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Exploring the Prospect of Enhancing Cancer Radiotherapy in Hospitals and Health Care Centers in Nigeria Through Artificial Intelligence: A Promising Frontier

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ABSTRACT: Radiotherapy remains a cornerstone in the treatment and management of cancer, however, current developments in artificial intelligence (AI) have shown promising opportunities in this field. Hence, the objective of this paper is to assess the need for integrating artificial intelligence to enhance cancer radiotherapy in hospitals and healthcare centers in Nigeria, using the twelve radiotherapy centers across the country. The article highlights the need for Nigerian hospitals and healthcare centers to start working towards embracing and integrating AI techniques into her radiotherapy (RT) procedures for optimized cancer treatment. Also, important groundwork required to ease the integration process is discussed. To highlight the need for Nigerian hospitals and healthcare centers to embrace and integrate AI into their radiotherapy procedures, a state-of-the-art review of accessible literatures from Scopus, PubMed, and Google Scholar was carried out. Finally, several applications of AI (machine/deep learning) techniques in radiotherapy were identified. Also, the current status of radiotherapy services in Nigeria and factors hindering its marriage with AI has been highlighted. Necessary groundwork required for a seamless AI integration was equally highlighted.

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Cancer is a deadly disease that has claimed lives the world over. Radiotherapy (RT), also known as radiation oncology, involves the use of radiation to control or eliminate tumour or cancer cells while minimizing damage to healthy tissues. This has, over the years, been one of the most effective ways employed to combat cancer globally. In Nigeria, radiotherapy services commenced since 1969 when the first Co-60 teletherapy machine was installed in Lagos University Teaching Hospital (Manson *et al.*, 2023). The international agency for research on cancer (IARC) reports from global cancer observatory (GCO) that, Nigeria with a population of over 206 million has an alarming number of 124, 815 new cancer cases including 79,000 deaths in the year 2020 (IARC/GCO, 2021). The top five cancer cases with the highest incidence and mortality are: breast, prostate, cervix uteri, non-hodgkin lymphoma, and liver cancers

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respectively, as shown in figure1. These disturbing statistics call for serious concern and serves as a clarion call for all stakeholders to device more standard and advanced ways of combating the scourge. It is currently obvious that advancement in technology, over time, has shaped the landscape of modern healthcare via artificial intelligence (Andersson *et al.*, 2021; Murphy Liszewski, 2019). The approval of AI in tuberculosis detection by the world health organization (Anazodo *et al.*, 2022) is heartwarming and a testament to the fact that AI has come to stay in our healthcare system. AI involves the application of algorithms and machine learning techniques to make machines imitate the cognitive functions of humans while also adapting to changing scenarios. It has surprisingly transformed the frontiers of medical interventions in a short time. Its integration into radiotherapy has promised a more streamlined, accurate, precise, and speedy cancer treatment procedures, that greatly minimizes radiation impact on healthy tissues (Kumar *et al.*, 2023; Sebastian, 2022). As the world partake strongly in these emerging frontiers of AI integration into precision medicine and radiotherapy, it is distressing to note that Africa's RT clinics and specifically Nigeria's twelve RT centers are not following the tide at the speed it should, and therefore lagging behind in planning and implementation efforts (Aruah, *et al.*, 2023a; Botwe *et al.*, 2021; Ige *et al.*, 2019; Manson *et al.*, 2023). This study elucidates the basic concept of AI and the several applications of its techniques (machine/deep learning) in radiotherapy. It highlights the need for Nigerian hospitals and healthcare centers to start working towards embracing and integrating AI techniques into her radiotherapy (RT) procedures for optimized cancer treatment. Also, challenges faced by RT centers and important groundwork required to ease the AI integration process is discussed.

Artificial Intelligence (AI): This is the ability of machines to simulate human intelligence in a manner that they can learn and think like human beings. The goal is to create machines that are self-reliant by virtue of their thinking, learning and problem-solving abilities (Bini, 2018; Janiesch *et al.*, n.d.). Subsets of AI are machine learning and deep learning (see figure 2). AI powered products include amazon Alexa – a personal assistant and it's currently applied in self-driven cars, robots like Sophia, speech apps like Apple's Siri, translation apps like Google Translate, etc.

Machine Learning (ML): This is a subclass of AI but is focused on developing computer algorithms and predictive models that solve problems having learnt patterns from data. for ML, it's performance 'improves with experience' (Bini, 2018; Janiesch *et al.*, n.d.). See figures 2 and 3. Three common types of ML are supervised (SL), unsupervised (UL) and reinforcement learning (RL). The first involves the use of labeled data for predicting future outcomes. Here, the model is trained with an input variable as well as an output variable. Examples of SL are: support vector machines (SVM), decision tree, logistic regression, Naive Bayes and linear regression. Unlike SL, UL uses unlabeled data from which patterns and hidden features are identified. E.g., anomaly detection, k-means clustering etc. The objective of RL is to instruct an agent in accomplishing a task within an environment characterized by uncertainty. The agent is provided with observations and a reward by the environment, and it communicates actions back to the environment. The reward serves as a metric to evaluate the effectiveness of an action in achieving the task's objective. Example of RL algorithm is Q-learning. ML processes require seven steps: Data gathering, pre-processing, model selection, model training, model testing, model tuning and prediction of results. Practical applications of ML include, fraud detection, sales forecasting, stocks prediction, treatment response prediction of patients during medical procedures etc.

Deep Learning (DL): DL is a subset of ML that involves algorithms tailored towards the functioning and structure of the human brain. It involves the use of neural networks with several layers and have the capacity to learn complex patterns from structured and unstructured datasets (Bini, 2018; Janiesch *et al.*, n.d.). DL network accepts data via the input layer, investigates hidden patterns and features using the hidden layer and outputs the predicted outcome of the process via the output layer (see figures 2 and 3).

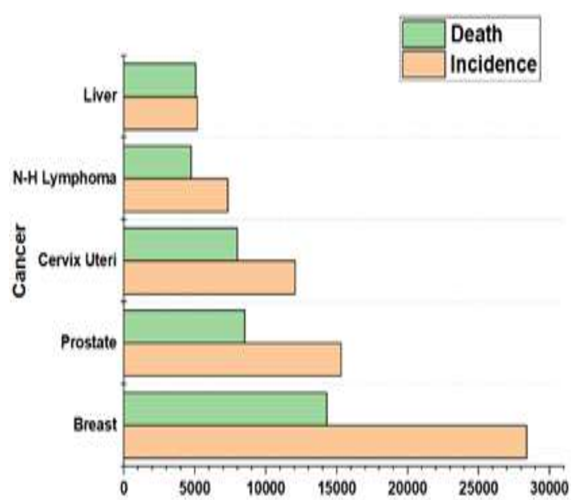

Fig 1: Top 5 cancers in Nigeria (Data adapted from (IARC/GCO, 2021))

Examples of deep neural networks are (Harrou *et al.*, 2022; Sarkar *et al.*, 2022): Convolutional Neural Network (CNN) – used mainly in image analysis, Generative Adversarial Network (GAN) – used mainly to generate synthetic images via two neural networks (generator and discriminator), Recurrent Neural Network (RNN) – used mainly in tasks demanding sequences like, natural language processing, time series prediction and speech recognition. In addition is, Deep Belief Network (DBN) – used mainly to probabilistically capture intricately ordered patterns in data applications of DL include, object detection, image colouring and enhancement, cancer detection etc. Table 1 shows the applications of ML/DL algorithms in cancer care.

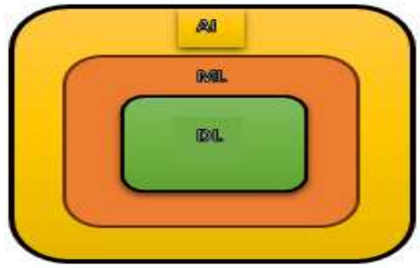

Fig 2: Artificial Intelligence and sub groups

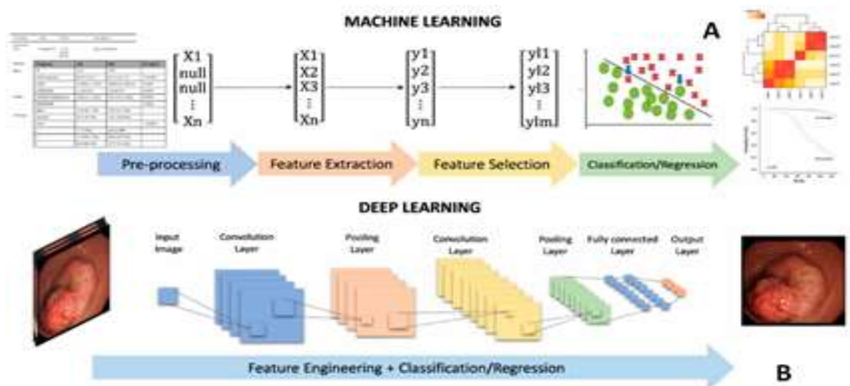

Fig 3: Showing ML -A and DL (CNN) -B (Qiu *et al.*, 2022)

Table 1. Applications of several ML/DL algorithms in cancer care (Adapted from (Ahmed *et al.*, 2020))

Selected ML/DL Algorithm	Examples of Applications in Cancer care
Support Vector Machine (SVM)	For breast cancer via SNPs analysis, and analysis of genomic, pathologic, clinical and epidemiologic data
	For oral cancer via molecular, genomic and clinical data analysis
	For cervical cancer via pathological and clinical data analysis
Deep learning e.g. CNN, GAN, RNN	Lung, skin and prostate cancer, detection
Logistic regression	Risks assessment of tuberculosis and breast cancers
Linear regression	Predictive modelling of prostate, brain and breast cancers
K-nearest neighbor	"Classification of Lymph node metastasis in gastric cancer"
	Classification of patterns in breast cancer diagnosis
	Prediction of pancreatic cancer

KEY: SNP- Single Nucleotide Ploymorphism

AI Integration into Radiotherapy procedures

1. *Treatment planning and personalization:* Designing a personalized and effective treatment strategy for patients who are candidates for radiotherapy is important for treatment success, as indicated in (Qiu *et al.*, 2022) where AI was used in colorectal cancer detection. It involves tailoring the treatment using patient-specific information to ensure that radiation is precisely delivered to intended lesion while reducing exposure to healthy tissues. DL algorithms are used to analyze large datasets while also learning from previous plans, hence can predict and enhance personalized treatment plans. Therefore, when aligned with treatment goals, we get automatically optimized beam angles and adjusted beam weights, as well as fine-tuned dose distributions (Dlama, 2022) which are key for best results.

2. *Treatment delivery:* Administering the treatment plan to a patient result from knowing the precise volume of target tumour, the appropriate dose required and optimizing other treatment parameters. Specialized machines like linear accelerators (LINACs) are employed for treatment delivery. Imaging data obtained in the course of treatment can be analyzed via DL algorithm to detect any changes or variation in lesion size and patient's anatomy. The information gotten can be used to adjust the treatment plan (in real time). Hence, precise delivery of radiation is ensured despite variations in anatomical structures. This is called adaptive radiation therapy.

3. *Image Registration and Verification:* The importance of imaging in radiotherapy cannot be overemphasized. Image guidance via AI has proved to be very helpful (Zhao *et al.*, 2021). DL based registration and verification of images have assisted in accurate patient's positioning during radiotherapy. DL algorithms can align 'planning images' with 'treatment images' automatically hence, minimizing the need for manual interventions and adjustments.

4. *Image Contouring and Segmentation:* Before, during, and after a radiotherapy session, imaging is key to measuring success rate of the procedure. DL enhanced image contouring and segmentation for accurate delineation of tumour volumes and other critical structures, has shown high accuracy as used in (Kano *et al.*, 2021; Lin *et al.*, 2019) for cervical and head and neck cancer delineation. This has also reduced the long hours spent on manual delineation and its attendant unintended but unavoidable variability in results.

5. *Quality assurance:* DL can be deployed to automatically flag potential problems like discrepancies in dosing (planned dose vs. delivered dose), anatomical variations and other issues that go against the treatment plan. QA with respect to machines and patients (contouring and dosing) show promising results when optimized with AI alongside other optimization efforts (Luk *et al.*, 2022; Simon *et al.*, 2021). With this, the medical physicist ensures a strict adherence to safety guidelines and standards.

6. *Patient's Monitoring, Support, and Response:* DL algorithms can constantly monitor a patient's progress during treatment and offer 'adaptive decision support'(Siddique Chow, 2020). AI powered virtual assistants and chatbots can be used to give patients needed information about the treatment procedures (Rebelo *et al.*, n.d.), to assuage their fears and concerns, and offer them the needed support for premium patient's experience. Also, patient's data can be analyzed including their treatment outcomes using DL algorithm to help predict how a patient would respond to radiotherapy procedures (Fionda *et al.*, 2020). This can help in treatment personalization for efficient results.

7. *Resource Optimization:* Effective allocation of personnel, scheduling patients' appointments and equipment maintenance, automation of data entry, image pre-processing tasks and similar routine tasks are examples of resource optimization abilities of AI in radiotherapy procedures (Lazebnik, 2023). This saves the time of the oncologist and medical physicist as they focus on more critical and dauting tasks.

8. *Total Work flow efficiency:* An overall work flow efficiency is enhanced using AI in radiotherapy. Treatment planning, image analysis, dose optimization, real-time treatment monitoring etc. employ cutting-edge AI algorithms to competently interpret complicated medical datasets (images) for precise lesion detection and organ delineation (Huynh *et al.*, 2020; Wang *et al.*, 2019). This is made possible by their constant learning from new data and from experiences in a process called adaptive learning, which eventually ensures precision, efficiency and improved patient outcomes.

9. *Research:* With the collection of vast amounts of patients' information like, imaging data, medical history, treatment outcomes, and patients' demographics, AI can help to identify patterns and extract useful insight from them hence, encouraging a better understanding of responses to treatment and the several factors influencing treatment outcomes. Note that these insights could have been overlooked by human researchers. Also, researchers, by virtue of AI adaptability, will find opportunity to improve and update treatment strategies as fresh data become accessible. This will foster a continuous and persistent learning cycle.

Factors Impeding AI Integration into Nigeria's Radiotherapy Procedures: Studies have shown that AI integration into Nigerian RT services will hit the rocks due to several challenges facing the sector. Tables 2 and 3 summarize this fact.

1. *Poor funding of hospitals and deficiency in infrastructure.* Most treatment centers available in Nigeria are government owned but are largely underfunded and underequipped (Aruah, Chidebe, *et al.*, 2023b). According to the above studies, there are 8 public funded RT centers in Nigeria, five have LINAC among which only 3 were functional as at 2021. Facilities like alternative power and water supply are largely inadequate. Generally, the country faces gross inadequacy in the number of functional radiotherapy machines, Treatment Planning Systems, modern 3D CT simulation equipment and nuclear medicine scanners (PET and SPECT), software etc. (Aruah, Chidebe, *et al.*, 2023b). See table 3.

2. *Paucity of needed staff:* When AI is deployed and there are no required manpower to manage it, it will be a waste of resources. Currently, the manpower situation of RT centers is very poor. (Aruah, Chidebe, *et al.*, 2023b) reports that there are forty-four radiation oncologists, forty-four medical physicists, forty-two radiation therapists, forty-five resident radiation oncologists, eight dosimetrists, fifty-seven oncology nurses, eight nuclear medical physicians, fifteen biomedical engineers and seven mould room technicians in Nigeria's government-funded RT centers (figure 4) which are supposed to cater for over 223 million people. The absence of inhouse or onsite technicians to attend to machine break-downs is the cause for most downtime experienced in most centers.

Table 2. Studies on artificial intelligence integration into radiotherapy across the globe

Study	AI Application In Radiotherapy
Esteva et al, 2017 (Esteva *et al.*, 2017)	A CNN was trained with 29,450 clinical images. It successfully **classified cancerous skin diseases** from non-cancerous ones. Was validated by 21 board-certified dermatologists.
Haskins *et al.* 2019, Cao *et al.*, 2018 (Haskins *et al.*, 2019)(Cao *et al.*, 2018)	AI based **Image registration** which is an important aspect of contouring and dose accumulation was successfully carried out. Clinical validation is pending
Zhong *et al.*, 2021, N. Pham, et al, 2022 (Pham *et al.*, 2022; Zhong *et al.*, 2021)	AI-based **segmentation tools** have been applied to tumors, normal tissues lymph nodes of brain, breast, heart, neck etc. Open source and commercial software available to the public.
Liu *et al.*, 2020, Dai et. al., 2021 (Dai *et al.*, 2021; Yingzi Liu *et al.*, 2020)	The successful implementation of **Synthetic Image Generation** facilitates comprehensive Magnetic Resonance (MR)-based planning by mitigating the discrepancies arising from the transference of contours between distinct image modalities, attributed to organ motion.
Takahashi et. al., 2020 (Takahashi Mori, 2020)	Artificial Intelligence (AI) has played a pivotal role in enhancing **Radiation Therapy (RT) treatment planning** by producing individualized dynamic motion management models tailored to patients. These models exhibit the capacity to enhance tumor tracking and intervene in instances of radiation delivery occurring in suboptimal target positions. Furthermore, the algorithms are capable of autonomously adapting to comprehensive respiratory patterns in real-time, thereby ensuring precise tracking and anticipation of tumor positions.
Kurosawa et. al., 2020, Gustafsson et. al., 2020 (Gustafsson *et al.*, 2020; Kurosawa *et al.*, 2020)	Accurate patient **positioning and monitoring** have been ensured via AI
Huang et al 2020, De Felice et al 2021, Tian et al 2019, Van et al 2021, Ubaldi et al 2021, Kawahara et al 2021, Haak et al, 2021, Yang et al 2021, A.L.D. Araujo, *et al.*, 2023; (Araújo *et al.*, 2023; De Felice *et al.*, 2021; Haak *et al.*, 2022; Huang *et al.*, 2020; Kawahara *et al.*, 2021; Sanne G.M. *et al.*, 2022; Ubaldi *et al.*, 2021; Z. Yang *et al.*, 2021; Zhen Tian *et al.*, 2019)	**Outcome prediction** like disease progression, toxicity, overall survival, disease recurrence, treatment response, quality of life and tumour classification and detection of several cancers have been successfully carried out in these studies among others.
S. Xie, *et al.*, E. Gong et al (2020) (Gong *et al.*, 2018; Xie *et al.*, 2018)	AI-powered algorithms were used to improve or better still, remove **low-dose CT artifacts** and reduce **noise in MRI images**
T.J. Loftus, *et al.*, 2020; S.P. TerKonda, et al F. Chadebecq *et al.* (2023); (Chadebecq *et al.*, n.d.; Loftus *et al.*, 2020; TerKonda *et al.*, 2024)	**Personalized treatment** and surgical strategies are enhanced by AI for surgical success. Also, **surgical robots** (its use records 30% increase/yr. in China) are powered by AI using millions of datasets
S. Markun, *et al.*, 2017, N.P. Birur, *et al.*, 2018 J. Griffin, *et al.*, 2020; (Birur *et al.*, 2018; Griffin *et al.*, 2020; Markun *et al.*, 2017)	Remote diagnosis via **mobile tele-dermatology and digital pathology** have been adjudged efficient in remote skin cancer screening and detection of oral cancers respectively.
H. Bollen, et al, 2023; C.E. Cardenas, *et al.*, D.J. Sher, *et al.*, (2021) (Bollen *et al.*, 2023; Cardenas *et al.*, 2021; Sher *et al.*, 2021)	**Precision in dosing** to prevent harm to healthy tissues. **Commercially available NN/CNN-powered volumetric dose prediction for head and neck cancers are efficient.**
M.F. Gensheimer, et al 2018; N. Kim, *et al.*, 2021 (Gensheimer Le, 2018; Kim *et al.*, 2021)	**Adaptive radiotherapy** which ensures treatment plan is changed for efficacy during the course of treatment, due to new imaging information available to doctors, has been made possible by AI
S.L. Kerns et al 2014; D.W. Yang, *et al.*, 2020; (Kerns *et al.*, 2014; D. W. Yang *et al.*, 2020)	AI has helped to **discover and validate new biomarkers** (genes, proteins, metabolites) which helps to predict patients' response to radiotherapy

This causes patients to wait for months before continuation of treatment. Information Technology (I.T) staff, which are vital for AI deployment, are also very inadequate.

3. Lack of Image databank and I.T infrastructure: I.T infrastructure is a very crucial need before A.I is deployed to clinics because it supports connectivity, security, data management, as well as AI solutions' integration with existing healthcare systems for a better patient care. It is obvious that AI relies much on large number of datasets for model training, validation and testing. So, health centers need a robust data bank for medical images as well as an efficient database for storage, management and safe retrieval of patients' medical records and other important information. A secure network which guarantees the safety and privacy of patients' records, images, and the like is a requirement that is currently lacking in Nigeria's healthcare systems and RT facilities in particular.

Table 3. Showing status of radiotherapy equipment among West African countries (Data gotten from (Manson *et al.*, 2023))

S/N	Country	RT Centers	MV Therapy	Proton Ion therapy	X-ray (KV) Therapy	Brachytherapy including El	Population (estimated in Million)	Total number of equipment per million of population*
1	Burkina Faso	1	1	0	0	0	23	0.05
2	Cote D'Ivoire	1	2	0	0	0	28	0.08
3	Ghana	3	6	0	0	3	34	0.29
4	Mali	1	1	0	0	0	23	0.05
5	Mauritania	1	3	0	0	1	4.5	0.86
6	Niger	1	1	0	0	0	27	0.04
7	**Nigeria**	**7**	**9**	**0**	**0**	**2**	**223**	**0.05**
8	Senegal	2	2	0	0	1	17	0.18
9	Togo	1	1	0	0	0	9	0.12
	*IAEA requirement (Stecklein *et al.*, 2020): 1RT Equipment for every 1million people, MVM- **Mega voltage radiotherapy Machine**							

Table 4. Summary of Nigeria's Radiotherapy Status and her level of preparedness for AI integration***

	Radiotherapy System					General Information				AI Preparedness	
Radio-therapy Centers	**LINAC (Status)**	**Co-60 (Status)**	**Brachy therapy (Status)**	**Simulation equipment (3D CT)**	**Treatment Planning System (TPS)**	**Ownership Status**	**Sufficient Manpower**	**Regular staff Training**	**Sufficient funding, salaries, maintenance budget**	**Training on AI use in Radiotherapy/ Awareness Programs**	**Suitable AI Infrastructure softwares/ Adequate training dataset**
[a]Abuja	**2(F)**	**0**	**LDR-F HDR-NF**	**1 (F)**	**1(F)**	**G**	**No**	**No**	**No**	**No**	**No**
[b]Enugu	**1(F)**	**0**	**HDR-NF**	**0**	**0**	**G**	**No**	**No**	**No**	**No**	**No**
[c]Owerri	**0**	**1**	**NI**	**0**	**NI**	**P**	**NI**	**NI**	**NI**	**NI**	**NI**
[d]Lagos 1	**2 (F)**	**0**	**HDR-NF**	**1 (F)**	**1(F)**	**G**	**No**	**No**	**No**	**No**	**No**
[e]Lagos 2	**0**	**1 (F)**	**0**	**NI**	**1 (NI)**	**P**	**7 staff**	**NI**	**NI**	**NI**	**NI**
[f]Lagos 3	**2(F)**	**0**	**1-NI (F)**	**1 (F)**	**1 (F)**	**P**	**Yes**	**NI**	**NI**	**NI**	**NI**
[g]Ibadan	**1(F)**	**1 (NF)**	**HDR-F, LDR-NF**	**0**	**1(NI)**	**G**	**No**	**No**	**No**	**No**	**No**
[h]Sokoto	**1**	**0**	**HDR - NF**	**0**	**1(NF)**	**G**	**No**	**No**	**No**	**No**	**No**
[i]Kaduna	**0**	**1 (NF)**	**HDR-NF, LDR-NF**	**0**	**0**	**G**	**No**	**No**	**No**	**No**	**No**
[j]Gombe	**0**	**0**	**HDR-F**	**0**	**0**	**G**	**No**	**No**	**No**	**No**	**No**
[k]Edo 1	**1**	**0**	**HDR-F**	**0**	**0**	**G**	**No**	**No**	**No**	**No**	**No**
[l]Edo 2	**0**	**0**	**1-NI (F)**	**NI**	**NI**	**P**	**NI**	**NI**	**NI**	**NI**	**NI**
TOTAL	**10**	**4**		**3**	**6**						

KEY: G- Government owned, P- Privately owned, F-functional, NF-Not-functional, NI-No Information, HDR-High dose rate, LDR-Low dose rate a- National Hospital Abuja, b-University of Nigeria Teaching Hospital, c- Imo project in Ikeduru near Owerri, d-NSIA/Lagos University Teaching Hospital, e- EKO Hospital Lagos, f-Marcelle Ruth Cancer Center and Specialist Hospital, g-University College Hospital, h-Usmanu Danfodio University Teaching Hospital, i-Ahmadu Bello University Teaching Hospital, j-Federal Teaching Hospital, k-University of Benin Teaching Hospital, l- La'Newton Oncology Clinic, Edo

****Data from Akinwande et al., 2023; Aruah, Chidebe, et al., 2023b; La'newton Cancer Clinic Benin City (Https://Www.Lanewtononcology.Com), 2023; Marcelle Ruth Cancer Center and Specialist Hospital (Https://Marcelleruth.Com/Who-We-Are/#Section_47_3), 2023; The IAEA Directory of Radiotherapy Centres (DIRAC), Https:/Dirac.Iaea.Org/ (Accessed on 12/2023), 2023; Manson et al., 2023)*

4. *Poor and irregular Staff training:* Generally, staff training and retraining is poor for RT centers in Africa and specifically, Nigeria and A.I training is worse or nonexistent (Aruah, Chidebe, *et al.*, 2023b; Manson *et al.*, 2023). Curriculum for RT training and residency is outdated (Lawal *et al.*, 2023), and the eight universities that run postgraduate programs in RT focus more on the academic aspects and not the practical, clinical aspects needed in hospitals (Ige *et al.*, 2019). Staff need to understand how the novel technology works, including its pros and cons. They also need to know how to use AI applications (for treatment planning, diagnostics, personalized medicine etc.) and tools for seamless workflows,

enhanced clinical decision making and efficient patient care.

5. *No legal framework for use of patient's data for AI and related matters:* Currently there is no legal framework for AI deployment in Nigeria (Botwe *et al.*, 2021; Manson *et al.*, 2023). Issues bordering on who has the right to access patients' data, who owns the data, privacy etc. need legislation. Staff and Patients' rights, liability, data protection and ethical standards are important areas that need serious governance policies. This will in the end, protect patients and even clinicians from harm and prevent unnecessary legal fireworks and arbitrations.

6. *Poor awareness by members of the public:* Expectedly, some healthcare practitioners especially RT staff are aware of AI even though they are yet to be trained on it. But members of the general public among whom would be candidates for RT care are ignorant of it (Aruah, Obinna, *et al.*, 2023; Oluwadiya *et al.*, 2023). Providing healthcare generally involves patients putting their trust in their healthcare providers so, it's imperative to inform the public of the high incidence of cancer (Lawal *et al.*, 2023) and the advantage of early detection, and treatment. Additionally, they should be informed of the possible integration of AI into the cancer treatment procedures for improved care, and also the need for the deployment of patient's data (images) in that course. This act of transparency, when well-articulated, will boost the confidence of would-be patients especially when they get to understand that the benefits far outweigh the shortcomings, and that ethical usage would be ensured after seeking their informed consent. This will douse apprehensions, misconceptions and address genuine concerns, thereby promoting public acceptance of the integration efforts. This can also help the clinic to tailor the integration towards the sensitivity and concerns of the communities it serves

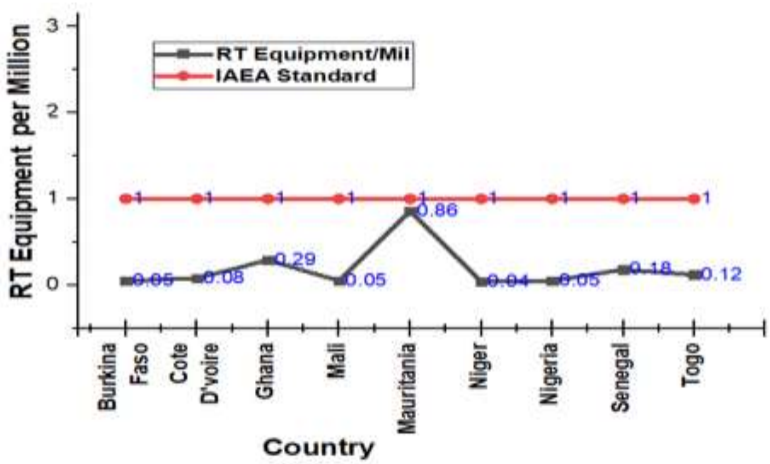

Fig 3. Graph Showing Number of RT Equipment Per Million of People in West Africa

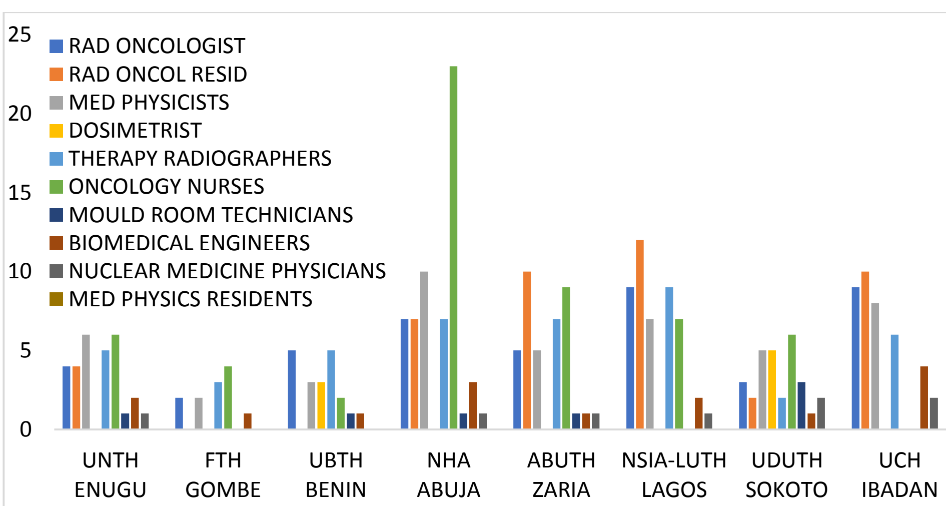

Fig 4. Staff Strength of Government-Funded RT Centers (Data adopted from (Aruah, Chidebe, *et al.*, 2023b))

Is Nigeria Ready for AI Integration into Her Radiotherapy Procedures?: As at December, 2023, studies show that there are a total of 12 radiotherapy centers in Nigeria and most are highly ill equipped for

RT services compared to other countries in the sub-region (e.g. Ghana and Mauritania) or elsewhere in Europe or America (figure 3). Among the centers, 8 are government-funded and 4 are privately owned as shown in table 4. Since government-funded RT centers are more in number, they naturally attract much emphasis in this study as they also cater for a larger number of the population in addition to their lower cost of treatment (Aruah, Chidebe, *et al.*, 2023b), as compared to the few privately owned centers. At the end of the year 2023, most government-funded RT centers are still partially functional or completely non-functional due to several challenges like constant machine breakdowns, unavailability or insufficiency of specific machines and software, lack of specialists manpower, lack of in house maintenance staff for RT machines and other equipment, unavailability of alternative power and water supply, inadequate/irregular staff training and retraining, poor remuneration of staff, and general neglect and poor funding by government. The private centers are few, and cannot cater for the vast majority of the patients. Their high cost of treatment, geographical locations and current security concerns may hinder people from travelling long distances to seek care. So, in this situation where the fundamentals are grossly lacking, AI integration can hardly be on the table for discussion among hospital managers or the government. AI is capital intensive to deploy (Chen Decary, 2020; Manson *et al.*, 2023) so, it is not surprising to see that Nigeria RT centers (and most African countries) have not keyed into it. AI studies are yet to be added to the medical school curriculum, no training and awareness program for medical staff in this respect, and ultimately, no infrastructure in place. It is safe to say that Nigeria currently, has little or no plans and preparations for AI integration into RT services in the country.

The following recommendations should help the situation. AI cannot be deployed on nothing, there must be infrastructure. The needed RT equipment, software, TPS, I.T centers, databases etc. must be on ground before its deployment. This is the first biggest problem that must be tackled. Also, employment of more staff with better pay is recommended because better remuneration will prevent brain drain in the health sector. Residency program for Nuclear Physicist, RT technologist and the likes will help them with the requisite practical clinical skillset for the job. Seminars, workshops and other train-the-trainer programs will help update their skills and the capacity to train any new staff. AI training programs should be organized for staff to get them abreast with the new reality of AI's marriage to medicine. AI models used in RT should be taught to staff, necessary software and troubleshooting skills should be taught as well. Government should include AI training in the schools' curriculum as this training will also help clinicians to explain satisfactorily the merits of AI to their patients, thereby dowsing their fears and reservations. Ethical standards and AI limitations would be learnt during trainings and staff would be reassured that AI will not make them jobless, rather it has come to ease and optimize the job for better health care delivery and patients' experience. Development of legal framework for AI deployment is important for data security, privacy and ethical issues. Templates from the European Commission should be a good guide. I.T infrastructure with efficient databases should be provided. A national data bank is key since a lot of images are required for successful modeling. Also, AI models need high computing power for training, so efficient servers and cloud computing facilities are required for the complex algorithms. To ensure effective maintenance of RT equipment and efficiency of healthcare services, including training and recruitment, a public private partnership (PPP) arrangement, already kickstarted by government in a few centers, should be expanded and sustained. However, considering the current harsh economic realities, pricing should be regulated or subsidized to encourage patients to seek care. Finally, the public needs to be educated generally about cancers and the need for early detection and treatment and emphasis should be made on the need to deploy AI in diagnosis and treatment. Information on how patients' data would be used and general privacy and ethical concerns should be appropriately addressed.

Conclusion: The advantages of embracing and integrating AI into Nigeria's radiotherapy protocols for optimized cancer treatment are very promising. The efficiency, speed and accuracy that it brings to bear in medical practice cannot be overemphasized. However, it is important that the infrastructural decay and other challenges in Nigeria's RT centers be addressed (in collaboration with the private sector). Also, the private sector should take the lead in the AI awareness, training, and integration efforts, in order that the country is not left behind in the current global race to deploy AI in the fight against cancer and other deadly diseases.

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