their learning journey.

Figure 1: VR Space Landing

Our findings resonate with existing literature indicating that VR can improve learning outcomes in medical education. For instance, studies have shown that VR simulations can enhance surgical training, diagnostic skills, and patient management strategies by providing realistic, hands-on experiences without the risks associated with actual clinical practice [5]. However, the application of VR in radiation oncology education has been less explored, making this study a significant contribution to the field. By demonstrating the potential of VR in this specialized area of medicine, our research adds to the growing body of evidence supporting VR's role in enhancing medical education across various domains. Figure 2 shows the Avatar navigation throughout the VR space to guide trainees via structured Oncology contents. We define proficiency of 80% as a clear indication of trainees acquiring and retaining the knowledge.

Figure 2: Radiation Oncology Navigation

Quantitative Results

Pre-assessment and Post-assessment scores

Table 1: Summary of Assessment Scores

Statistic	Pre-Assessment Score	Post-Assessment Score	Improvement
Count	32	32	32
Mean	12.38	18.84	6.43
Standard Deviation	2.74	2.38	3.66
Minimum	8	13	0
25th Percentile	10.75	18	3
Median	12	19	7
75th Percentile	14	21	9
Maximum	19	23	13

Table 1 illustrates the improvement in knowledge among the participants from the pre-assessment to the post-assessment after undergoing the VR education module. Note that this table reflects a preliminary experiment consisting of 32 participants with very little to no background in radiation treatment therapy and VR technologies. On average, there was a notable improvement score of approximately 6.43 points, indicating the effectiveness of the VR intervention in enhancing the understanding of radiation oncology topics. The count reflects the number of participants for whom both pre- and post-assessment data were available and analyzed.

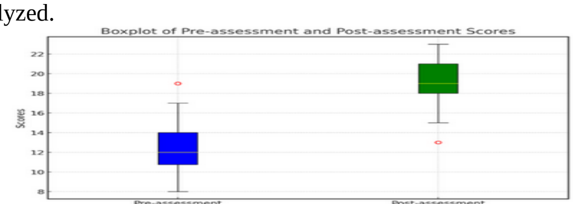

Figure 3: Plot of pre and Post assessment scores

Figure 3 is Box-and-Whisker Plot of Pre- and Post-Assessment Scores. This plot visually represents the distribution of scores before and after the VR education intervention. It illustrates the central tendency, dispersion, and outliers in the scores for both assessments. From the plot, you can observe the improvement in scores from the pre-assessment to the post-assessment, as indicated by the higher median and shifted quartiles in the post-assessment scores. This visualization supports the quantitative analysis provided earlier, highlighting the effectiveness of the VR module in enhancing participants' understanding of radiation oncology.

Attempt Analysis

The achievement level of attaining 80% answers correct in less than 4 attempts is considered high, in less than 7 is considered moderate and anything higher needs improvement.

Table 2: Number of attempts required for Mastery

Participant ID	Number of Attempts
05MA97	2
09CO76	1
01DO75	3
05SI91	1
05DI83	1
01MI92	1

The table 2 displays the number of attempts of partial participants needed to achieve a predetermined mastery level in the VR module for a subset of participants. These statistics suggest that a significant number of participants achieved mastery with few or no additional attempts, indicating the VR module's effectiveness in facilitating quick learning and understanding.

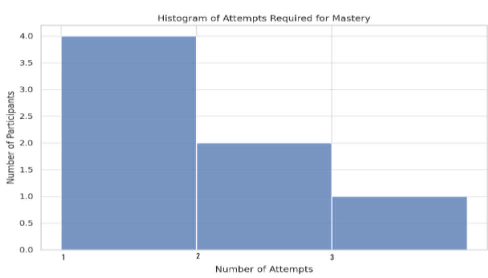

Figure 4: Histogram of attempts for mastery

This plot illustrates the distribution of the number of attempts participants needed to achieve a predetermined mastery level in the VR module. From the histogram, we observe that a significant number of participants were able to grasp the material with few attempts, demonstrating the VR module's effectiveness in facilitating rapid learning. This visualization complements the data presented in Table 2, providing a clear picture of how quickly participants could master the material through the VR education module.

Qualitative Results

Participant Feedback and Experience

The qualitative feedback from participants regarding their experience with the VR training reveals a range of responses, reflecting various aspects of the VR module, including engagement, realism, usability, and learning satisfaction. Here's a summary of key themes identified from the unique feedback entries:

- **Positive Experience**: Several participants described their experience as "Great," "Very Positive," and one even emphasized with "GREAT PLEASE THROW THIS WHOLE THING AWAY," possibly indicating strong approval in a humorous tone.
- **Suggestions for Improvement**: Some feedback included constructive suggestions, such as changing the visual environment to resemble a hospital more closely to enhance realism.
- **Content Appreciation**: Participants appreciated the content's quality and clarity, with one noting it was "not overly long but was thorough enough to convey the information."
- **Technical Aspects and Usability Issues**: There were comments about the desire for additional resources like a glossary or acronym list for quick reference, indicating a need for support in understanding technical material. Usability feedback mentioned difficulty in angling the camera to read signs, suggesting areas for improvement in the VR interface.
- **Pre-Assessment Clarifications**: A few responses were clarifications about not having started the VR module yet, indicating these were pre-assessment comments.

Given the diverse nature of the feedback, summarizing it quantitatively as initially planned with a Likert scale might not fully capture the richness of the qualitative data. However, this feedback provides valuable insights into the participants' experiences, highlighting areas of strength and opportunities for enhancing the VR training module.

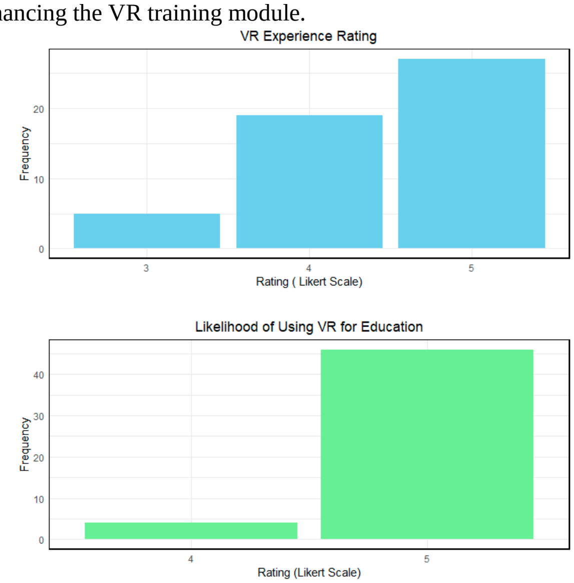

Figure 5: Participant Feedback Scores

As shown in figure 5, for the VR Experience Rating data, we have a range of responses from 3 to 5, with a significant number of 5s indicating a generally positive experience among participants. For the Likelihood of Using VR for Education, the responses are overwhelmingly 5s, showing a very high likelihood that participants would use VR for education and learning purposes.

Discussion

The introduction of a cost-effective virtual reality (VR) platform represents a transformative approach in the training of oncologists, physicists, medical students, and the onboarding of new engineers, as well as in educating patients about radiation treatment. This innovative tool not only offers a preview of the patient journey through radiation therapy but also serves as an invaluable educational resource in meeting some key learning objectives shown in figure 6. By allowing users to immerse themselves in the environment of a treatment bunker, complete with a radiotherapy linear accelerator, the platform enables interaction with equipment controls, such as the bed and gantry, mimicking real-life scenarios. This immersive experience provides access to highly sought-after equipment without the associated costs or logistical challenges.

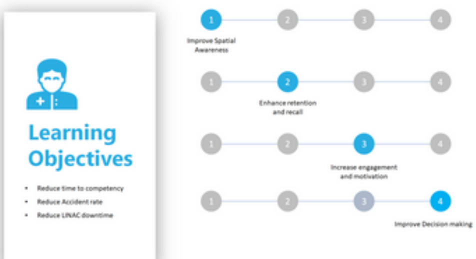

Figure 6: Learning Objectives

The utilization of VR in radiotherapy training is a relatively novel concept, yet it boasts several distinct advantages, both qualitative and quantitative. For instance, research indicates [6] that patients who participate in VR-based education programs, offering detailed insights into their upcoming procedures, experience significantly reduced emotional distress. This underscores the platform's potential to enhance patient preparedness and resilience.

Furthermore, the VR platform offers considerable benefits for academic and medical professionals. It not only saves time for academic staff but also garners positive feedback from medical students, especially in terms of preparation for clinical placements. Students particularly appreciate the opportunity to practice in a risk-free environment, allowing them to familiarize themselves with clinical workflows before encountering real-world clinical settings. The case-study-based approach integrated within the VR training further bolsters medical students' confidence, ensuring they make the most of their time in clinical environments.

Beyond its educational applications, the VR platform is poised to improve patient outcomes and reduce healthcare expenses. This is achieved through multiplayer collaboration features and the facilitation of accurate treatment delivery. Accessible via both keyboard and Oculus VR Quest headset, the VR simulation bridges the gap between theoretical knowledge and practical application, offering a comprehensive and immersive learning experience. By embracing this technology, the medical field can enhance the efficacy of radiation therapy training and patient education, ultimately contributing to improved healthcare delivery.

VR experience may provide a comprehensive learning environment that enables students to acquire the knowledge, skills, and attitudes necessary to deliver safe and effective radiation therapy. By providing an immersive and interactive experience, students can learn to apply the expected learning outcomes in a practical and engaging manner, improving their confidence and competence in delivering radiation therapy.

Implications for Practice

The implications of this study are manifold. Firstly, the adoption of VR in radiation oncology education could revolutionize how future oncologists are trained, offering them an immersive learning environment that closely mimics real-life clinical situations. This could potentially shorten the learning curve for complex procedures and improve clinical outcomes. Furthermore, the use of VR could facilitate continuous professional development and skill enhancement among practicing oncologists, enabling them to stay abreast of the latest techniques and treatment modalities in a rapidly evolving field.

Limitations

Despite the promising findings, this study is not without limitations. The sample size of 32 participants, while sufficient for preliminary analysis, is relatively small, and larger studies are needed to generalize the results. Additionally, the study focused on short-term knowledge gains, and the long-term retention of information learned through VR remains to be explored. The study also did not compare VR education directly with other educational methods, such as traditional lectures or hands-on training, which could provide further insights into the relative effectiveness of VR in medical education.

Directions for Future Research

Future research should aim to address these limitations by conducting randomized controlled trials with larger sample sizes to validate the findings of this study. Comparative studies examining the effectiveness of VR against other educational modalities in radiation oncology and other medical fields would also be valuable. Furthermore, investigating the impact of VR education on clinical skills and patient outcomes would provide a more comprehensive understanding of its role in medical training [7]. Additionally, exploring the long-term retention of knowledge and skills acquired through VR and the potential for VR to support interdisciplinary learning in healthcare could open new avenues for educational innovation.

Conclusions

The cost-effective virtual reality (VR) platform serves as a powerful enhancement to existing traditional educational methods by providing a consistent and replicable approach to patient education. The survey [8] remains open and we invite you explore the forefront of medical innovation by participating in our VR radiation Oncology study.

As the healthcare industry evolves towards more cost-effective methodologies, the scalability of Augmented Reality (AR) and Virtual Reality (VR) technologies presents a significant opportunity for enhancing healthcare education. The research we have analyzed consistently shows that AR/VR training is at least as effective as traditional training methods for individuals new to clinical settings. Specifically, for residents in radiation oncology, these technologies offer a deeply immersive learning experience crucial for developing the visuospatial and technical skills necessary in the field. The potential for integrating AR/VR extends well beyond the confines of residency training. Practicing radiation oncologists could benefit from AR/VR technologies to demonstrate their procedural skills as part of their continuous certification process, ultimately contributing to higher patient safety and maintaining the utmost quality of care. This forward-looking approach not only redefines educational paradigms within healthcare but also aligns with the pressing need for cost-efficiency and excellence in patient treatment outcomes.

1. User Friendly interface, easy to onboard and relatively easy to add contents
2. Supports multiple file formats but the file size is a huge problem as the size limit is only 100MB. That is not big enough for 3D models
3. Avatar customization support is great and you can have your own digital twin in the space if you feel lonely
4. Creating collaborating learning environment is relatively easy and invites users to go through the training at their own pace and time.
5. We have seen up to 66% improvements of scores after the trainees have gone through the contents and acquired Radiation Oncology knowledge in the VR space.
6. Users find it easier to navigate and get unlimited access to contents and set-ups

In conclusion, this study underscores the potential of VR as an effective educational tool in radiation oncology, highlighting its capacity to improve learning outcomes with minimal attempts. By offering an immersive, interactive learning experience, VR has the potential to enhance the training of future oncologists and contribute to the advancement of cancer care. Despite its limitations, this research paves the way for further exploration of VR in medical education, promising to revolutionize how healthcare professionals are trained in the digital age.

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Author Biography

Kulbir S. Sandhu is a global head of R&D at Varian Medical systems. Kulbir Started his career with Hitachi and subsequently taken on progressive technical roles with Abbott, Roche and Earlens, focused on developing innovative medical devices and therapies in Cardiovascular, Oncology and mental health. Kulbir is a co-inventor of more than 60 patents in medical devices and healthcare technology. Kulbir received his MS in Electrical Engineering from San Jose State University (1999), MBA in Finance and Strategy from Johns Hopkins University (2008).

Marie Vans is an associate professor of Systems Engineering at Colorado State University. She was a senior research scientist at HP Labs from 2000-2021. She is the author of more than 55 publications and 35 U.S. granted patents. Experienced in developing virtual reality simulations for education, product introduction, and analytics associated with educational experiences in VR. In addition, she has done research in natural language processing, document understanding & analytics, image analytics as well as security printing, information science, automatic 3D printer part defect detection, and bio-analytics.

Appendix: Survey Instrument

1. What does the term "malignant" mean in the context of cancer?
   a. Cancer that is easily treatable
   b. Cancer that does not spread to other tissues
   c. Cancer that can invade adjacent organs and spread to other tissues
   d. Cancer that is benign and harmless
2. What are the three primary therapies for cancer mentioned in the text?
   a. Acupuncture, naturopathic medicine, chiropractic
   b. Surgery, radiation, and chemotherapy
   c. Nutrition, pain management, genomics
   d. Depression, anxiety, fatigue management
3. What is the main goal of precision medicine in cancer treatment?
   a. To provide generic treatment options for all cancer patients
   b. To focus on treating pain and depression in cancer patients
   c. To tailor treatment to the specific genetic profile of a patient's tumor
   d. To use only surgery as the primary treatment for all cancers
4. What is the phenomenon where cancerous cells invade blood vessels to obtain oxygen and nutrients?
   a. Angiogenesis
   b. Metastasis
   c. Radiotherapy
   d. Chemotherapy

5. Which of the following factors can't contribute to the development of cancer?
   a. Exposure to toxic agents
   b. A diet rich in fruits and vegetables
   c. Consuming alcohol and tobacco
   d. Hereditary genetic anomalies
6. What percentage of the total circulating lymphocyte population is comprised of natural killer cells?
   a. 1-5%
   b. 5-15%
   c. 15-25%
   d. 25-35%
7. What is the primary role of natural killer cells in the immune system?
   a. Recognizing specific antigens and releasing toxins
   b. Creating antibodies against viruses
   c. Destroying cancer cells and viral-infected cells
   d. Producing interferons to fight infections
8. How do natural killer cells kill their target cells?
   a. By inducing apoptosis in the target cell
   b. By engulfing and digesting the target cell
   c. By blocking the target cell's receptors
   d. By producing antibodies against the target cell
9. What is radiation therapy primarily used for?
   a. Treating bacterial infections
   b. Managing pain in cancer patients
   c. Killing cancer cells and shrinking tumors
   d. Reducing inflammation in the body
10. Which types of radiation are used in radiation therapy?
    a. Radio waves and microwaves
    b. Sound waves and ultraviolet rays
    c. X-rays, gamma rays, and protons
    d. Infrared radiation and visible light
11. What is the most common type of radiation therapy used to treat prostate cancer?
    a. External beam radiation therapy (EBRT)
    b. Brachytherapy
    c. Stereotactic radiation therapy (SRT)
    d. Chemotherapy
12. How long does a typical radiation therapy session last?
    a. 5 to 10 minutes
    b. 15 to 30 minutes
    c. 1 to 2 hours
    d. Several days
13. What are some common side effects of radiation therapy?
    a. Weight gain and muscle growth
    b. Skin changes and hair loss
    c. Improved memory and cognitive function
    d. Reduced appetite and fatigue
14. Why are radiation machines surrounded by thick concrete and often housed in the basement of hospitals?
    a. To make the hospital look more secure
    b. To protect the machines from dust and moisture
    c. For safety reasons, as radiation machines need shielding
    d. To keep the machines hidden from patients
15. What is the name given to the room where radiation treatments are administered?
    a. The Radiation Lab
    b. The Radiation Chamber
    c. The Radiation Vault
    d. The Radiation Suite
16. How often did the patient receive radiation treatments?
    a. Once a week
    b. Every day except Saturday, Sunday, and holidays
    c. Only on weekdays
    d. Once a month
17. During a radiation treatment session, where are the radiation therapists while the machine is in operation?
    a. Inside the treatment room with the patient
    b. In the basement of the hospital
    c. Outside the treatment room, monitoring the patient
    d. In a different building
18. How is the radiation therapy tailored for each patient?
    a. Patients receive the same dose and duration of radiation
    b. Radiation therapy is not customized; it's a standard treatment for everyone.
    c. Radiation doses are adjusted based on the tumor location and the body's response.
    d. All patients receive chemotherapy in conjunction with radiation therapy.
19. What is the primary goal of radiation therapy in treating cancer?
    a. To reduce pain in cancer patients
    b. To target and kill abnormal cancer cells in tumors
    c. To stimulate the immune system
    d. To prevent the formation of tumors
20. What role does the linear accelerator (LINAC) play in radiation therapy?
    a. It measures the patient's radiation dose
    b. It controls and conforms the radiation beam
    c. It administers chemotherapy to patients
    d. It monitors the patient's vital signs
21. How are high-energy electrons accelerated in the linear accelerator?
    a. By a series of magnets
    b. By microwave radiation
    c. By radio frequency waves and an electron gun
    d. By heating a tungsten filament
22. What is the purpose of the primary collimator in the LINAC?
    a. To generate radio frequency waves
    b. To control the temperature of the electron gun
    c. To shape the x-ray beam into a cone
    d. To measure the radiation dose
23. How is the size of the clinical radiation beam defined?
    a. By the primary collimator
    b. By the waveguide
    c. By the tungsten target
    d. By the multi-leaf collimator
24. What is the purpose of the multi-leaf collimator (MLC)?
    a. To control the LINAC's cooling system
    b. To create radio frequency waves
    c. To shape the x-ray beam to match the tumor's shape
    d. To measure the radiation dose
25. How is clearance defined in the context of LINAC treatment?
    a. It refers to the number of ionization chambers used.
    b. It is a combination of the distance and head diameter.
    c. It measures the energy of the x-rays produced.
    d. It indicates the temperature of the tungsten filament.