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MEDICAL PHYSICS INTERNATIONAL
The Journal of the International Organization for Medical Physics

Aims and Coverage:

Medical Physics International (MPI) is the official IOMP journal. It provides a platform for medical physicists to share their experience, ideas and new information generated from their work of scientific, educational and professional nature. The e-journal is available free of charge to IOMP members. MPI- History Edition is dedicated to History of Medical Physics.

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EDITORIAL FROM CO-EDITORS-IN-CHIEF

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Dear colleagues and friends,

We are happy to release the publication of Medical Physics International (MPI) Vol.13, No.1; 2025.

This current edition of MPI (Vol. 13, No. 1) contains 14 articles in various educational and professional areas of medical physics from contributors around the world.

The articles by Prof. Sprawls, Prof. Martin, and Prof. Padovani highlight the challenges, and present concepts for the effective development and dissemination of knowledge in medical physics education and practice. Prof. Chougule's article gives an overview of the possible role of AI in medical physics. Other articles describe various practical QC methods that the authors have used in their clinical practice. Of particular mention is the article by Dr. Uwadiae & Dr. Abdul reporting on the International Women's Day Workshop help in Nigeria, 2025.

We appreciate the support and research work of all those who have contributed to this current issue and encourage readers to continue submitting articles for future issues on matters of interest to the international fraternity of medical physicists.

COLLABORATING ORGANIZATIONS

WOMEN'S ISSUES MATTER: REPORT OF THE INTERNATIONAL WOMEN'S DAY WORKSHOP

I.B. Uwadiae, F.E. Abdul

Women's Committee, Nigerian Association of Medical Physicists

I. INTRODUCTION

The International Women's Day (IWD) is a global event marked annually on the 8th day of March to celebrate women. The first IWD was commemorated in 1911 well over a century and since then it has become a platform for shining the light on women's progress all over the world with the goal of fostering gender equality. According to the IWD, the aim of the day is to celebrate women's achievements, raise awareness on persistent issues concerning women, mobilize action for equality, donate and fundraise for women-focused charities, and foster solidarity amongst men and women [1]. The day is used as an opportunity to showcase their talents and have their voice.

Women all over the world celebrate this special day and scientists like Medical Physicists, are not left behind. Medical physics is a fast technically advancing field predominantly dominated by men and women in medical physics still form a small percentage compared to men [2, 3, 4]. Like other male dominated fields, there are challenges faced by female medical physicists. These challenges are not exclusive to female medical physicists; they are common to women building careers, particularly in male-dominated fields, as reported by some studies [5, 6, 7]. The challenges vary from region to region.

The perception of women in Africa for example, particularly those who pursue careers, has been met with diverse opinions. These opinions over the years continue to change and evolve slowly despite the resistance and traditional mindset and beliefs of the society [8]. Some examples of these mindsets even though unspoken, are that women who pursue careers like those meant for men, cannot effectively balance family life; women in high positions are only able to get the roles or opportunities they get because of their gender and so on [8, 9]. On the contrary, reports have shown that women must work as twice as the male counterparts to prove themselves and achieve those statuses. Traditionally in most African and western cultures decades ago, women's jobs were primarily home makers but in the present day, they have taken additional jobs that were traditionally meant for men [5].

One recommended way of trying to resolve these issues is to continue to create awareness, encourage more women to take up these careers to balance the male dominance and address the issues bothering career women through education. Workshops, webinars and similar events have been and are still effective tools in empowering women and imparting them.

As a way of bridging the gap, the Nigerian Association of Medical Physicists in 2025, decided to host a series of workshops to discuss these issues one after the other. It was important to showcase successful women who were at the peak of their careers who have succeeded in all areas of their lives including the family and are considered successful regardless of gender. Women who were considered to 'have it all'. This report is an evaluation of the effectiveness of the first IWD workshop organised by NAMP. The global campaign theme for the 2025 IWD was "*Accelerate Action".*

II. THE INSPIRATION

A survey was carried out in 2023 to identify the challenges facing the women in NAMP. The results of the survey revealed the following as the most common challenges:

- Not being able to balance building a successful career and being wives and mothers.
- Lack of confidence to take up leadership roles due to cultural and gender stereotypes.
- The stress of working and feeling the need to work twice as hard as the male colleagues to gain equal recognition.
- Lack of women to look up to, and mentorship opportunities; and
- Lack of women support groups

This outcome informed the decision to organize a series of workshops to address these challenges. The results of the survey only revealed that there were deeper issues facing women in science especially women in male dominated fields like physics and by extension, medical physics.

III. THE 1st WORKSHOP

The theme of the workshop was titled: *"Balancing work, life, career and family".* It was held on the 7th of March 2025 at 11 am to 1 pm GMT +1. The aim was to create an environment for women in medical physics and related fields to discuss specific issues affecting work-life balance by hearing from women who have overcome these barriers and challenges in question and have risen to attain the level of success they have attained in their careers and businesses while also winning at the home front. The women were well known leaders in their fields with global influence. The

workshop was held online via the zoom platform. 204 persons registered to attend. Even though the targeted audience were women, 11 % of the registrants were men and a few of them attended the workshop.

The workshop took the form of interactive, down-to-earth, no-holds-barred presentations mixed with conversations. The speakers spoke for 20 mins each on given topics, followed by questions from participants and a panel session. The topics were: (i) *Navigating Career Advancement while Prioritizing Family* delivered by Dr Modupe Oresegun (ii) *Managing bias and Stereotypes* delivered by Professor Soheir Korraa (iii) *Managing Cultural Expectations* delivered by Dr Zainab Shinkafi – Bagudu and (iv) *Career Advancement: Breaking the Glass Ceiling* delivered by Dr Anna Barnes.

At the end of the workshop, a feedback survey using Google forms was administered to gain perspective of the attendees' opinion of the program and to chart the course for the next set of workshops to be organized.

Fig. 1: 2025 NAMP IWD workshop poster

IV. SUMMARY OF THE PRESENTATIONS

Session 1: Navigating career advancement while prioritizing family- Dr. Modupe Oresegun (Radiation Safety Specialist).

Dr Oresegun spoke passionately about her topic as one who had successfully navigated the challenges well. Her presentation highlighted several barriers and crossroads women face when considering progression in their careers. One which was worthy of mention from her personal experience was the crossroad of decision to either focus on raising a family or accepting a life-changing offer that would 'sky-rocket' her career as a physicist. She shared tips on how to navigate such crossroads without sacrificing one for the other. She pointed out that that while it is a challenging task, it is possible to excel in both areas. She discussed factors that can hinder success for women, such as biological roles and societal expectations, as well as factors that facilitate success, like prioritizing one's children and spouse. She advised participants to enjoy their womanhood, be less ambitious when necessary, and use their success to benefit their families. Dr Oresegun concluded by encouraging women to choose happiness and balance their professional achievements with personal relationships and not sacrificing personal life for work.

Session 2: Managing gender bias and stereotypes – Professor Soheir Korraa (President, Women in Nuclear, Africa)

Professor Soheir was also a passionate speaker, and she traced the problem of gender stereotypes to its source by revealing how men and women have been programmed from childhood to take up certain roles, a major contributing factor to the now perceived traditional roles that men and women are expected to take. She emphasized the need for women to improve their skills and knowledge, and not to rely on societal expectations or gender roles. She also highlighted the importance of self-confidence and not being deterred by negative human emotions that may arise as one climbs the career ladder but to learn to manage them and use them to one's advantage. She highlighted the importance of self-satisfaction from the love received from family and the importance of not seeking external validation for one's achievements. The conversation ended with a call to action for participants to work hard and strive for personal growth.

Session 3: Managing cultural expectations - Dr Zainab Shinkafi - Bagudu (President-Elect, Union for International Cancer Control)

Dr. Zainab Shinkafi-Bagudu was another excellent speaker who had traversed many waters from medicine to politics to being an influential advocate for women's health. Her background and experience unraveled the unspoken challenges of the cultural expectations of women. She emphasized the importance of understanding cultural norms and expectations, and the impact it has and can have on one's career and personal life. She also highlighted the challenges faced by women, such as gender discrimination and the pressure to fulfil traditional family goals. Dr. Bagudu suggested strategies for managing cultural expectations, including education and awareness, advocacy and support networks, communication, and the role of mentors. She encouraged women to be agents of change and work together to challenge and redefine social norms.

Session 4: Career advancement: Breaking the Glass Ceiling – Dr. Anna Barnes (President, Institute of Physics and Engineering in Medicine)

Dr. Anna Barnes rounded off the talks with the all-too-important subject of breaking glass ceilings. She is the first female president of IPEM and was just the right person to do the topic justice. She shared her journey as a woman in science, from her early education to her current leadership role, she spoke on the importance of mentorship, building

professional networks, and developing strong communication skills to overcome barriers and advance in male-dominated fields. She also discussed how she deliberately took her time to develop her skills and network before stepping into leadership positions. Dr Barnes pointed out the importance of having allies, both male & female throughout one's career and building good rapport. She stressed the importance of knowing oneself and defining personal success, rather than being swayed by external accolades, noting the value of teamwork and work-life balance. She ended by highlighting the value of enjoying the journey rather than focusing solely on the career goal.

The profiles of the speakers are on the NAMP website [10], and the recorded talks can be found on NAMP's YouTube channel.

V. POST-WORKSHOP SURVEY

Several responses were received from the survey. In terms of educational qualifications, 57 % of the respondents had master's degree, 21 % had bachelor's degree while the rest had PhD as their highest level of education. All the responses came from women in the African continent, with Nigeria having over 70 %, while Tanzania and Cameroun had 14 % each. About 64 % of the responses were from scientists including medical physicists, 14 % from medicine and 7 % each from the social sciences and technology.

When asked about the topics that best resonated with them, 78 % resonated with the first session titled, Navigating Career Advancement while Prioritizing Family; 43 % resonated with Career Advancement: Breaking the Glass Ceiling; 21 % with Managing Gender Bias; and 14 % with Managing Cultural Expectations.

With regards to the effect that family responsibilities had on their career advancement, 36 % of the respondents agreed that family matters affected their career progression; 36 % were not sure; 21 % disagreed, while 7 % were unmarried and therefore could not relate. Those who attested to the effect of family on their careers in a free response section gave the following as reasons: raising children, cultural barriers, and lack of ample time for research.

In terms of the challenges of career development, most (50 %) of the respondents chose the ability to balance responsibilities as the number one challenge, followed by lack of mentorship (42 %), pregnancy & motherhood (36 %) and lack of funding (36 %). Participants were further asked if they would be interested in being mentored and over 70% agreed to participate, while 21 % were not sure.

VI. DISCUSSION

The workshop successfully fulfilled and contributed to the goals of the 2025 International Women's Day. The attention, enthusiasm and engagement by the participants showed that these topics were important and relevant. The issues discussed revealed underlying and unspoken issues bothering career women especially those in male-dominated fields and those who really want to succeed in all areas, including the home front. Aside from the fantastic topics presented, the nature and quality of the speakers were such that they had practical and relatable models that the participants could easily connect and identify with. These are women who had gone through life's challenges and still going through them to arrive at where they are today.

If women in Africa will survive and thrive in their careers, attention and consideration need to be given to their unique challenges. In this age of globalization, it would become very easy to lose track of cultural and traditional challenges unique to us. The standard of success need not be the same, success should be personalized. A woman who decides to take a break from her career to raise a family should not be considered less successful than one who had no career break and so goes similar examples. No one should feel pressured. We need more female models who have taken diverse paths to achieve the level of success they are in, to show the younger generation that it is possible.

The authors redirect the readers to a very comprehensive review study carried out by Torres et al [11]. They analyzed 52 papers that looked at the impact of motherhood on the career progression of women and concluded that there are negative and positive impacts with the former surpassing the latter. They offer valuable insights for organizations and policymakers with the goal to create environments that professionally support women while allowing them to fulfill their maternal roles.

It was discovered during and at the end of the workshop that there was a need to continue to have these conversations on a broader level, decimating more time to it. It was also discovered that there was a serious need for mentorship programs for women dedicated to addressing specific issues. There is no better way to address an issue than learning from the one who has experienced and dealt with it. The speakers and participants were open to the idea of mentorship as seen from the feedback survey.

As for the low number of female medical physicists in the world today, it can obviously be traced to the relatively limited number of women who study physics as a first degree whereby physics or sometimes engineering is the entry path to becoming a medical physicist. The way to increase the number of women in medical physics would be to increase the number of women who take up physics or engineering degrees. A lot of awareness needs to be created for this to happen.

VII. CONCLUSION

Overall, this workshop gave participants a sense of direction on how to balance their family, work, life and career and provided a beacon of hope to women who had long given up the desire to advance in their careers particularly in male-dominated fields. More workshops and seminars dedicated

to women are needed to promote these conversations and get enlightened. Topics should be tailored to the specific needs of women in a region, country or culture as they vary from place to place. Safe places for women to discuss more sensitive topics should be created without bias or barriers. If a woman thrives and succeeds, the workplace, family, society and humanity will thrive and succeed. Therefore, women's issues should concern all.

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EDUCATIONAL TOPICS

IMPACT OF 10 YEARS OF THE INERNATIONAL MASTER OF ADVANCED STUDIES IN MEDICAL PHYSICS

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Abstract— **The Master of advanced studies in medical physics (MMP) has been jointly organized by the International Centre for Theoretical Physics (ICTP) and the Trieste University since 2014, with support from IAEA. The MMP consists of one academic year followed by a year of supervised clinical training in hospitals. It aims to address the shortage of high-quality education and training for medical physicists in low- and middle-income countries (LMICs), equipping graduates with clinical skills and competencies to be applied in their home countries. The paper analyses the answers of 125 graduates, out of the 174 graduates up to the 2023, to a survey distributed in 2024 to evaluate the impact of the MMP on individual careers, clinical activities, and on the developed activities to contribute to the development of medical physics at national level.**

This paper analyses the responses of 124 graduates -out of a total of 174 graduates up to 2023 - to a survey distributed in October 2024. The aim is to evaluate the impact of the MMP on individual careers, clinical practice, and the graduates' contributions to the development of medical physics at the national level.

Keywords— **master after master, academic, clinical training, LMICs, survey.**

I. INTRODUCTION

The Master of Advanced Studies in Medical Physics (MMP) was jointly established in 2014 by the Abdus Salam International Centre for Theoretical Physics (ICTP) and the Trieste University with support of the IAEA. As an UNESCO and IAEA affiliated institution, the ICTP has been a driving force in advancing scientific expertise in the developing world for over 60 years. In line with this mission, the MMP programme aims to address the scientific demand for qualified and well-trained medical physicists in most of the low- and middle-income countries (LMICs). The programme requires important financial resources primarily provided by ICTP and IAEA, with additional contributions by TWAS (The World Academy of Science), KFAS (Kuwait Foundation for the Advancement of Sciences), and ACS (American Cancer Society).

The 2-year programme offers one academic year of theoretical classes followed by one year of supervised structured clinical training with the aim at addressing the scarcity of quality education and training of medical physicists in most LMICs [1]. An additional aim is to provide students with advanced academic knowledge and practical skills, to be brought back to their home countries and willing to train young medical physicists.

The academic education of the first year is covering the relevant specialties of medical physics, to prepare the student to enter, in the second year, in a formal clinical medical physics residency. The major outcome of the academic programme, based on IAEA recommendations [2], would be to provide students with a thorough grounding in the analytical methods and fundamental aspects of medical physics and instil an attitude of integrity, professionalism, critical-thinking and scientific rigor. Teaching is provided by academic staff, clinical medical physicists, radiation protection experts and health care professionals, like radiologists and radiation oncologist physicians.

This is followed by a full-time year of supervised clinical training in a medical physics department of a hospital in the programme's training network. The network for the clinical training comprises 26 Italian Medical physics department from university, oncology or general hospitals. The Resident practices mainly in a specific area of medical physics: diagnostic imaging or radiation oncology. The programme of activities developed and the assessment methodology of the acquired skills and competences are derived adapting the IAEA [3,4,5] and AFRA (African Regional Co-Operative Agreement for Research, Development and Training Related to Nuclear Science and Technology) [6] clinical training of medical physicist guidelines and are implemented in a resident's portfolio. At the end of the programme the resident has to defend a thesis on a research activity developed during the clinical training.

The programme was accredited by the International Organization for Medical Physics (IOMP) in 2016 and re-accredited in 2022**,** further enhancing the international recognition of the Trieste University degree**.** Additionally, graduates can pursue IMPCB (International Medical Physics Certification Board) certification exams at ICTP, thanks to the programme's collaboration with IMPCB since December 2018.

II. SURVEY RESULTS

Of the 174 graduates in the first 9 cycles of the programme 71% responded to the survey with the region and cycle distribution as reported in Table 2. On the financial support to the program: 76% and 16 % of graduates were sponsored respectively by IAEA and ICTP.

Table 2. Responses to the survey by the first 9 cycle graduates of the MMP programme (2014-2023).

Region	No. of graduates	No. of responders
Africa	85	56 (66%)
Asia	39	29 (74%)
Europe	12	10 (83%)
Latin America & Car	37	28 (76%)
Oceania	1	1 (100%)
Total	174	124 (71%)

With reference to the activity performed before joining the programme, 27% were studying, 57% working in medical physics on in related fields, 13% working in other fields, 2% were unemployed.

67% declared that present activity is what they wanted to do after the graduation and for 20% only partially. The MMP was significantly useful to achieve their aims for the 67% and only useful for the 30% of the graduates.

A. MMP graduate activities

The present occupation of the graduates is reported in Figure 1. 88% have a job, 5% are yet studying, usually in a PhD programme and 8% are not working. Typically, 45% resumed the position they had before joining the programme and 39% get a job in less than 1 year. The type of occupation is reported in Table 3.

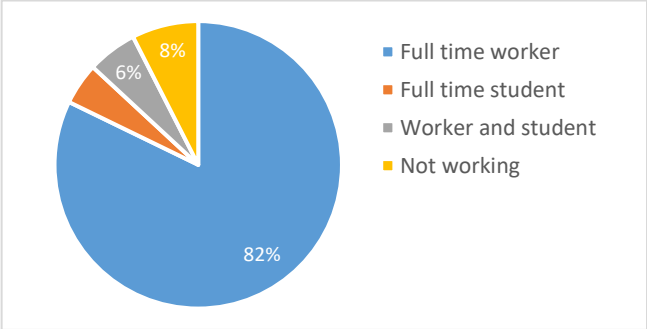

Fig. 1. Present occupation of the MMP graduates.

Independently from the present activity, Table 4 reports what they see themselves in the next 5 years, included the opportunity for a job abroad.

Table 3 Type of work reported by the of the 101 graduates having a job

Type of work	%
Clinical Medical Physics job	55
Clinical Medical Physics, Teaching, Research	26
Teacher and researcher in MP	3
Work not related to clinical medical physics	5

The last is an indication of the few positions of medical physics available in LMICs and the low salaries frequently associated to the non-recognised and not regulated profession. A few interesting comments reported: 'MMP has been a blessing in my professional life', 'All the individual and collective actions carried out to increase my salary and create the profession of medical physicists have failed … paradoxically my country is hiring expatriates to fill the shortage of medical physicists' or 'MMP gave me all the tools and knowledge to be able to face my profession abroad'.

B. Clinical medical physics activity

With reference to the clinical medical physics job, only 26 (40%) of the 66 working in radiotherapy are full time in this sub-specialty. Most of the MPs are sharing their time in different sub-specialties (RT, NM, DR and radiation protection) or as teachers and researchers, as reported in Figure 2.

This confirms the need to provide to our MMP students an education covering all areas of a medical physicist working in an hospital with a limited, sometime very limited, medical physics staff. In fact, 1% of the responders is reporting only 1 medical physicist in the hospital, 24% only 2 and 22% 2 or 3.

Table 4 Type of work foreseen in the next 5 years as reported by 122 graduates.

Type of work	Number (%)
In the home country:	
Clinical Medical Physicist	64 (53%0
Medical Physics lecturer/researcher	45 (37%)
Officer in the regulatory body	14 (12%)
In another country:	
Clinical Medical Physicist	39 (32%)
Medical Physics lecturer/researcher	33 (27%)
Officer in the regulatory body	32 (27)

On the radiation oncology practice, some questions are providing regional information on the type of pathologies treated, treatment technologies and techniques used. Figure 3 shows the large percentage of palliative treatment performed in the MMP centres, in particular in Africa, Asia and LA and Caribbean regions. This large number of palliative treatments justifies the simple 2D/3D radiotherapy technique used in more of the 40% of the cases in the same regions. Table 4 reports the average number and type of therapy machine installed per centre in the different regions, showing the large number of cobalt machine still used in African countries.

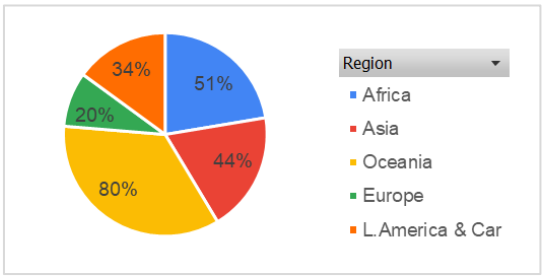

Fig. 3. Radiotherapy practice. Percentage of average palliative treatments on the total number of treatments per geographical region in the MMP graduates centres.

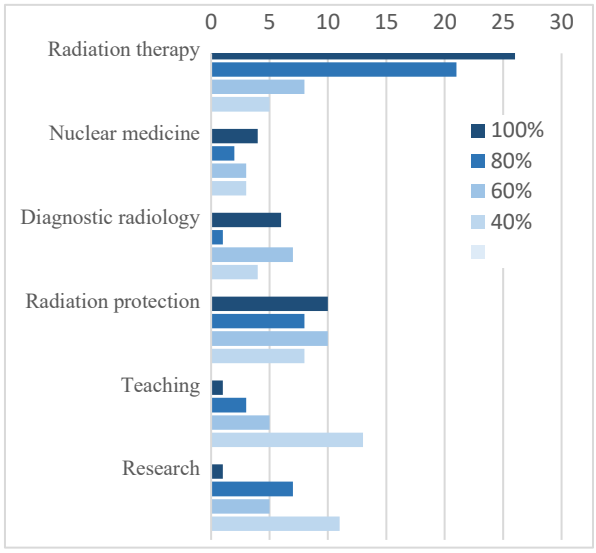

Fig. 2. Percentage time spent in the different medical physics sub-specialties, radiation protection or as teacher and researchers.

At the same time, a quite large percentage of the treatments are performed with modulated techniques, to demonstrate that availability of at-the-state-of-the-art technologies and that staff is trained to introduce advanced therapy techniques in all the regions (Figure 4).

Table 4 Average number of therapy machine per centre and per region.

Region	No. ^{60}Co	No. of linacs	No. brachy
Africa	1.8	1.6	1.2
Asia	1.0	2.5	1.1
Oceania	1.0	2.0	1.2
Europe	1.0	3.2	
LA and Caribbean	1.5	2.1	1.1

On diagnostic radiology and nuclear medicine practice, no one of the MMP graduates is full time working in these sub-fields and, in general, very few MMP graduates are involved (Figure 2). But, those involved are performing a large number of tasks demonstrating good competences (Figure 5).

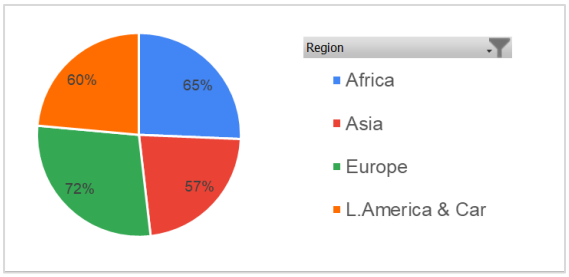

Fig. 4. Average fraction of IMRT/VMAT therapies on the total number of treatments in the centres of the MMP graduates per region.

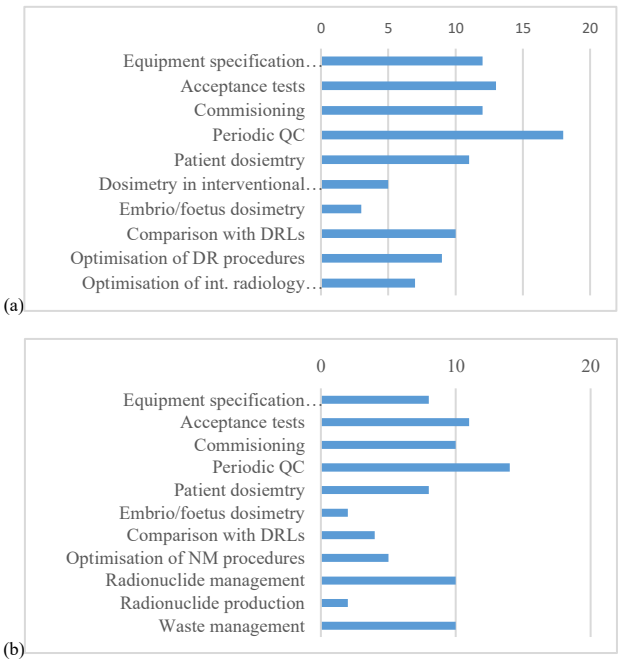

Fig. 5. Type and frequency of diagnostic radiology (a) and nuclear medicine (b) tasks performed by the MMP graduates.

Almost 50% of the graduates are reporting part-time involvement in radiation safety, acting as RPE or RPO. 43% of them are the only experts in the hospital and covering all regulation requirements (Figure 6).

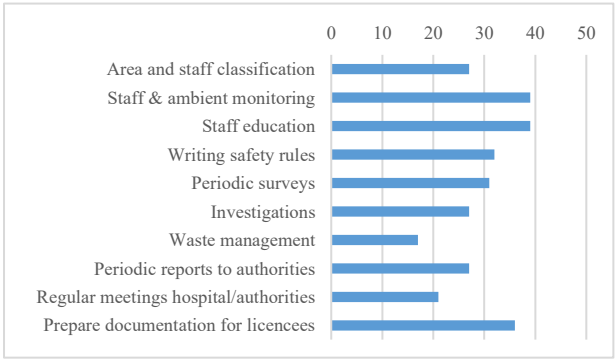

Fig. 6. Type and frequency of radiation safety tasks performed by the MMP graduates.

C. *MMP graduates for the development of medical physics in the country*

In order to understand how the MMP graduates are contributing to the grow of the medical physics in the country, a number of questions identified the activities performed in parallel to the clinical work. 73 (58%) were declaring to teach or train medical physicists, to participate to IAEA national or regional projects, to represent the ministry of health or other national institutes abroad, to act as expert in national institution or to act, 7 of them, as expert in IAEA missions (Figure 7).

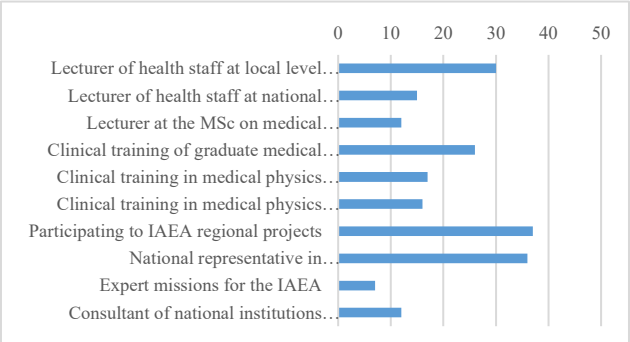

Fig. 7. Activities outside the hospital to understand the impact of the MMP graduates on the development of medical physics in the country.

D. MMP programme evaluation, profession recognition and medical physics association

On the evaluation of the MMP programme, 89% of the responders consider it 'Relevant for the current career' and 10% 'Partially relevant'. 50% are using the educational material for their teaching, 42% distribute to colleagues, 23% uses in national courses/workshops. On the clinical training, 72% are reporting that almost all the staff of the medical physics department in the hospital was involved in the supervision, 72% had regular meeting with the supervisor and 67% declare the training was covering all modules of the proposed portfolio. Finally, 71% report they reached competences able to directly perform the different task. After the, programme, 70% have continuous or occasional contacts with their supervisors for advices. Most graduates consider the year clinical training too short and not sufficient to acquire sufficient skills and competences.

The formal recognition of the profession of clinical medical physicist is a challenge internationally. 86% of the graduates declare that the profession is not recognised in the home country. On the MMP degree recognition, for 58% of them the country officially recognised the MMP degree without difficulties. And, 53% of them has been recognised as clinical medical physicists, while for 11% it was requested to an additional period of clinical training. For 31% the degree was recognised as master of science degree.

On the interest to get an international certification, 8 graduates have completed the IMBCB certification and other 15 have passed some exams; 6 got another certification.

Medical physics association is not present in the country for the 46% of the graduates. When the association exists, 44% participate to the activities and 22% frequently contribute to them.

III. CONCLUSIONS

The Master of Advanced Studies in Medical Physics offers participants a highly regarded academic programme, complemented by a structured one-year clinical training, facilitated through a comprehensive hospital network. The programme is designed to provide academic education and practical training, aligning with international recommendations to ensure standardised competency development.

The MMP has demonstrated its effectiveness in equipping participants with the necessary expertise, with 73% of surveyed graduates returning to their home countries to apply their acquired skills.

The programme received international accreditation from the International Organization for Medical Physics (IOMP) in 2016 and was re-accredited in 2022. Since 2018, in collaboration with the International Medical Physics Certification Board (IMPCB), graduates who meet the required criteria have the opportunity to undertake examinations leading to international certification.

Since the 2015–16 cycle, the programme has benefited from IAEA support, both in candidate selection and through financial aid, awarding the highest number of fellowships to date.

A survey conducted among 174 graduates from the first nine cycles of the programme received 124 responses, offering valuable insights into career trajectories, clinical activities, and initiatives contributing to the advancement of medical physics at the national level.

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ENHANCING MEDICAL IMAGING PHYSICS LEARNING AND TEACHING AROUND THE WORLD WITH SHARED VISUALS

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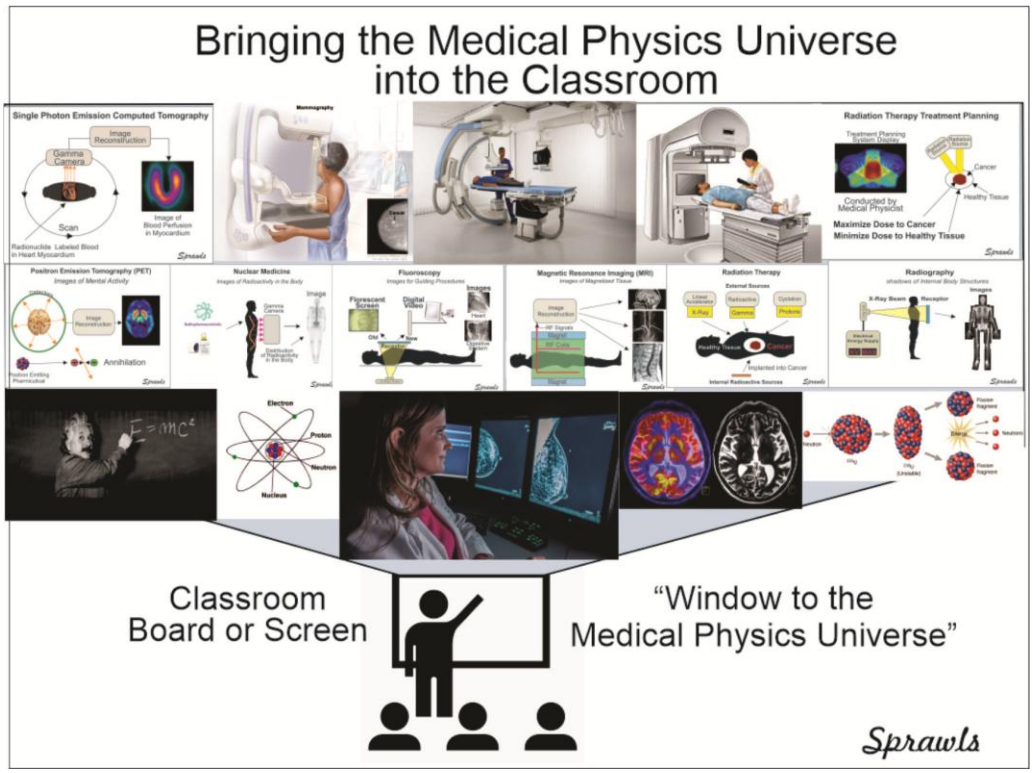


Abstract—**Teaching, a major professional activity of medical physicists, has two, often conflicting characteristics, effectiveness and efficiency. The effectiveness of a classroom presentation determines the value of the learner's acquired knowledge for performing future professional activities. The efficiency is determined by the time, effort, and resources required to provide the learning opportunity, typically a classroom presentation. Conceptual knowledge, rather than symbolic knowledge (text and mathematical quantities and relationships is generally more valuable preparation for professional activities, especially for radiologists and for medial physics educators teaching radiologists and residents. Visual representations of the often-invisible physics phenomena of medical imaging procedures are useful for connecting classrooms to the clinical environment for effective learning. Collaboration between visual creators and classroom teachers (collaborative teaching), contributes to increased effectiveness and efficiency both for the teachers and the learners/students.**

Keywords— **Effectiveness, Efficiency, Concepts, Visuals, Collaboration.**

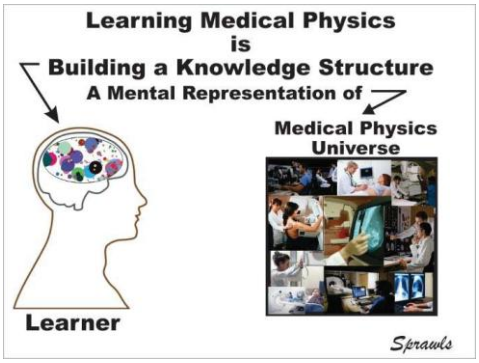
I. INTRODUCTION

Physics is the foundation science of medical imaging modalities and methods, requiring a comprehensive knowledge of the related physics topics for radiologists who use it for clinical detection and diagnosis of pathological conditions and medical physicists who have responsibilities for the effective and safe operation of the equipment. Physicists are also the educators (teachers) who provide learning opportunities (classes, conferences, etc.) for both medical physics students, radiologists, and radiology residents.

Learning physics is the process of building a mental representation in the mind of specific segments (like medical physics) of the actual physical universe. Each teaching and learning activity, especially classroom presentations, is affected by two, often conflicting characteristics, *effectiveness* and *efficiency*. These need to be considered when developing classes and other types of learning activities.

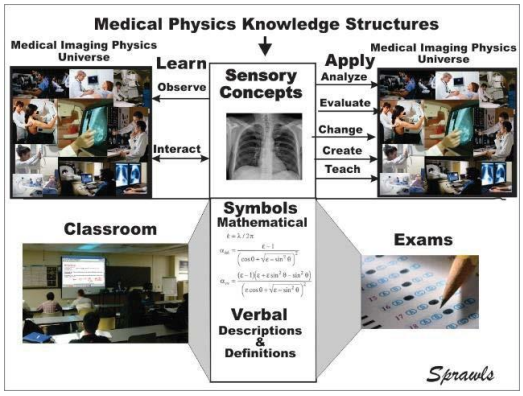
II. PHYSICS KNOWLEDGE

As described previously [1,2] physics knowledge is a mental representation of some segment, such as medical physics, of the physical universe. Learning is the process of building knowledge structures, and teaching is the process of *helping someone build* knowledge structures.



Knowledge structures are complex networks, for the most part, beyond what we need to know, except for specific characteristics that apply to the physics of medical imaging.

The two major elements of knowledge that are significant to us currently are *sensory concepts* and *symbolic representations.*



Sensory Concepts:

Sensory concepts are the natural form of knowledge we develop throughout life as we encounter and experience the world around us with our senses (sight, sound, touch, etc.)

It is the type of knowledge that is needed to perform many personal and professional activities. As illustrated above, valuable physics concepts are formed by interacting and observing in the actual physical environment, for us, the imaging clinic, and with the guidance of an experienced professional, the teacher.

Symbolic Representations:

Segments of the physical universe can be represented in the mind by symbols. Letters of the alphabet and words providing definitions, descriptions, etc. Mathematical symbols are used to represent quantities and quantitative relationships with equations and graphs.

Developing and Using Knowledge:

Both types of knowledge (concepts and symbolic) have value and are useful for specific, but often different, applications as illustrated. They are developed, or learned, in very different ways, a major factor that must be considered in creating and conducting learning activities, including classroom sessions.

Traditional physics, including medical physics, education has generally emphasized symbolic knowledge for two reasons. It is relatively easy to teach with lectures in a classroom and the objective of many courses and classes is to prepare for tests and examinations, both in college or university and professional board certifications. Examinations are easier to prepare and grade when they are based on symbolic knowledge (definitions, solving equations, etc.).

Laboratory sessions, often associated with classroom activities, provide direct interaction with physical objects and instruments that help develop conceptual knowledge. Using phantoms or test objects to evaluate image characteristics for radiography is an example.

This would be the most *effective* type of learning experience for physics of medical imaging using the actual imaging equipment for all modalities (CT, MRI, etc.). This is generally not practical, with the equipment being available only when not used for clinical procedures, limited to just a few students at a time, and requiring additional staff for equipment operation. Very much less *efficient* than having larger groups of students in a classroom, or laboratory session with one teacher.

In general, classrooms are highly *efficient* for teachers giving lectures to large groups of students at the same time. However, they are NOT *effective* learning environments for developing conceptual knowledge by observing and interacting with the physical universe, specifically the medical imaging methods and procedures.

III. WINDOWS FOR THE CLASSROOM

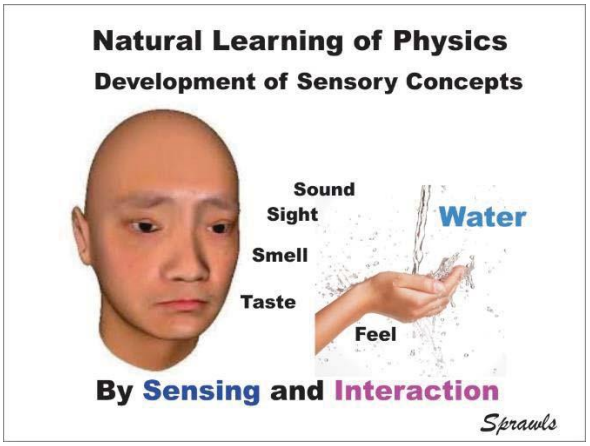
When the author (PS) first began teaching physics it was in a large classroom equipped with a writing board at the front and a few pieces of chalk. With this he could make a few sketches, solve mathematical problems, write a few words, and not much more.

Perhaps out of frustration, he developed the idea that a classroom was ‘just a box’ in which we enclosed our

students hiding them from the physical universe that they were to be learning about.

Classrooms needed "windows" through which segments of the physical universe could be viewed and learned about with a teacher guiding the process.

As an educator and his reading, research, and personal experience on the process of leaning, he developed an understanding and appreciation of *concepts* as valuable components of physics knowledge. He uses our knowledge of the physical principles (physics) of water to illustrate this.



Our knowledge of water is conceptual until we add the symbolic (words and mathematical) representations in physics courses later.

The challenge was bringing the physical universe into the classroom so it could be experienced and contribute to the formation of conceptual knowledge. This was possible with classroom demonstrations using small items…but not a CT machine!

Of the different senses, especially for medical imaging physics, sight or vision is the most significant.

Visual Representations for the Classroom:

This began a career-long activity of developing "classroom windows" in the form of visuals and images that could be projected in front of the class to provide a connection to the physical universe.

An early activity as a young teacher was to add" windows" to the classroom in the form of screens and two projectors, an overhead projector for diagrams and illustrations drawn or copied onto transparencies and a 35 mm slide projector for photographs of instruments, equipment, procedures, and illustrations copied from textbooks and other publications.

This was before computer graphics were generally available and illustrations were drawn by hand, a slow process. It was not practical or efficient for individual teachers to draw all the illustrations they needed, and it required some artistic talent to produce visually appealing illustrations.

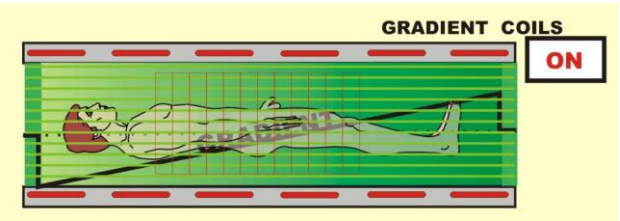
The author (PS) was also producing illustrations for a textbook and used a professional illustrator to draw the illustrations. Medical physics educators who used, or had access to the book, could copy the figures and use them in classroom presentations.

As computer graphics continued to develop with the capability to produce high quality images in color using vector-based DRAW and bit-map PAINT programs, it became more practical for teachers to produce visuals to use in their classroom activities.

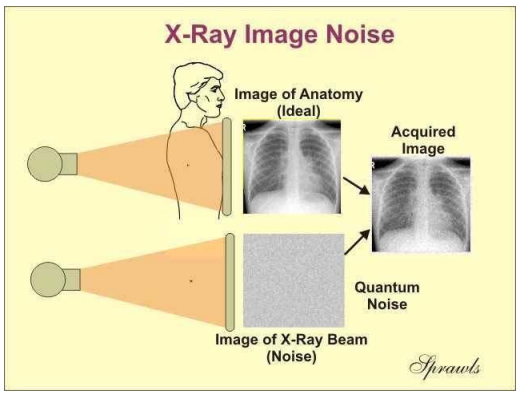
IV. VISUALIZING THE INVISIBLE

Unlike other fields of physics, such as mechanics, optics, and sound that can be touched, seen, or heard, much of the physics of medical imaging, including the magnetic fields and tissue magnetization, radiation and radiation interactions, are invisible to humans. This makes it difficult, or perhaps impossible, to form useful sensory (visual) concepts.

Visuals in which the *invisible* is made *visible* by the visual creator enhance the formation of concepts. The example shown here is using shades of green to represent the intensity of a magnetic field to illustrate the concept of gradients.



Another example is showing an image of the X-ray beam as the source of image noise in radiography.



V. EFFECTIVE AND EFFICIENT TEACHING.

Teaching is a complex activity with varying definitions, forms, and examples. It is a profession practiced by many at all academic levels, K-12 and College and University. Throughout much of our lives, we have been "taught" in many classes and have our view of what teaching is.

As medical physics educators/teachers we want to be both effective and efficient. Effective in helping our students develop the knowledge that will be useful in their professional activities and efficient with respect to the time and effort we must devote to preparing and providing a class activity, lecture or discussion.

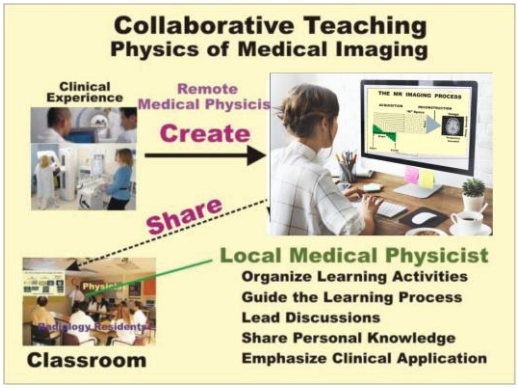
The almost universal model of teaching is a teacher in front of a class lecturing on a specific topic and attempting to convey some of their knowledge to the learners/students. This is very *efficient* because one teacher can "teach" a large group of students in a relatively short period of time. However, it is *not very effective* in helping learners/students develop knowledge, especially conceptual knowledge, that will be useful later in their professional activities.

. Recognizing that visuals (diagrams, illustrations, images, etc.) are required for providing effective learning experiences the challenge is producing or obtaining the many visuals that are needed. Sketching on the board at the front of the classroom during a lecture is traditional but not very effective with respect to quality and not efficient because of the time required and they are used one time and then erased.

VI. COLLABARATIVE TEACHING

Collaborative teaching is the comprehensive process of *helping someone learn* and includes several activities, not just standing in front of a class giving a lecture. Authoring textbooks are examples. Textbooks are not only studied by students they contribute to the effectiveness of teachers by providing material for lectures and figures or illustrations (visuals) that can be used in classroom presentations.

A significant and developing form of collaborative teaching is the creation and sharing of visuals with other medical physics educators/teachers.



As considered here, *collaborative teaching* is the collaboration between a *visual creator* and a *classroom teacher* to provide an effective and efficient learning experience for both the teacher and the students. Each one provides valuable contributions to the process.

Visual Creation:

The visual creator is generally an experienced clinical physicist who understands the imaging procedures and who can *imagine,* in their mind, the invisible elements of the imaging process, and express the concepts as visible illustrations.

Visual Sharing:

The value comes when visuals are *shared* with other educators, and the internet is the most effective method for this [3] A continuing issue that is being considered by some medical physics organizations, the AAPM is one, is the development of repositories where creators can post or publish their visuals in an organized format that will be available to all medical physics teachers.

The e-Encyclopaedia of Medical Physics on the web at: https://www.emitel2.eu/emitwwwsql/encyclopedia.aspx. is a source of visuals along with text and references.

Local Classroom Teachers:

With the availability of appropriate visuals, the classroom teacher can be both more *efficient* and *effective*. More *efficient* by not having to devote time and effort to preparing visuals. More *effective* by using their knowledge and experience, along with the visuals, to provide effective learning opportunities for students.

VII. THE SPRAWLS VISUALS SHARED FOR COLLABORATIVE TEACHING

The Sprawls Visuals described here is an example of what can be achieved with shared visuals.

Perry Sprawls (author of this article) is a clinical medical physicist in the field of medical imaging with a long career as an educator/teacher for both radiologists continuing education, radiology residents in training, and medical physicists, both graduate students and continuing education courses for medical physicists in over 30 countries of the world.

His work as a clinical physicist, usually in collaboration with radiologists, provided an understanding of the physics knowledge they needed in their professional practice. This included understanding image characteristics that affect clinical visibility and the related protocol factors for imaging procedures. This experience has been used to develop courses and visuals that contribute to effective

learning experiences and enhancements to class presentations and discussions.

These are available as an open and free resource on the web at: http://www.sprawls.org/SprawlsVisuals/

VIII. SUMMARY AND CONCLUSIONS

A major professional activity of many medical physicists is that of educators or teachers. This is a highly significant role because it prepares future professionals, medical physicists and radiologists for their careers. A continuing challenge is providing learning opportunities (classes, conferences, consultations) that are effective in contributing to the knowledge required for professional activities, from optimizing imaging procedures to understanding and adjusting image quality characteristics that affect clinical visibility. This generally requires conceptual knowledge to go along with symbolic knowledge (text and mathematical quantities and relationships). Concepts are a natural form of learning as experience the physical universe around us through our senses, especially sight, sound, and touch.

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PROFESSIONAL ISSUES

RADIATION PROTECTION PRACTICES AMONG SOME DIAGNOSTIC FACILITIES IN RIVERS STATE, NIGERIA

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Abstract— **Despite detrimental health effect (DHE) of ionizing radiation, they are still beneficial for diagnosis and therapy of ailments under strict adherence to principles of radiation protection. Reported DHE of radiation often arises from unsafe practices among operators. The aim of the study was to assess level of radiation protection culture among diagnostic facilities in Nigeria. This pilot study was conducted among 50 Radiographers from eight diagnostic centres in Port-Harcourt, Rivers State, one of the largest cities in Nigeria. Structured questionnaire was used to collect data on socio-demographic and radiographic practices, which include availability of radiation protection/monitoring devices, design of X-ray room, quality control test and others. Their responses were analysed with SPSS 20.0 and results were presented in Tables. All (100%) respondents had university degree in radiography and 30% frequently participated in radiation protection courses. Radiation protection devices available in all the facilities are: Lead Apron (47.6%), Gonad shield (22.9%), Lead glass (10.5%), Lead glove (13.3%), thyroid shield (5.7%) and 84% used monitoring devices (personnel dosemeter). Only 84% of the respondents had rooms suitably designed for X-ray units. While 80% of the respondents hardly repeat X-ray procedures, only 60% had routine quality control test performed on their X-ray units. All engaged the services of radiation safety adviser/officers. Adherence to radiation protection practices by some of these centres was below the recommended standard, due to non-availability or insufficient radiation protection/ monitoring devices. Diagnostic centres should therefore comply strictly with radiation protection guidelines in order to reduce DHE of radiation on humans.**

Keywords— Ionizing radiation, separated by commas, principles of radiation protection, radiation practices, detrimental health effect, radiation protection

I. INTRODUCTION

Ever since the discovery of X-rays by Wilhelm Conrad Roentgen in 1985 and the recent advancement in imaging technology for solving arrays of health challenges, the use of ionizing radiation in the field of medicine has been on the increase [1].

The wide use of ionizing radiation is medicine is not without health hazards. Some of these hazards were reported a few months after X-ray discovery and from these and other findings were conclusion drawn that X-rays have deleterious biological effects on humans. These effects include microscopic damage to living tissues, skin burn, radiation sickness at high exposures and statistically elevated risk of cancer at low exposures [2].

When patients undergo X-ray examinations, millions of photons pass through their bodies. These ionizing photons have potential to damage any molecule through ionization but the damage to DNA in the chromosomes of the exposed medium is of particular importance [3].

Radiographers in the early days of X-ray discovery mostly died of cancer as a result of over exposure to ionizing radiation and their lack of adequate knowledge of radiation protective devices and measures [4]. The realization of these harmful effects of ionizing radiation gave rise to the principles of radiation protection, which aims at promoting adequate protection of the Operators of X-ray units /Radiographers, the patients, who undergo medical X-ray examinations, the general public and the environment from the harmful effects of ionizing radiation [5]. The main goal of radiation protection is to limit human exposure to ionizing radiation to a degree that is reasonable and acceptable in relation to the benefits gained from the activities involving the exposure.

The negative effects of ionizing radiation can be reduced through filtration of X-ray beam, field size trimming/collimation, shielding with the use of appropriate lead apron, gonad shield, lead-lining of the walls, which has to do with the standard X-ray room design. It has been reported that formal training or refresher courses in radiation protection for handlers/operators of X-ray units greatly helped in reducing radiation exposure to medical staff and patients [6].

Radiographers play a major role in medical X-ray examinations of patients, and their level of radiation protection practices is a key to achieving radiation exposure that is as low as reasonably achievable, ALARA principle [3].

There are established regulations that govern the use of ionizing radiation in medicine but some health professionals, X-ray operators, technicians, radiographers, etc. are either unaware of these regulations or are not compliant [7]. The knowledge, awareness and adherence to

these regulations are germane to reducing the level of exposure to ionizing radiation and its associated deleterious consequences [8].

Also, most studies in medical X-ray examinations were usually focused on the protection of the workers only [9] but it is imperative also for radiation facilities to provide safety measures that will protect patients undergoing medical X-ray examinations [10].

This study aims at assessing the level of radiation protection practices among radiation facilities at eight diagnostic centres located in one of the largest cities in Nigeria, Port-Harcourt Rivers state, as a pilot study. The findings from this study would enhance accreditation of X-ray facilities and eradicate unethical use of X-rays for medical examinations of patients in Nigeria.

II. MATERIALS AND METHODS

This pilot and prospective cross-sectional study was conducted in eight diagnostic facilities, randomly selected in one of the largest cities in Nigeria, Port-Harcourt city, Rivers State from September-December 2022. The target population of this study is the X-ray Operators/ Radiographers in these diagnostic centres, namely: University of Port-Harcourt Teaching Hospital (UPTH), Rivers State Teaching Hospital (RSTH), Government House Clinic (GHC), Image Diagnostic Centre (IDC), RNZ Occupational Hospital (RNZOH), Shawsand Diagnostic Centre (SMC), Save a Life Mission Hospital (SALMH), Georges Diagnostic Centre (GDC). Fifty Radiographers, who consented to participate and returned the filled questionnaires were included in the study and their distribution among the centres was: UPTH (13), RSTH (18), GHC (3), IDC (3), RNZOH (3), SMC (2), SALMH (2), GDC (3).

The semi structured questionnaire used for data collection consists of two sections namely, A and B. While section A contained four questions on socio-demographic data of the respondents, section B contained twenty different questions on radiographic practices in relation to radiation protection. To facilitate data quantification and analysis, the respondents' responses to the questions in the questionnaires were used. These were analysed with statistical package, SPSS version 20.0 and the results were presented in table of frequency and percentages.

III. RESULTS

The respondents' socio-demographic data, which include their sex, age, academic qualification and years of experience in radiation practices, are presented in Table 1. The distribution of Radiographers, who returned the filled questionnaires, among the selected diagnostic centres, is presented in Table 2. The level of adherence of the selected diagnostic facilities with the principles of radiation protection in terms of the availability of protective devices for both patients and operators, type of protective devices used for shielding patients during medical X-ray examination, appropriateness of the design of the room that housed X-ray unit and other safety measures put in place for protection of both patients and the personnel from scattered radiation are presented in Table 3.

Table 1: Socio-demographic characteristics of the Radiographers (n = 50)

Characteristics	Frequency (n)	Percentage (%)
Sex		
Female	20	40
Male	30	60
Age Group		
20 – 29	14	28
30 – 39	19	38
40 – 49	13	26
50 and above	4	8
Academic Qualification		
B.Sc.	37	74
M.Sc.	11	22
Ph.D.	2	4
Work Experience		
≤ 5 years	25	50
6 - 10 years	13	26
11 - 20 years	7	14
> 20 years	5	10

Table 2: Distribution of Radiographers among the Diagnostic Centres

Diagnostic Centres	Frequency (n)	Percentage (%)
University of Port-Harcourt Teaching Hospital (UPTH)	13	26
Rivers State Teaching Hospital (RSTH)	18	36
Government House Clinic (GHC)	3	6
Image Diagnostic Centre (IDC)	6	12
RNZ Occupational Hospital (RNZOH)	3	6
Shawsand Medical Centre (SMC)	2	4
Save A Life Mission Hospital (SALMH)	2	4
Georges Diagnostic Centre (GDC)	3	6

Table 3: Level of adherence to radiation protection practices among Radiographers

Radiation Protection Practices	Frequency (n)	Percentage (%)
What are the radiation protection devices available in your facility?		
Lead Apron	50	47.6
Gonad Shield	24	22.9
Lead Glass	11	10.5
Lead Gloves	14	13.3
Thyroid Shield	6	5.7
In what investigation do you use gonad shield?		
Chest X-ray	22	40.7
Abdominal X-ray	24	44.4
Pelvis	7	12.9
Children Examination	1	2
How often do you give lead apron to persons supporting patients during examination?		
Always	44	88
Occasionally	2	4
When I remember	1	2
Not at all	3	6
What personnel monitoring devices do you use in your facility?		
Film Badge	5	10
TLD	28	56
OSL	3	6
Instadose	6	12
Is your facility originally designed for Radiology department/to house X-ray machine?		
Yes	42	84
No	4	8
Not sure	12	24
The X-ray room is designed with what material?		
Lead-lined wall	50	40
Lead-lined doors	50	40
Concrete walls	24	20
The operators' cubicle is designed with what material?		
Concrete wall	50	50
Lead screen	50	50
How long does a patient stay in the waiting room?		
Less than 30 minutes	36	72
More than 30 minutes	5	10
Up to an hour	2	4
Depending on investigation	7	14
Do you encounter repeat cases while working?		
Frequently	1	2
Occasionally	8	16
Rarely	40	80
Not at all	1	2
What is/are the possible causes of repeat?		
Processing Fault	1	2
Poor radiographic technique	5	10
Un-cooperative patient	42	84
Error in exposure factors	2	4
How often is quality control test done on your facility?		
Routinely	30	60
Occasionally	13	26
When it is convenient	1	2
Rarely	5	5
None	1	2
What type of quality control test is carried out?		
Beam quality test	20	14
Radiation leakage test	50	35
Light beam alignment	50	35
Timer accuracy	21	15
Have you ever attended training and/or refresher courses on radiation protection?		
Frequently	15	30
Seldom	22	44
Never	9	18
No response	4	8
Do you close the X-ray room door during exposure?		
Yes	50	100
No	-	-
Do you ask female` patients of reproductive age about their menstrual cycle before exposure?		
Frequently	20	40
Rarely	25	59
When I remember	5	10
Do you have radiation safety adviser/officer?		
Yes	50	100
No	-	-
Do you have survey meter at your facility?		
Yes	50	100
No	-	-
Do you have radiation warning signs/notices and caution light at the facility		
Yes	50	100
No	-	-

IV. DISCUSSION

The implementation of the standard procedures recommended for radiation protection practices in the diagnostic facilities are vital for safety of the radiation workers, the patients and the general public [11]. In this study, among the respondent Radiographers, there were more male 30 (60%) than the female 20 (40%) and most (38%) of them were in the age range of 30 – 39 years. This agrees with the study conducted by Mohammed et al., [12], where majority of the Radiographers reported in their study were male and the highest age group reported was 30 - 39 years. It was observed in this study that none of the respondents were below 18 years of age. This complies with the regulations of the international radiation protection organization, which states that anyone below the age of 18 years should not be permitted to operate radiation facilities [11].

In terms of work experience, those with work experience under 5 years were more (50%) than those (10%) with work experience of 20 years and above. This means that majority of them are new generation Radiographers with few years of experience in radiation practices. Most (74%) of the respondents had B.Sc. Radiography as their minimum qualification. This is quite impressive as diploma in Radiography used to be their minimum qualification for employment.

This was in agreement with a study conducted by Kyei et. al., where most practicing radiographers were university graduates [7]. Regarding training and refresher courses in radiation protection, 18% had never attended training, 44% seldom attended and 30 % attended frequently. This is in line with the findings by Mohammed et al., [12], where two-third of respondents surveyed have never attended radiation protection training/refresher courses.

It is highly recommended that every necessary radiation protection device is available in a diagnostic facility. Ascertaining the availability of radiation protection devices, it was made known from the responses that lead aprons 50 (47.6%) were very much available and 44 (88%) of the respondents always provide lead aprons to the persons supporting the patient when the need arises but availability of radiation protection devices like lead glove 14(13.3%), gonad shield 24 (22.9%), thyroid shield 6 (5.7%), lead glass11 (10.5%) were inadequate in some centres.

Also, from this study, it was observed that some of the centres that had gonad shield, did not know when to use it. Gonad shield is recommended for use on patients during medical diagnostic X-ray procedures when the gonads lie within or close to the primary X-ray field. It is also recommended when the clinical objective of the examination is not compromised and when the patient has a reasonable reproductive potential [13].

Availability of personal monitoring device is very important because it provides a means of detecting the radiation dose absorbed by workers. It ensures that the incident of radiation leakage is kept on check [14]. Having assessed the availability of monitoring devices, it was noted that majority of the respondent 42(88%) had monitoring devices and were read as at when due while some did not have monitoring devices. This agrees with the findings of Eboh et al., [15], that 93% of staff in their study were provided with personnel radiation monitoring devices.

The design of X-ray rooms is very important due to the nature and properties of X-ray; the X-ray rooms must be properly designed to prevent radiation leakages. From this present study 42 (84%) of the respondents revealed their centres were built for X-ray practices, 6 (12%) of the radiographers were not sure and 2 (4%) indicated that their centres were never built for X-ray practices but was converted. This is in contrast with the study conducted by Okeji et. al, [16], where it was reported that there was inadequacy in the design of the majority of diagnostic centres they considered.

Proper shielding of X-ray facility to absorb scattered radiation during exposure is very crucial for protection of workers, other patients or the visitors that may be present in the adjacent rooms, waiting areas or nearby offices. The following number of radiographers indicated that their X-ray facility was equipped with lead-lined wall 50 (40.3%), lead-lined doors 50 (40.3%), cubicles with concrete wall 50 (50%) and lead-lined cubicles 50 (50%). This is similar to the findings by Eboh et al. [15].

Repeat of X-ray exposure should be avoided as much as possible in compliance with "ALARA principle". Majority of the responses to the cause of repeat was non-cooperative patients, 42 (84%), followed by poor radiographic techniques, 15 (30%). This agrees with the report by Eze et al, [17], where the repeat cases were attributed mainly to lack of patient co-operation and lesser degree to processing fault, poor radiographic technique and lack of trained operators. With respect to how often the radiographers encountered repeat cases, majority, 40 (80%), responded that they rarely experienced it while, 8 (16%), experienced it occasionally.

The code of practice in medical diagnosis of the National Radiation Laboratory (NRL) requires that each X-ray facility has an appropriate quality control programme in radiation protection. This is to ensure that radiation doses emanating from the X-ray unit for patients' exposure are kept as low as reasonably achievable. Majority of the respondents, 30 (60%), acknowledged that quality control was done routinely on their X-ray units, 13 (26%) responded occasionally, 5 (10%) indicated rarely and 1 (2%) indicated when it is convenient. Regarding the type of quality control performed on the diagnostic units, 47 (94%) indicated radiation leakage, 29 (54%) highlighted light beam alignment, 21 (42%) responded timer accuracy, while 20 (40%) revealed beam quality.

With respect to the engagement of radiation protection officers/advisers by the facility, all respondents were positive. This result is in contrast with the report of Okaro et al., [14], where radiation protection personnel are hardly available at the centres they considered.

Other radiation protection measures undertaken by all the respondents, 50 (100%), was the closing of the X-ray rooms during radiation exposure. While 20 (40%) of the respondents always ask the female patients, of reproductive age, about their menstrual cycle before exposure, 25(50%) rarely asked and 5 (10%) usually asked when they remembered.

Lastly, all the respondents 50 (100%) affirmed that they had survey meter, radiation warning signs/notices and caution lights in their facilities.

V. DISCUSSION

Ionizing radiation can be detrimental to human health if the principles of radiation protection are violated. In this study, the adherence to the principles radiation protection by all the facilities considered was fairly satisfactory. This was due to unavailability and inadequate use of radiation protective devices for patients and staff. Other factors are irregular refresher/training course in radiation protection for Radiographers and some of the Operators were not provided with monitoring devices while at work. To achieve optimal radiation practices, these facilities should improve on their

existing radiation protection procedures, measures and devices.

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WORKING TOGETHE(RT): A UNIQUE NEED FOR AN ETHICAL FRAMEWORK FOR GLOBAL RADIOTHERAPY RESEARCH

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I. INTRODUCTION

The recent recognition of Global Oncology as a formal academic discipline has given birth to innovative research [1]. This has led to an increased push to eradicate exploitative research activities and instead pursue equitable research practices [2]. It wasn't until the 1970s that ethical frameworks made their way into academic global health [3] Ethical frameworks assist clinicians and scientists by providing a plan and approach to balancing moral values in line with research and clinical activities. With the rising burden of cancer seen in low- and middle-income countries (LMICs) but the disproportionate publication of research coming from high income countries, the impetus for an ethical framework of research in global oncology has never been greater [4]. In this commentary, we discuss a brief history of ethical frameworks in global health and introduce a new ethical framework, specifically applicable to global radiotherapy research: TOGETHE(RT).

II. BRIEF HISTORY OF GLOBAL HEALTH ETHICAL FRAMEWORKS

According to the World Health Organization (WHO), global health ethics covers a spectrum of topics that range from the issues surrounding "brain drain," equitable distribution of health services, and proper informed consent for clinical trial [5]. Global health ethics researchers also make a plea in their research to elevate global health education so that students are equipped with the correct framework, that focuses on developing humility, awareness of limitations, and how involvement in developing countries without sustainability can create harm even with the best of intensions [6].

Particularly relevant in global health ethical research is a need to prevent against "parachute" research, exploitative research by high income countries about the state of health in low-and-middle-income countries (LMICs), without proper acknowledgement of expertise and knowledge of local partners [3]. Prior global health mostly focused on communicable diseases [7], however the need for an ethical framework for non-communicable and chronic diseases is paramount [8].

The pursuit of a framework to encompass global health ethics has been complicated and at times political. In a recent editorial, Dr. Cancedda and colleagues describe challenges in this new age of global health. Even with the knowledge that sustainability is critical and that priorities of chronic disease come into focus, funders and donors may be driven by an agenda of favoring disease-specific initiatives that are HIV or infectious focused or opt to provide funding through NGOs and academic institutions rather than the communities themselves [9].

Historically, traditional ethical health frameworks utilized include the preference utilitarianism of Peter Singer, which states that "the more affluent should support the least privileged whenever this can be achieved without costing anything of comparable moral significance." or the cosmopolitanism of Thomas Pogge which suggests that "the manipulation of the global structure has advantaged, and continues to advantage, the affluent whilst disadvantaged the underprivileged and, therefore, perpetuates global inequity" [5]. These theories represent an ethical baseline, but certainly do not encompass the nuances from which a framework in global health ethics for radiation oncology are needed.

III. WHY IT'S IMPORTANT FOR A SPECIFIC FRAMEWORK FOR RADIATION ONCOLOGY

While there has been a push for ethical frameworks in various disciplines of medicine and global health research with select examples seen in Table 1, there is currently no guiding ethical framework in global radiotherapy. In a 2014 editorial published by Zietman [8], the case was made for increased participation of radiation oncology professionals (physicians, medical physicists, dosimetrists, radiation oncology nurses, radiation therapists and social workers at all levels) in improving health and achieving equity globally. Over the years there has been a growing interest (Figure 1) in radiation oncology research in LMICs where radiation presents unique challenges and opportunities to provide cancer care.

Ethics in Global Surgery [10, 11] encompass components including clinical care delivery education and exchange of trainers and engagement in collaborations and partnerships.

Table 1. Examples of frameworks in other global health disciplines

Ethical considerations in infectious disease [12].
Ethics in obstetrics and gynecology [13].
Ethics in Oncology [14-16].

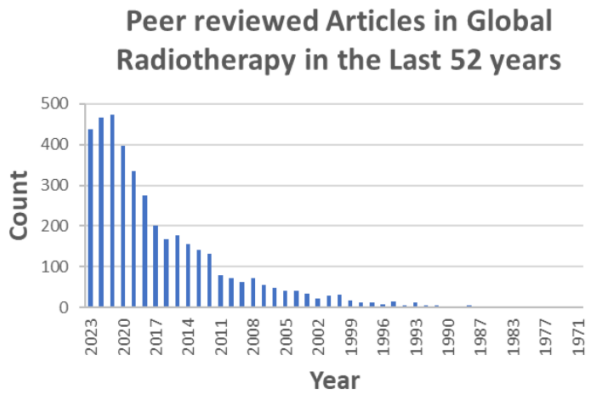

Figure 1. Publications on Global Radiotherapy on PubMed database from 1971-2023

In a comprehensive search of MEDLINE databases, there were almost 20,000 articles containing the phrase "global oncology," that had been published between 1973 and 2023 as shown in Figure 2. Out of these only 517 that contained the phrase "global oncology" and "ethics," and none that contained the phrase "global health" and "radiation oncology" and "ethics."

Figure 2. Publications on Ethics in Global Health on PubMed database from 1977-2023

By creating a framework for global health research, the goal is to ensure that partnerships are equitable and that for research conducted, there is consensus on a compass and rubric for funding organizations like the National Institutes of Health (NIH) or National Cancer Institute (NCI) to grade and assess projects to be applied globally.

IV. UNIQUE CHALLENGES AND OPPORTUNITIES PRESENTED BY RADIOTHERAPY

Radiation oncology as a discipline is unique, involving continuous technical progress as evidenced by innovation that led to adoption of linear accelerators, high dose rate brachytherapy (HDR), low-dose (LDR) brachytherapy, Cyberknife, and relatively newer technologies like proton therapy.

This technological wave, however, is not always universally and equitably adopted. Indeed, global progress requires that collaborative research between institutions is guided by a framework that provides a solution in combating parachute research in global health. There are limited regulations governing consensus in international training of radiation oncologists, physicists, and radiation therapists. There is also a dependency on vendors and supply chains of governments to acquire the appropriate equipment to deliver radiation safely and effectively. This begs the question: in this era of global health research in radiation oncology, how are these decisions being made and by whom?

V. TOGETHE(RT)

The TOGETHE(RT) framework will allow institutions (academic and private), non-profits, and vendors that manufacture and supply radiation oncology equipment, to carefully consider if their research activities and collaborations in less resourced facilities fit into this framework. Our proposed TOGETHE(RT) is shown in Figure 3. framework has the following tenants:

Technology

The first tenant of this framework draws on the specific nature of radiation oncology as a field dependent on the delivery of photon energy and radionuclides. Technology highlights the importance for institutions and industry to ensure that the machines, computer software, and supplies all meet the needs of the provider and patients. As intensity modulated radiation therapy (IMRT) and stereotactic body radiation (SBRT) have made their way into academic medical centers in the Global North, there is an important need to discuss best practices of implementing these tools, globally. Even with current technology, including linear accelerators and CT simulators, regular maintenance and on-the-ground trouble shooting is challenging in many countries.

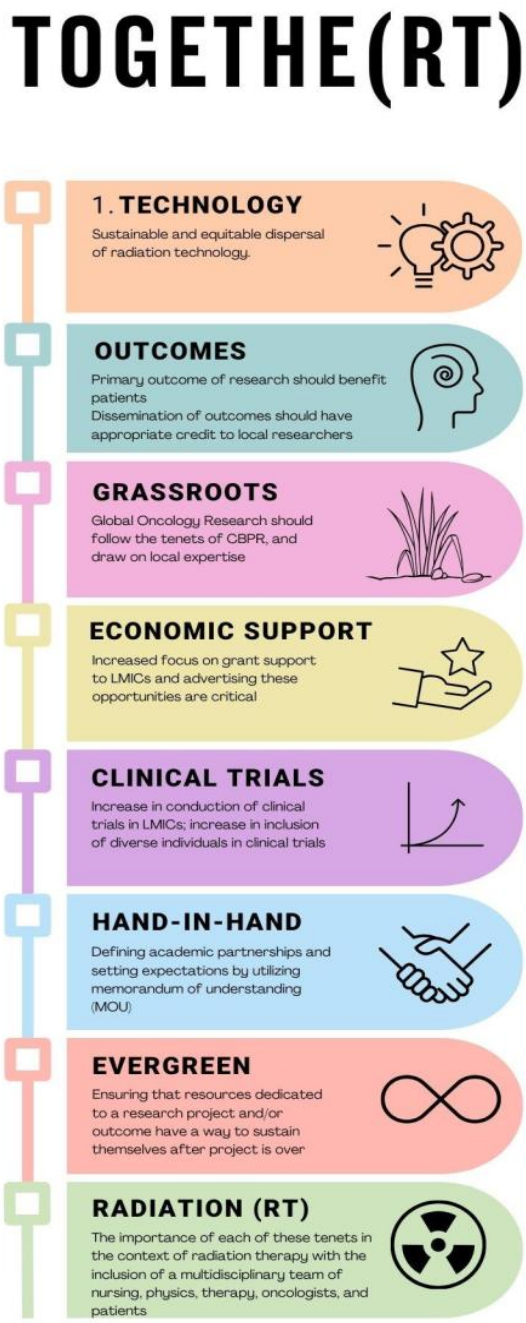

Figure 3. Diagrammatic Representation of TOGETHE(RT)

In a summary of four decades of experience, Reichenvater and dos S. Matias [10] described the importance of providing regular maintenance and repair plans for sustainable linear accelerator use. Traditionally, in higher income countries maintenance was completed with contracts with suppliers, while within Africa, it was conducted by in-house maintenance. While material costs and availability of hard currency were available in higher income countries, in Africa, there are exorbitant material costs and hard currency restrictions. Physicists are often the first line personnel who execute maintenance and repair of linear accelerators, whereas in High income countries, the labor is divided among engineers, hospital engineers, or contracted out by the vendor.

The authors delineate four areas of improvement:

1) Governmental support for experienced personnel who are taking on additional roles to support their radiation facility

2) Decrease in prohibitive training course prices offered by the manufacturers after the purchase of new equipment

VI. OUTCOMES

The primary beneficiary and center of global health oncologic research should be our patients. As researchers in global health, outcomes for global health research must be focused on mitigating disparities in inequitable access to resources or in unacceptably high morbidity and mortality rates. Finally, outcomes must impact those who need it (i.e., conducting a trial on utilization of stereotactic body radiation therapy (SBRT) for spinal metastasis when there is no sustained commitment to support SBRT via training of radiation therapists, physicists, nurses, and physicians), or provide the infrastructure to promote advanced technology in places that do not have it An example of outcomes stratified to the resources and what is available in the country is the development of the National Comprehensive Cancer Network Resource Stratified Guidelines [14]. Further, publishing and disseminating outcomes must be done equitably. Authorship of research publication and grant proposals should be fairly and respectfully discussed with due credit given to authors from lower-resource settings with active input where there is a critical need to disseminate knowledge.

VII. GRASSROOTS

This pillar identifies the importance of being present and capacity building from the ground up. The concept of grassroots embraces the knowledge and experience of experts already working in a location. Within the established framework of Community Based Participatory Research (CBPR), creating and answering a research question is done alongside the community [15]. In the fields of medical anthropology and implementation science, CBPR has long held that if a researcher is not local or native to a community, experts from that community work with the researchers to develop and answer questions. The same holds true for global radiation oncology. Developing professional relationships between departments of radiation oncology, ministries of health, or hospitals, is critical to ethically provide the right question and solution. When proposing a new research question, the group should pause and ask where the questions originated from the community it impacts

VIII. ECONOMIC SUPPORT

Funding for cancer research has increased greatly in recent years. A recent publication shows that over 60,000 grants totaling almost 25 billion dollars were awarded between 2016 to 2020 [16]. Considering the global cancer burden and the over 10 million deaths attributed to cancer in 2020, it is important that a healthy portion of these grants are awarded to cancer research in LMICs if we want to make tremendous progress towards reducing global disparities in cancer outcomes. Additionally, this tenet also discusses grant bias against research conducted in LMICs. Grant reviewers should evaluate the outcome of the research proposal and its magnitude of effect and although the trendiest topics in the field may be worth researching, this might not be beneficial to the targeted population. Currently, some professional organizations give grant funding purposely for global oncology efforts (Table 2).

It is worth mentioning that although the NIH currently utilizes the categories of: Significance, Investigator, Innovation, Approach and Environment to score an application, there are limited guidelines on equity and its weight in grant scoring projects.

Table 2: Above are examples of grants offered by professional organizations to support global health research. It should be noted that this is not an exhaustive list.

AAPM International Council collaborative microgrants which provide up to 6,000 USD to research projects focused on conducting needs assessment on technologies to advance care, research and education and address global health disparities.
AAPM International Council Global Health seed funding. Support early career researchers in Global health with $25,000
ASTRO- Association of Residents in Radiation Oncology (ARRO) Global Health Scholars (GHS) provides a stipend of $2,500 dollars to residents who are interested in global health work to pursue their research.
ASTRO Radiation Oncology Institute (ASTRO ROI) provides grant funding to investigators whose research aims to advance radiotherapy care for all patients and improve access to care. A total of $50,000 is awarded over a span of 2 years.
The Beginner Investigator Grants for Catalytic Research (BIG Cat) which is a collaborative effort between the American Association for Cancer Research (AACR) and the African Organization for Research and Training in Cancer (AORTIC) which offers a two-year $55,000 USD to support early-career African investigators (https://aortic-africa.org/big-cat/)
The ASCO and Conquer Cancer Global Oncology Young Investigator Award (GO YIA) provides research funding to early-career investigators whose research aims to improve health equity and champions diversity and inclusion in oncology. The grant is aimed at investigators from underrepresented populations in medicine and low and middle-income countries.
The NIH International Research Career Development Award (K43) was instituted to support research scientists from LIMCs who hold junior faculty positions at academic or research institutes with the aim of improving research sustainability and helping these individuals develop into independent researchers.
Similarly, the NIH D43 grants support for pre- and post-doctoral researchers who are citizens of LMICs.

IX. (CLINICAL) TRIALS:

From the onset of clinical trial design to patient recruitment, the importance of utilization of community informed participation is critical. Recent publications have emphasized the importance of diversity and inclusion in clinical trials. However, critically important is that as new technologies or fractionation patterns (i.e., hypofractionation for breast and prostate cancer) allow for improved resource utilization, these practices must also be tested in international settings. The major clinical trials for hypofractionation of breast cancer were all completed in North America and Europe (reference); yet the burden of breast cancer mortality falls unequally in low-and-middle-income countries. In order to improve resource utilization in these countries, an emphasis on the broader application and conduction of clinical trials must be undertaken. An article in 2018 PLOS medicine examined the clinical trial density in all fields in a span of 7 years. Between 2006 to 2012, 83% of the trial sites operated in 25 high-income countries, and only 5% were conducted in 91 LMICs [17]. In the years since there's been ongoing clinical trials in LMICs specifically in sub-Saharan Africa (Table 3).

Table 3: A few examples of ongoing clinical trials in Africa

Pediatric Oncology Clinical Trials and Collaborative Research in Africa: Current Landscape and Future Perspectives. van Heerden et al.
ARETTA: Assessing Response to Neoadjuvant Taxotere and Subcutaneous Trastuzumab in Nigerian Women with HER2-Positive Breast Cancer: A Study Protocol Ntekim et al.
Working Together to Build a Better Future for Children with Cancer in Africa Chitsike et al.
Challenges of HIV Lymphoma Clinical Trials in Africa: Lessons from the AIDS Malignancy Consortium 068 Study Strother et al.
Clinical Trials for Treatment and Prevention of HIV-Associated Malignancies in Sub-Saharan Africa: Building Capacity and Overcoming Barriers Lin et al.
Challenges and opportunities for implementing hypofractionated radiotherapy in Africa: lessons from the HypoAfrica clinical trial. Olatunji and Swason, et al.

X. HAND-IN-HAND/PARTNERSHIPS:

As the field of global radiotherapy grows, academic institutions and non-profits organizations recognize the need to support global health cancer research that improves health systems and outcomes in less resourced areas. This has spurred interest in academic partnerships like the one between the University of Pennsylvania and Botswana, University of North Carolina - Chapel Hill and Malawi, Emory University and Ethiopia, University of Washington - AIIMs Institute in India, Uganda Cancer Institute and Komfo Anokye Teaching Hospital in Ghana, Moffitt Cancer Center – University of Ghana to name a few. As such we must be careful not to repeat activities of historical colonialism but undertake research collaborations and

educational training and interventions tailored towards their needs. A recent publication recommends that while collaborative work is often desirable, misunderstandings are inevitable hence one method used to minimize misunderstandings having pre-defined terms of engagement in a memorandum of understanding (MOU) [18]. In the space of global health research this is highly recommended and key elements specified should include scope of the research, leadership and the team, time commitment of each team member and methods or approach, review process and finally how to disseminate and publish results [4]. It is also important to mention that working hand-in-hand means equitably sharing authorship and in the case of clinical trial enrollment, equal enrollment of patients [9].

XI. EVERGREEN

Finally, in the advent of a new intervention or a new technology adoption, it is important to make sustainability a central theme. In the field of global health research, the gong of sustainability is often chimed and yet it seems to be very challenging to achieve this mark. Studies shows that these challenges could be due to attempting to address issues in geographic isolation, siloed by the regions that experience them [9]. There is also the issue of time and resources allocated to improve health outcomes and reducing health inequalities require longer commitments to see sustainable impacts. Another challenge is the power structure within the global health ecosystem and the behavior of outside actors which has often been seen as undermining the pursuit of sustainability in less resourced environments. In the context of global radiotherapy, some of the questions to ask will be how sustainable or self-sufficient is an intervention or technology? What is the guarantee that the findings of a research will make their way to impact the community long after the research funding support ends? How will these studies be monitored and evaluated and improved?

XII. RADIATION (RT)

The last tenet aims to bring the framework back to radiation. These 7 criteria we have laid out and the examples provided can prove to assist departments looking to expand their global health reach, or companies interested in mitigating inequities in cancer research, globally.

Thus, these 7 tenets directly to radiation oncology with specific examples, data, and case scenarios. Radiation Oncology's unique requirements of equipment, technology, technique, imaging, and personnel, all underline the urgent need for a framework to guide our field ethically in this space.

Our hope is that by building this framework it can be used to evaluate and guide, future research proposals, studies, trials, partnerships, and memorandums of understanding. We urge funding agencies and academic institutions alike to evaluate proposals based on these ethical principles. The tenets listed here are by no means exhaustive, but we do believe they prioritize important fundamentals of ethical research in global radiation oncology to promote future equitable access to radiotherapy.

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INVITED PAPERS

TOTAL BODY IRRADIATION: DOSIMETRIC DATA AND CLINICAL EXPERIENCE USING TOMOTHERAPY

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Abstract— **This study aimed to verify the dosimetric accuracy for TBI patients treated in Helical Tomotherapy (Radixact X9) by deliberately evaluating: (i) TPS planned dose versus reconstructed 3D dose distribution from measured MLC Leaf Open Times in the in-house exit detector using 3Dγ evaluation (2%,2mm); (ii) D_{90} to PTV and D_{50} to OARs of the planned DVH and the reconstructed DVH. To validate the accuracy for the exit detector, point dose measurement was carried out alongside the exit detector approach.**

A total of 5 patients were taken and two sets of CT scans for each patient; one in the Head First Supine (HFS) and Feet First Supine (FFS) position have been obtained. Planning was performed in Accuray Precision treatment planning system (version 3.3.1.3). Prescription was 12 Gy in 6 fractions (2Gy/Fx), each fraction delivered twice for three consecutive days. QA plan was generated in the Cheese phantom and the plan was irradiated with no object on the couch for the exit detector measurement. Point dose measurement was carried out in the same phantom using an Extradin A1Sl cylindrical ion chamber (0.05cc) at three different sites (brain, chest and feet).

For the planning, the average D_{98} of upper (HFS) and lower (FFS) PTV were 94.52±2.4% and 96.48±2.4% respectively. And the average V_{95} of upper and lower PTV were 94.02±3.18% and 98.78±1.02 respectively. The exit detector gave an excellent 3Dγ pass rate of 100% for 2%, 2mm and the D_{90} for PTV and D_{50} for OARs from reconstructed DVH yielded a result within ±3% when compared with the planned DVH for all patients. Point dose measurements were within ±3% for all sites.

The close agreement between the exit detector and the point dose measurement, validated the accuracy and reliability of LOTS reconstruction method as a pre-treatment verification.

Keywords— **Total body irradiation, Helical tomotherapy, Exit detector.**

I. INTRODUCTION

Total body irradiation (TBI) is a special radiotherapeutic approach that provides to a patient's whole body a uniform dose to within ±10% of the prescribed dose based on IAEA acceptation [1,2] - far greater than would be accepted for standard radiotherapy techniques (within +7% and -5%) [3]. Megavoltage photon beams, either ^{60}Co γ-rays or megavoltage X-rays, are used for this motive.

A preferred dose for TBI as a myeloablative regimen, 200 centigray (cGy) two times daily (bid) for three consecutive days with a total radiation dose of 1,200 cGy, has been performed since 1997 as part of bone marrow transplantation program [8-11].

The upward thrust of IMRT-based TBI, which include HT help reduce detrimental complications by increased dose control over OARs. The OARs exposed in TBI, in contrast to usual cancer treatment, is extensively greater, consisting of lungs, liver, heart, kidneys and bladder. So minimal dose to these regions is paramount [4]. TBI is an obvious candidate for delivery with the Tomotherapy machine.

Tomotherapy is a unique machine to deliver IMRT and has the benefit that the beam travels helically along the axis of the patient, with multi-leaf collimators (MLCs) offering dose sculpting. The MLCs modulate the beam intensity over the PTV of interest, which can provide a large dose gradient around OARs [5, 6]. Treatment planning system (TPS) software is used for dose calculation and optimisation.

Helical tomotherapy is a treatment choice that offers MVCT-based image guidance and intensity-modulated radiotherapy using a fan beam of radiation. Performing a MVCT before the treatment improves the accuracy of the treatment delivery. With tomotherapy, a new capability exists to conform the dose to very specific areas of the body and it is possible to target the specific parts of the patient's anatomy, in principle with the bone marrow, while sparing sensitive tissues such as the lung. By providing a 360◦ continuous, yet controlled exposure of the PTV, HT's unique delivery enables a larger field exposure at nominal treatment distance in contrast to conventional linac-based IMRT. HT can potentially offer less radiation-induced toxicity to surrounding OARs.

II. MATERIALS AND METHODS

A. Patients

Data from all patients that underwent TBI between 2021 and 2024, in our institute had been analysed. A total of 5 patients had been analysed (Table 1). TMLI patients were excluded considering the fact that it is far out of topic for this study. All patients were immobilised in supine position. TBI treatment at our institution involved a total dose of 12 Gy delivered in 2 daily fractions of 2 Gy over 3 days.

Table 1 Patients treated with TBI between 2021-2024

Patient No.	Sex/ Age (years)	Diagnosis
1	Male (17)	Leukaemia
2	Female (19)	B – ALL
3	Male (23)	ALL
4	Male (43)	B – NHL
5	Male (22)	B – All

B. Treatment Unit

Radixact X9 Tomotherapy takes the shape of an RT device with a linear accelerator mounted on a slip-ring construction, much like a CT device however with a much higher energy and dose rate. It uses an IMRT technique in which the patient is treated slice by slice by IMBs in a way analogous to CT imaging. A unique collimator is designed to generate the IMBs as the gantry rotates around the longitudinal axis of the patient. These days, helical tomotherapy permits the couch to translate constantly with the rotating fan beam, akin to helical CT, administering a helical treatment pattern to the patient. The linac has a maximum energy of 6 MV, with Flattening Filter Free (FFF) delivery of IMRT with increased dose rate of 1000 MU/min. Daily imaging is acquired using the treatment beam at lower energy 3.5 (MeV), so the imaging and treatment isocenters coincide.

The gantry rotation period is 1-5 rotations per minute (RPM). MLC on a Tomotherapy device is driven by pneumatic controllers and has 64 interlacing leaves, made of tungsten and the leaves are interlaced (tongue and groove design) arranged in banks of 32 leaves each. The MLC provides the intensity modulation during treatment. The width of the MLC at the isocentre is 0.625 cm, and the linac target to-isocentre distance is 85 cm. The pneumatic drivers enable the MLC to open or close the leaves in 12-17 milliseconds. This technical gain of the MLC and the helical delivery pattern allows excessive delivery modulation.

Opposite to the linac is an MVCT detector for imaging and QA purposes, i.e., a 640-channel xenon-filled tungsten septal-plate detector with a field of view (FOV) of 39.4 cm. The gantry rotation speed is 11.8–60 secs per revolution and the leaves are binary; they are always programmed to be open or closed. The total opening time per optimisation angle is called the leaf open time (LOT) and is usually presented as a leaf open time histogram (LOTH).

The MVCT imaging system of the Tomotherapy system is used for the treatment position verification of the patients. The on board detector similarly may be used for delivery verification without the patient on the couch. The reconstruction of three-dimensional doses on HT using exit dose measurement via the in-line CT detector array is feasible.

C. CT Simulation

The CT images of the lower and upper region of the phantom with a slice thickness of 3 mm were acquired using SOMATOM confidence CT (Philips Medical Systems, Cleveland, OH, USA). Due to the limitation of helical tomotherapy to a length of 135 cm, two sets of CT scans of 5 mm slice thickness were acquired for legs and corpus separately. First scan was from vertex to mid-thigh in the head first supine (HFS) position, and the second scan from toes to the upper thigh in the feet first supine position (FFS) by means of rotating the patient to 180°. Patients were immobilized in the course of CT scans acquisitions using a head support with a five clamps immobilizing mask covering the head and the thorax, as well as a mask positioned on the thighs secured to a carbon fiber plate (Orfit Industries, Vosveld, Belgium). External feet rotations blocking was achieved using a specific ankles baseplate system. Reference fiducial markers had been located at three different positions in planning CT scans. In the first CT scan labelled as HFS, two reference markers are positioned at the head region and mid-chest level and second CT scan labelled as FFS, a third marker is positioned at the mid-thigh knee plane to create junction for planning. These fiducial markers then assists in the positioning of the lasers and the field junction position on the thighs during treatment. Verification and alignment of all three fiducials in axial planes were done on CT couch at the time of CT simulation. The CT datasets were then transferred to the Tomotherapy treatment planning system (Precision, Accuray, v 3.3.1.3) for contouring.

D. Contouring

After importing CT scan images, two treatment plans were created: HF (Head First) for the upper body and FF (Feet First) for the lower body.

PTVs and critical organs were outlined for each slice. PTV consists of the whole body excluding the OARs; larynx, lungs, heart, kidneys, liver, eyes, lens and the anal canal**.** The junction in the thigh region in HFS was divided into five target volumes of 2 cm thickness and are named as 1PTV, 2PTV, 3PTV, 4PTV & 5PTV from top to bottom to receive 10 Gy, 8 Gy, 6 Gy, 4 Gy and 2 Gy of dose respectively. FFS is also divided into PTV (Lower) & five target volumes of 2 cm thickness and are named as 5PTV, 4PTV, 3PTV, 2PTV and 1PTV from top to bottom to receive 10 Gy, 8 Gy, 6 Gy, 4 Gy and 2 Gy of dose respectively.

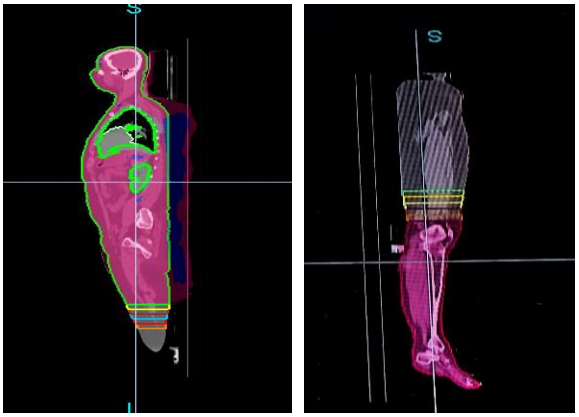

Figure 1: Feet-first supine plan (left); Head-first supine plan (right)

E. Planning and Dose Prescription

A helical tomotherapy treatment plan for TBI was generated for the patient images and contours. The prescription 12 Gy, 2 Gy/fx, 6 fractions was used for planning to cover PTV with 90% of the total dose.

Table 3: Treatment plan parameters used

Patient	Treatment Plan Parameters		
	Field width (cm)	Pitch	Modulation factor
1	5	0.40	3.00
2	5	0.30	3.00
3	5	0.30	3.00
4	5	0.30	3.00
5	5	0.29	2.60

The tomotherapy Accuray Precision treatment planning system version 3.3.1.3 carried out the dose calculation and optimisation for the imported contouring information. Field width was set to 5 cm and dynamic jaw mode was used. Each 2 Gy fraction was delivered twice a day for three consecutive days, with a minimum of six hours between the two daily fractions. Main dose constraints for organs at TPS were mean lung doses of less than 7.5 Gy to decrease the risk of lung complications, and mean kidney doses of 10 Gy. The general method for dose optimisation involved controlling the dose to the lungs and the kidneys, at the same time having maximum coverage to the PTV and the CTV. The upper and lower part of the body was planned separately and united in MIM software version 7.1.90 (MIM Software, Inc.) to control hot and cold spots in intersecting areas.

F. Patient Specific QA

With the intention to ensure agreement in between the delivered radiation with calculation, the patient quality assurance (QA) was accomplished before each patient treatment, required to assure patient safety and to validate every treatment plan. Two methods were performed as a patient specific quality assurance. The first is the point dose measurement carried out using 0.05 cc Extradin A1SL cylindrical ionisation (Standard Imaging, Inc. Middleton, WI) and the second, by using the in-build MVCT detector.

G. Delivery Analysis Using In-House Exit Dosimetry Tool

The Delivery Analysis software operates on a stand-alone workstation separate from the treatment system network and can process input data from multiple machines. The Delivery Analysis receives all data via direct connection to the treatment system database. The pre-treatment QA in Delivery Analysis software makes use of the on-board detector data to infer the MLC leaf open times. The leaf open times, along with beam parameters inclusive of the transverse profile shape, determine the delivery fluence. Prior to pre-treatment QA, a QA plan of the phantom was created. Then the plan is delivered on the machine. The treatment plan is irradiated with no object on the couch. The MVCT detector recorded transmitted radiation from the carbon-fiber Tomo couch were used to reconstruct the MLC-LOTS, which subsequently was used to reconstruct the 3D dose distribution on the CT datasets of the patient. The ensuing dose distribution is compared and analysed to the planned dose distribution using 3D gamma analysis and planned versus reconstructed 3D dose distribution using standard dose-volume histogram (DVH). The gamma acceptance criteria of 2%2mm were used for 3D-γ analysis.

H. Treatment Delivery

TBI was delivered with the head first to the thigh region junction, and the patient was later rotated and put in with the toes towards the gantry position and radiation was delivered from the toes to the thigh region junction to complete the TBI procedure. Pre-treatment imaging and treatment delivery were divided as the patient was treated in both HFS and FFS positions. Treatment was interrupted each time after a pre-specified time for image verification. In HFS treatment, the first MVCT scan was obtained from lower neck to upper abdomen level and the second MVCT was acquired from the vertex to the mid-chest level. After applying the necessary lateral and vertical corrections, patient was treated up to the upper abdomen. The third MVCT scan was obtained covering the entire abdomen up to mid-thigh, the position of scrotum was verified, and the rest of the patient treatment was completed for HFS plan. Next, the patient was rotated by 180° (in yaw plane) with

the same immobilization and alignment in place for FFS treatment plan. The fourth MVCT was acquired in the ankle and couch corrections were applied (including the longitudinal corrections since the patient was moved manually) and treatment was delivered with FFS plan.

III. RESULTS

A. Planning

We evaluated the dose received by 98% of the volume of the target (D_{98}) and volume covering 95% of the dose (V_{95}) for both upper PTV and lower PTV regions and the mean dose (D_{mean}) for OARs from the dose–volume histogram (DVH) report of each plan.

D_{98}- The average D_{98} doses of PTV (upper) and PTV (lower) were 94.52± 2.4% and 96.48± 2.4%

V_{95} – The average V_{95} doses of PTV (upper) and PTV (lower) were 94.02±3.18% and 98.78 ± 1.02%

The D_{mean} values for OARs were taken into account and the data is shown in Table 4.

Homogeneity index- The homogeneity index is another important quality indicator, which indicates the degree of uniformity of dose within target (Table 3).

Table 3: Homogeneity Index for PTV

Patient No.	HI	
	Upper PTV	Lower PTV
P1	1.17	1.06
P2	1.62	1.13
P3	1.60	1.25
P4	1.49	1.18
P5	1.48	1.18

HI = maximum dose/ prescribed dose

$$= \frac{Dmax\ (100\%)}{Rx\ dose}$$

In a perfectly homogeneous case, 100% of the structure gets 100% of the dose (HI=1.0).

Table 4: D_{mean} values for OARs

Structure	$D_{mean\%}$ (Gy)				
	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5
Lung (L)	7.38	6.98	7.59	7.68	7.40
Lung (R)	7.57	6.92	7.05	7.75	7.19
Kidney (L)	5.40	8.79	7.11	9.77	6.48
Kidney (R)	5.04	8.64	6.81	10.34	5.76
Liver	6.39	9.09	7.52	9.93	7.35
Heart	6.43	8.05	7.39	9.54	6.35
Lens (L)	2.37	2.84	1.80	2.20	1.56
Lens (R)	2.63	2.89	1.96	2.25	1.50
Eye (L)	6.19	5.58	3.53	2.93	2.02
Eye (R)	6.42	5.72	3.30	3.00	2.02
Larynx	4.34	12.21	8.25	8.25	11.65

B. Pre-Treatment Verification

In the in-house exit detector tool, two types of results were analysed with exit detector tool which includes 3D gamma and D_{90} and D_{50} values for PTV (upper and lower) and OARs respectively from DVH reconstruction.

DVH reconstruction - The DVH reconstruction allows direct comparison between the planned and measured doses across the PTV and OAR sub-volumes. This is shown in Figure 2.

3D Gamma - Good agreement was observed between planned and reconstructed 3D dose distribution having dose difference not more than 2% at 2 mm in upper body plan as represented by isogamma levels. No isogamma levels above 1 were seen for all patients except one which is shown in Figure 3.

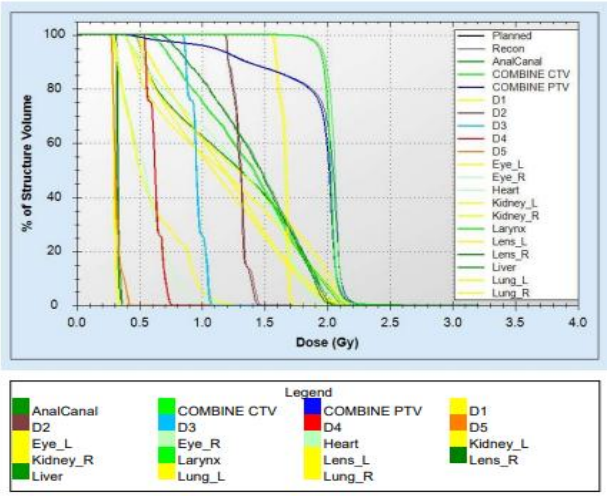

Figure 2: Planned and reconstructed cumulative DVH for various sites in the upper body plan. Planned dose profile in bold line and reconstructed dose profile in thinner line.

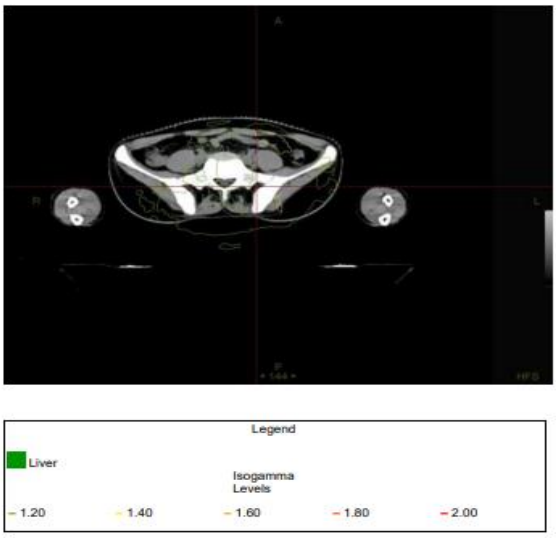

Figure 3: Iso-gamma level seen greater than one for patient 3

The overall dosimetric results evaluated are given below. The difference is presented as mean ± standard deviation (from five clinical plans).

The 3D gamma pass rate, using 2%/2mm criteria determined by exit dosimetry tool were all 100%. No uncertainties were present as the measurement was conducted once.

Table 5: 3Dγ values of 2%/2mm for various sites

Site	3Dγ values from comparison of planned and reconstructed dose distributions in various sites				
	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5
Upper body PTV	100%	100%	100%	100%	100%
Lower body PTV	100%	100%	100%	100%	100%
Lungs (L)	100%	100%	100%	100%	100%
Lungs (R)	100%	100%	100%	100%	100%

The ionisation chamber measurements were within ±5% for all sites (Table 6)

C. Overall Dosimetric Evaluation

The overall dosimetric results evaluated are given below. The difference is presented as mean ± standard deviation (from five clinical plans)

Table 6: Overall dosimetric results

Dosimeter	Dose and other metrics used	Result
Ionisation chamber	% dose difference	PTV brain: -0.89 ± 1.78% PTV chest: -1.83 ± 1.84% PTV lower limb 0.35 ± 2.6%
Exit dosimetry	D_{90} dose difference	Upper PTV: 0.72 ± 0.13% Lower PTV: 0.99 ± 0.62%
	D_{50} % dose difference	Lung (L): 0.99 ± 0.17% Lung (R): 0.94 ± 0.15% Liver: 0.72 ± 0.21 % Kidney (L): 0.81 ± 0.35% Kidney (R): 0.70 ± 0.37% Eyes (L): 0.65 ± 0.51% Eyes (R): 0.43 ± 0.61%
		Upper PTV: 100% Lower PTV: 100% Lung (L): 100% Lung (R): 100%

IV. DISCUSSION

The specialized HT delivery method is commonly used for treating lengthy or large areas like total body irradiation. The main intention of this study was to deliver TBI using helical tomotherapy. Despite the fact that it is simple in contrast to conventional treatments, HT TBI is a time-consuming process and is particularly tough to manage in the context of other indications. As helical tomotherapy is limited to a maximum treatment length of 135 cm, patients taller than 135 cm require two planning computed tomography (CT) scans to fully cover the body.

The planned-measured dose disagreements across PTV and OAR sites were within the recommended 5% set by ICRU [46, 4], as proven in table 6 using ionisation chambers and exit dosimetry. The in-house exit dosimetry tool yielded a 3D gamma pass rate, using the 2mm/2% criteria of 100%. The high pass rate is due to the absence of set-up errors from phantom positioning. However, a few regions of the PTV, those of which did not meet the criteria of 2%/2mm tolerance having gamma values greater than 1 have also been observed (Figure 3). A likely reason for this dose discrepancy is the presence of a non-uniform dose region and also as a result of balancing among PTV to acquire 12 Gy while additionally minimising exposure of radiation to vital organs. The good agreement both in absolute dose and 3Dγ of less than 5% between ion chamber and exit detector measurement, in all patients confirmed the accuracy and reliability of LOTS reconstructed method in Delivery Analysis against the standard methods. 3Dγ was 100% for all plans and PTVs even after tightening the calculation standards to 2%/2mm.

This study shows that helical tomotherapy can effectively decrease the radiation dose to crucial organs, like the lungs, without the need of extra measures including external blocks or compensators required for shielding each individual organ. The dose to the lungs was reduced, while still maintaining full dose coverage in areas like ribs and sternum that can be affected with traditional methods.

TBI plans couldn't be established using the ArcCHECK dosimeter because of limited experience of using ArcCheck for long targets. Nevertheless, the Exit detector DQA tool provided a valuable solution for accurate treatment verification in such cases. The advantage of exit detector DQA is that, if machine delivery errors result in dose errors beyond the measurement surface, those phantom-based QA techniques won't be capable to detect them. The OBD has higher resolution than external planar or cylindrical detectors arrays, taking into consideration the increased detection sensitivity to MLC errors. However the exit detector DQA tool focuses specifically on MLC movements and their effects on patient dose, so there will be numerous other mechanisms for plan delivery failure which could be studied in the near future. Additionally, the reconstruction method in Delivery Analysis does not test for differences in couch position, or treatment field position. Only variations in MLC-LOT are considered when calculating dose differences and the reconstructed 3D dose calculation assumes that there is no change in the patient anatomy and tumour geometry.

V. CONCLUSION

The use of an in-house exit dosimeter as a dosimetric verification system permit the DQA analysis to be made in three-dimensional (3D). Therefore, users can evaluate the dose distribution between the measurement and calculation in more detail compared with the phantom based QA methods. TBI with helical tomotherapy although takes a lot of effort away, it can be concluded that it is one of the efficient methods to treat TBI due to its higher dose homogeneity and hence sparing of critical organs.

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ARTIFICIAL INTELLIGENCE (AI) – BOON OR BANE FOR MEDICAL PHYSICS PROFESSION?

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I. INTRODUCTION

The term AI was first coined by John McCarthy in 1956 as the science of engineering and making intelligent machines. However, early works in AI had not achieved many breakthroughs due to the limited computing power. It was only in the last decade that AI research in healthcare and medicine had started to show promising results and practical applications, from facial recognition to fully automatic detection, and even finding new biomarkers for diagnosis and follow up. It has been recognised as both a productive and disruptive force in healthcare. In particular, radiology, radiotherapy and pathology are the three medical specialities that saw the more prominent AI role and therefore has impacted directly the medical physicist's profession. Some medical physicists may view AI as a threat to the future of the medical physics profession.

Artificial Intelligence (AI) is rapidly transforming various domains, including healthcare, and medical physics is no exception. The integration of AI in medical physics is poised to revolutionize the field by enhancing diagnostic accuracy, streamlining treatment planning, and improving patient care where it is revolutionizing medical physics primarily in radiation therapy, diagnostic imaging, and nuclear medicine. As AI gains prominence, medical physicists face the dual challenge of integrating AI-driven advancements while ensuring accuracy, safety, and ethical compliance. In this article, I am trying to explore the potential of AI to transform medical physics, focusing on its applications, challenges, and future directions and whether AI is going to be boon or bane for the medical physics profession, examining its impact on clinical practices, research, professional roles, and ethical considerations.

If AI is used with its full understanding with taking care of its limitations and pitfalls, AI can benefit medical physics in numerous ways, enhancing efficiency, accuracy, and patient safety. For example, in radiation therapy, AI-driven treatment planning systems optimize dose distribution, reducing planning time and improving precision. In diagnostic imaging, AI-powered tools assist in segmenting tumour regions in MRI and CT scans, minimizing human error. AI also supports quality assurance by predicting equipment failures before they occur, ensuring continuous and safe operation. Additionally, AI accelerates research by analysing vast datasets to identify trends, leading to improved patient-specific treatment plans and predictive modelling for better healthcare outcomes. However, AI has pitfalls and limitations that must be addressed. One significant issue is the risk of algorithmic bias, where AI models trained on limited or unrepresentative datasets may produce inaccurate or inconsistent results. Additionally, AI systems may lack transparency, ensuring continuous and safe operation. making it difficult for medical physicists to interpret and validate AI-generated recommendations. Over-reliance on AI could also lead to skill degradation among medical professionals, reducing their ability to assess and correct potential errors. Moreover, regulatory and implementation challenges persist, as AI systems require thorough validation and continuous monitoring to ensure their reliability. Addressing these limitations is crucial to integrating AI safely and effectively in medical physics practice.

Now, I will focus on areas where AI can be applied efficiently and effectively by Medical Physicist in clinical practice.

II. RADIATION THERAPY (RT)

In radiotherapy, AI is used to enhance the accuracy of treatment planning by reducing human intervention and improving plan quality. AI platforms can predict the radiation sensitivity of tumours before treatment starts, helping determine the optimal dose for patients. Additionally, AI can assist in image-guided radiotherapy by generating synthetic CT images from MRI data, reducing the need for additional CT scans and lowering radiation exposure.

a. Treatment Planning

- AI can automate and optimize treatment planning for radiation therapy, especially in Intensity-Modulated Radiation Therapy (IMRT), Volumetric Modulated Arc Therapy (VMAT), and Stereotactic Body Radiation Therapy (SBRT).
- Machine learning models can predict optimal dose distributions, organ-at-risk (OAR) sparing, and treatment plan quality assurance.
- AI-based tools such as deep learning algorithms help in auto-segmentation of tumours and

OARs in CT and MRI images, reducing manual workload and increasing output.

b. Quality Assurance (QA)

- AI-driven predictive analytics can help detect treatment errors before delivery of treatment giving a chance to correct.
- AI-enhanced gamma analysis and dose verification tools improve patient safety and treatment accuracy.
- Automated machine learning models can predict and correct equipment deviations before failure/breakdown/malfunction.

c. Adaptive Radiotherapy

- AI can help in daily image-guided adaptive radiotherapy (IGRT) by predicting anatomical changes during fractionated treatments and suggesting real-time plan adjustments.
- Deep learning models analyse imaging data to improve dose recalculations and motion management.

III. MEDICAL IMAGING AND DIAGNOSIS

AI plays a crucial role in automating routine tasks in medical imaging, such as image processing, quality control, and data management. It can automatically segment and label structures in medical images, reducing the time and effort required by healthcare providers. AI algorithms can analyse medical images to identify patterns and abnormalities that may not be visible to the human eye, aiding in more accurate and timely diagnoses.

a. Image Processing and Enhancement

- AI can improve image quality and reduce noise in MRI, CT, and PET scans.
- AI-based denoising algorithms help in low-dose CT (LDCT), reducing radiation exposure to patients while maintaining image quality.
- Super-resolution techniques using AI enhance imaging details without increasing scanning time.

b. Automated Image Segmentation

- AI can segment tumours, organs, and lesions with high precision, reducing inter-observer variability.
- Deep learning-based segmentation models are widely used in brain, lung, breast, and prostate cancer imaging.

c. AI-Assisted Diagnosis

- AI can detect early signs of cancer, neurological diseases, and fractures from imaging scans at pixel level before it is visualised by clinicians on image without AI.
- Deep learning models in MRI and CT scans help identify even very minute abnormalities that radiologists might miss without AI.

d. Radiomics and Predictive Analytics

- AI can extract and analyse imaging biomarkers for tumour characterization, choose treatment options, treatment response prediction, and prognosis estimation.
- Radiomics, combined with machine learning, can help differentiate between benign and malignant tumours without pathological or biochemical sampling.

IV. RADIATION SAFETY AND DOSIMETRY

a. AI-Driven Dosimetry

- AI models can estimate radiation dose distributions in patients undergoing radiotherapy [dose painting/mapping] or diagnostic imaging.
- AI-based Monte Carlo simulations can improve dose calculations for complex cases more precisely.

b. Radiation Protection and Monitoring

- AI-enhanced sensors and wearables devices can monitor radiation exposure in real time for medical staff and the opportunity to take preventive measures by modifying work practice immediately, if need be.
- AI-powered systems can predict radiation leakage or errors in shielding design in radiotherapy rooms so that corrective measures can be taken in a timely manner.

c. AI in Brachytherapy

- AI can optimize dose planning for high-dose-rate (HDR) and low-dose-rate (LDR) brachytherapy, ensuring precise dose delivery, maximising dose in tumour and sparing OAR effectively.
- AI-based algorithms can automatically adjust dwell times and catheter placements for better outcomes of the treatment.

V. AI IN PROTON AND HEAVY ION THERAPY

- AI is used for beam range prediction, ensuring precise proton stopping points thereby overcoming the uncertainty in RBE and dose deposition.
- AI-driven models optimize treatment plans to account for uncertainties in proton range and dose distribution.

VI. AI IN NUCLEAR MEDICINE AND PET IMAGING

a. AI in SPECT and PET Imaging

- AI algorithms improve image reconstruction and reduce scan times in PET and SPECT imaging thereby increasing efficiency and efficacy.
- AI-based noise reduction allows for low-dose radiotracer imaging thereby minimizing patient radiation exposure.

b. AI in Radiopharmaceutical Production

- AI can assist in optimizing radioisotope production, predicting radiopharmaceutical decay, and enhancing supply chain management efficiently.

VII. AI IN MEDICAL PHYSICS EDUCATION AND RESEARCH

a. AI for Medical Physics Training

- AI-based simulations, e-tutorials can train medical physicists in radiotherapy planning, quality control, and safety assessments.
- Virtual AI tutors and decision-support systems enhance learning efficiency.
- One of the IMPW2025 webinar on 7 May 2025 is focusing on AI in Medical physics education and training.

b. AI for Research and Development

- AI models accelerate Monte Carlo simulations for dosimetry calculations.
- Machine learning aids in predicting treatment responses and improving personalized precision medicine approaches.

VIII. AI FOR WORKFLOW AUTOMATION AND DECISION SUPPORT

a. AI in Hospital Workflow Optimization

- AI helps in automating scheduling for radiation therapy, reducing patient waiting times.
- AI-powered systems optimize machine usage, staffing, and patient throughput more efficiently and economically.

b. AI for Clinical Decision Support

- AI-based predictive models assist oncologists in selecting optimal treatment strategies.
- AI-driven algorithms provide evidence-based recommendations for patient management.

IX. AI IN GUIDED SURGERIES AND ROBOTICS

- AI is integrated with robotic-assisted radiation therapy (Cyberknife, MR-Linac, PET-Linac) for real-time tumour tracking.
- AI-driven robotic systems enhance precision in biopsy procedures and brachytherapy seed placement.

X. BENEFITS OF AI IN MEDICAL PHYSICS

a. Enhanced Accuracy and Efficiency

AI significantly reduces human error in tasks such as image segmentation, treatment planning, and dose calculations. Machine learning models improve precision in detecting anomalies in imaging, leading to earlier and more accurate diagnosis.

b. Improved Workflow and Productivity

AI automates repetitive tasks, allowing medical physicists to focus more on complex decision-making and patient-specific treatments. Automated treatment planning reduces planning time, making radiation therapy more efficient.

c. Personalized Treatment and Adaptive Radiotherapy

AI-driven models analyse patient-specific characteristics, allowing personalized treatment regimens. Adaptive radiotherapy uses AI to adjust treatment in real time, enhancing efficacy and minimizing side effects.

d. Advancements in Research and Innovation

AI accelerates research by analysing large datasets, identifying patterns, and predicting patient responses to treatments. This facilitates innovation in treatment protocols, imaging techniques, and predictive analytics.

e. Enhanced Quality Assurance and Safety

AI-powered quality control ensures equipment calibration, detects anomalies, and predicts failures in medical devices. This helps medical physicists to enhance patient safety and reduce treatment-related errors.

It is now clear that AI is transforming Medical Physics by improving the accuracy of radiation therapy, imaging, dosimetry, and radiation safety. With continued advancements, AI will enhance patient outcomes, reduce human errors, and optimize clinical workflows, making Medical Physics more efficient and effective, however there are challenges which need to be addressed.

XI. CHALLENGES AND FUTURE PERSPECTIVES

While AI has immense potential in Medical Physics, there are many pitfalls and challenges which need to be tackled

XII. POTENTIAL HARM AND CHALLENGES OF AI IN MEDICAL PHYSICS

a. Risk of over-reliance and loss of expertise:

Over-dependence on AI may lead to skill degradation among medical physicists, reducing their ability to critically evaluate AI-generated outputs. This could be detrimental in cases where AI fails or produces incorrect results. Medical Physicists needs to alert and avoid becoming slaves of machine/ AI but to remain the master of it.

b. Job displacement and changing roles:

Automation of routine tasks might reduce the demand for traditional roles in medical physics, leading to concerns about job displacement. However, AI also creates opportunities for new roles focused on AI oversight and algorithm development. AI will not completely replace medical physicists but medical physicists who fail to embrace and acquire skills in AI will definitely be replaced.

c. Data bias, generalizability issues and limited patient diversity:

Models trained on datasets lacking diversity may not generalize well across different populations. AI models are only as good as the data they are trained on. Bias in training datasets can lead to inaccuracies in treatment recommendations, potentially compromising patient outcomes. Therefore, generating own data and updating/validating the software tuned to country/region is necessary. It's like garbage in, garbage out.

d. Regulatory and Implementation Barriers:

Ensuring the accuracy and reliability of AI algorithms is crucial. AI integration in medical physics requires stringent validation, regulatory approvals, and continuous monitoring. Standardizing AI practices across institutions remains a complex challenge.

e. Data privacy and security:

Patient privacy and safety are paramount. AI systems must be developed and used responsibly to maintain trust in healthcare and must comply with data privacy regulations of the country.

f. Interpretability of AI decisions:

AI-driven medical decisions need to be explainable to clinicians and clinicians need to be trained and acquainted with the system.

g. Integration with existing workflows:

AI tools must seamlessly fit into ongoing clinical practice and adaptation to future issues.

h. Informed Consent:

Patients must be informed about the use of AI in their care, including how their data is used and the potential risks and benefits of AI-driven decisions. This ensures that patients have autonomy over their healthcare choices.

i. Accountability and Transparency:

AI models can be complex and difficult to interpret, making it challenging to hold anyone accountable for their decisions. Ensuring transparency in AI decision-making processes is essential to build trust and ensure accountability.

j. Education and Training:

Medical physicists need updated education and training to effectively integrate AI into their practice

XIII. FUTURE DIRECTIONS

Rather than replacing medical physicists, AI should be viewed as a collaborative tool that enhances their capabilities. The future of AI in medical physics is promising for medical physics and lies in integrating AI responsibly, ensuring ongoing research aimed at addressing current challenges:

- **Integration with Emerging Technologies:** Combining AI with other technologies like big data

analytics and machine learning will further enhance its capabilities in medical physics.

- **Development of Guidelines:** Establishing clear guidelines for the use of AI in medical physics is essential to ensure safe and effective implementation.
- **Continuous Education:** Medical physicists must acquire AI literacy to understand, validate, and oversee AI-driven systems. Regular updates in education and training programs will be necessary to keep medical physicists proficient in AI technologies.
- **Human-AI Collaboration:** AI should assist, not replace, expert judgment, with physicists providing oversight for AI recommendations.
- **Ethical and Transparent AI Development:** AI algorithms must be explainable, unbiased, and continuously refined based on real-world data.
- **Regulatory Adaptation:** Policies should evolve to ensure AI's safe and effective use in medical physics.

XIV. CONCLUSION

AI has the potential to revolutionize the practice of medical physics by improving diagnostic accuracy, enhancing treatment planning, and optimizing patient care. AI presents both opportunities and challenges for the medical physics profession. While it enhances accuracy, efficiency, and innovation, concerns regarding expertise retention, ethics, and job displacement must be addressed. By adopting a balanced approach—leveraging AI's strengths while maintaining human oversight—medical physicists can harness AI's potential to improve patient outcomes and advance the field. The future lies in collaboration, ensuring AI serves as an augmentation rather than a replacement for human expertise in medical physics and ongoing research and development are poised to address these issues, paving the way for a future where AI is integral to medical physics. Now, almost every one of you will agrees with me that AI is essential and will only continue to play increasing roles in medical physics and it is you will make use of this revolutionary technology as a boon for medical physics professionals.

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THE HIDDEN PSYCHOLOGY OF RADIATION SAFETY - HOW FEAR SHAPES DOSE DECISIONS IN MEDICAL IMAGING

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I. INTRODUCTION

Radiation dose optimization is a critical component of medical imaging, aiming to balance diagnostic accuracy with patient safety by minimizing radiation exposure. Medical professionals, including radiologists, technologists, and referring physicians, continually strive to adhere to the ALARA principle – keeping radiation exposure "as low as reasonably achievable." Yet, despite advancements in technology and established safety protocols, achieving this balance remains challenging, partly due to complex psychological factors that influence clinical decision-making.

Balancing diagnostic certainty with patient safety involves confronting not only technical and procedural challenges but also the hidden psychological pressures healthcare professionals face. This article explores these often-overlooked psychological dimensions – such as risk aversion, fear of diagnostic errors, and liability concerns – that shape decisions related to radiation dose. By highlighting these factors, we aim to encourage integration of psychological awareness into training programs and organizational policies to foster more informed, confident, and safer imaging practices.

II. PSYCHOLOGICAL DRIVERS BEHIND DOSE DECISIONS

Healthcare providers frequently encounter psychological influences that subtly guide their radiation dose decisions. One prominent factor is risk aversion, particularly the fear of uncertainty or missing a critical diagnosis. Radiologists and other medical professionals may unconsciously favor higher radiation doses to enhance diagnostic confidence, often selecting advanced imaging modalities over lower-dose alternatives. Cognitive biases such as availability bias – where recent rare cases significantly influence decision-making – further reinforce this cautious, dose-intensive approach [1].

A closely related driver is the fear of diagnostic errors. Medical professionals often worry that lower radiation doses might compromise image quality, potentially leading to missed findings. This anxiety, especially prominent among radiologists, is well-documented. A recent analysis underscores that radiologists – deeply aware of the consequences of diagnostic errors – often lean toward higher radiation doses or follow-up studies to ensure accuracy [2].

Another major influence is liability concern, which fuels a culture of defensive medicine. Physicians may order unnecessary imaging tests to protect themselves against potential litigation. This medico-legal fear leads to over-imaging and elevated radiation exposure. Expert discussions confirm that legal concerns often override adherence to evidence-based best practices [3,4]. Referring physicians are particularly susceptible, as legal fears and patient expectations contribute to excessive imaging orders [5].

By openly acknowledging and addressing these psychological drivers – fear of errors, legal repercussions, and ingrained cognitive biases – medical imaging departments can better manage radiation safety, ensuring decisions align more closely with evidence-based best practices and patient well-being.

III. RADIOLOGISTS' DILEMMA: QUALITY VS. RISK

Radiologists face a unique challenge in balancing image quality with patient safety due to their direct role in interpreting imaging studies. Unlike other healthcare providers, their diagnostic interpretations carry immediate clinical and legal weight, often heightening anxiety over uncertainty.

To mitigate this, radiologists benefit from specialized training in uncertainty management and structured peer-review programs that validate image adequacy even at lower doses. Role-specific strategies, such as confidence-building through decision-making simulations, and active engagement with dose optimization guidelines, can help reinforce that lower-dose imaging can still yield high diagnostic value.

Organizational support is also key. A strong safety culture that encourages second opinions, shared decision-making, and transparent error reporting can empower radiologists to resist fear-driven choices and uphold ALARA principles without compromising diagnostic confidence.

IV. TECHNOLOGISTS ON THE FRONTLINE: ADHERENCE VS. AUTONOMY

Radiologic technologists, who implement imaging protocols directly, face their own set of psychological pressures. A key factor is the fear of producing suboptimal image quality, which could lead to repeated exams,

criticism, or compromised patient outcomes. Technologists often default to familiar, higher-dose protocols rather than risk subpar results from dose-reduced methods [4].

Studies reveal significant knowledge gaps in advanced dose management strategies, such as diagnostic reference levels. While many technologists recognize the ALARA principle, fewer understand or apply quantitative dose metrics in daily practice. This gap highlights the need for targeted education to enhance technologists' confidence in optimizing dose [1].

Building a supportive organizational culture that values technologists' input, promotes communication with radiologists, and offers continuous education can alleviate these pressures, helping them confidently apply optimization techniques without sacrificing diagnostic quality.

V. REFERRING PHYSICIANS: THE FEAR FACTOR IN OVER-IMAGING

Referring physicians play a pivotal role in determining whether imaging is ordered in the first place. Unlike radiologists or technologists, they often lack detailed training in imaging appropriateness or radiation dose considerations. This knowledge gap, combined with medico-legal fears and pressure from patients or families, makes them particularly vulnerable to over-imaging due to uncertainty.

Addressing this requires focused education on evidence-based imaging guidelines, including campaigns like Choosing Wisely and the ACR Appropriateness Criteria. Integrating clinical decision support systems (CDSS) into electronic ordering platforms can provide real-time feedback on imaging choices and reduce unnecessary referrals.

Additionally, risk communication training can equip referring physicians to manage patient expectations more effectively, shifting conversations from "more testing equals better care" to informed, safety-first dialogue.

VI. TOWARDS A CULTURE OF CONFIDENCE AND CLARITY

Addressing psychological barriers to radiation dose optimization requires cultivating confidence and clarity in decision-making. Training should include psychological awareness, helping professionals manage anxiety around uncertainty and liability.

As emphasized by the WHO and IAEA, developing a robust radiation safety culture involves not just policies but the emotional empowerment of staff through education, collaboration, and supportive leadership [6].

Decision-making simulations, peer feedback sessions, and role-playing are useful for helping radiologists and technologists gain confidence in using lower-dose protocols. Similarly, risk communication workshops can empower referring physicians to make decisions less driven by fear.

Initiatives like the Image Gently and Image Wisely campaigns demonstrate effective ways to institutionalize such approaches, blending psychological insight with practical tools for safer imaging.

VII. CONCLUSION: REFRAMING RADIATION SAFETY

Integrating psychological insight into radiation safety represents an untapped opportunity to improve imaging practices. Recognizing and addressing fear-based decision-making – whether related to diagnostic confidence, legal exposure, or cognitive biases – can lead to more rational, evidence-based choices.

Leadership in imaging departments and healthcare institutions must support training and policies that promote psychological resilience. A culture that emphasizes transparency, team collaboration, and continuous education will allow imaging professionals to act confidently in the best interest of patient care.

Reframing radiation safety through a psychologically informed lens provides a clearer path toward optimized, patient-centered imaging – where low-dose decisions are not feared, but trusted.

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AN INITIAL QUANTITATIVE COMPARATIVE STUDY OF THE CONTRAST RESOLUTION OF DIFFERENT ULTRASOUND IMAGING TRANSDUCERS

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Abstract – **The current established guidelines to assess the contrast resolution in ultrasound (US) systems suggest that tests are done qualitatively. To limit subjectivity, various quantitative methods were investigated to analyse the contrast resolution across different US transducers, frequencies and depths. This includes the index contrast (IC), the gamma of the system, and the contrast-to- noise ratio (CNR). From the data gathered by using the CIRS Model 040GSE phantom and ImageJ, it was found that the IC increases with hyperechoic structures, for all transducer types. Regarding the gamma values, it was found that it depends on the type of transducers and not on the frequency whilst for the CNR, all transducer types established characteristic U-shaped scatter plots. Through these methods, it was concluded that the sector probes established better performance at the near and far field zones. Moreover, from most data plotted, it was found that the contrast resolution is not frequency- dependent.**

Keywords- ultrasound, contrast resolution, quantitative methods, transducers, probes, quality assurance, quality control

I. INTRODUCTION

US imaging is a non-ionising radiation modality which can be used for real-time assessments of foetal development and tumour diagnosis in abdominal organs, Lanzolla et al. (2011). As thoroughly highlighted by Lanzolla et al. (2011), US images can be obtained using various modes. For this study, the brightness display mode (B-mode) was utilised where the brightness of a 2D greyscale image is proportional to the signal amplitude.

This research study addresses the problem of how contrast resolution in diagnostic US modalities is assessed. Standards and published documents, such as reports from the IPEM and the AAPM, recommend that contrast resolution should be measured visually using scoring methods. This subjective approach results in less efficient quality assurance (QA) and quality control (QC) testing when monitoring the contrast resolution of different US systems and probes.

In light of this, the need to develop a quantitative method will provide a clear understanding of the contrast resolution behaviour across different probes, depths and frequencies. Based on the current literature, different ways to analyse contrast resolution are present. This study had the following objectives:

- To develop a quantitative approach to investigate and assess contrast resolution.
- To analyse the behaviour of contrast resolution of different transducers: linear, curvilinear and sector.
- To investigate contrast resolution for different frequencies.
- To understand the behaviour of contrast resolution at different depths.

To investigate the above, various greyscale images from acceptance testing were acquired as part of the data collection. Then, using ImageJ and Microsoft Excel Version 16.86, data was extracted and analysed.

A. Contrast Resolution

Contrast resolution is defined as "the ability of the US imaging system to detect subtle differences in the echogenicity of two targets" (Sarassoli et al., 2019). Multiple studies investigated this parameter, considering different phantoms and software programmes along with various probes operating at different frequencies. The probes include the ones shown in Fig. 1.

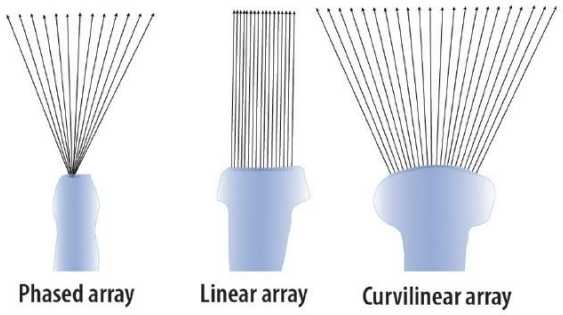

Fig. 1. (2021) Diagram of the Transducers FOV, Vanderland and Kumar

B. International Standards

For the contrast resolution or the greyscale performance test, the IPEM 102 report mentions that it can be tested by imaging a section within the phantom with different echoic targets ranging from hypoechoic to hyperechoic. In this way, each target would be subjectively analysed by using a 3-point scale rating as defined through Table I.

Table I: Lesion target scoring based on IPEM 102

IPEM 102 - Lesion Target Scoring - 3-Point Scale	
Score 1	Not seen
Score 2	Seen but distinct
Score 3	Clearly seen

On the other hand, even though AAPM does not have a specific protocol for assessing the greyscale performance of an US system, it emphasises its importance within a comprehensive QC procedure. Moreover, AAPM suggests that consistent greyscale performance is crucial for comparing US systems and probes over time.

II. MATERIALS AND METHODOLOGY

A. Data Collection Technique

Images were gathered from various acceptance tests which were performed over four years. For images to be obtained, a Standard Operating Procedure (SOP) based on IPEM 102 was followed to ensure that testing on the contrast resolution is conducted as suggested in these guidelines. Using a dedicated phantom, such guidelines allowed different US transducers to be tested on various US devices available at Mater Dei Hospital (MDH).

The ultrasound images collected retrospectively were saved in Digital Imaging and Communications in Medicine (DICOM) format to be further evaluated through ImageJ. Through this chosen software, the images saved from the US systems were investigated, allowing quantitative data to be extracted and gathered.

With the use of a TETO and coupling gel, the linear, curvilinear, and sector probes were tested on various US systems. Endocavity/endovaginal and hockey-stick type probes were also assessed. For the contrast resolution to be analysed through the system's greyscale performance, the following steps were considered to obtain an optimised US image:

1) The dedicated phantom was scanned by applying coupling gel on the phantom area which has an attenuating material 0.5 dB/(cm·MHz), as shown in Fig. 2.
2) With the transducer under test, the first set of different grey cylindrical targets was scanned. A total of six targets; -9 dB, -6 dB, -3 dB, +3 dB, +6 dB and +15 dB were imaged at a depth of 3 cm within the phantom.
3) Upon scanning the TETO, the image was optimised by ensuring that contrast between the speckle background and the target is achieved. This was achieved by adjusting the Amplification Gain, Time-Gain Compensation (TGC) and by setting the focus at the greyscale targets set.
4) The image/s of the cylindrical targets located at this depth were saved and exported in DICOM format, as shown in Fig. 3, for further analysis on ImageJ.
5) The above steps were repeated for the other five different grey cylindrical targets located at a depth of 11.5 cm. At this depth, the -6 dB, -3 dB, +3 dB, +6 dB and +15 dB targets were tested.

Fig. 2. Scanning the CIRS Model 040GSE TETO, CIRS (n.d.)

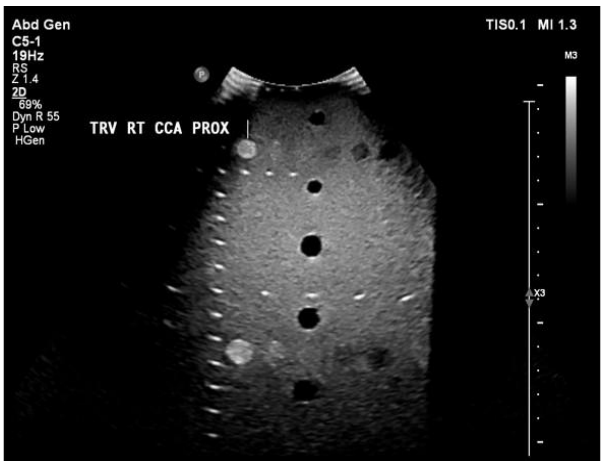

Fig. 3. An US image using a curvilinear transducer on the Philips EPIQ Elite 5G system

B. Data Collection Tool

As shown in Table II, 21 US systems equipped with 52 probes were tested. The probes are further classified into 17 linear, 20 curvilinear and 15 sector. For these to be evaluated, the CIRS Model 040GSE TETO shown in Fig. 4 was used together with the ImageJ software for data analysis.

Table II: A table of all the US systems and probes assessed

		Probe Details		
Manufacturer	**Model**	**Linear**	**Curvilinear**	**Sector**
Philips	Sparq	L12-4	C5-1	S5-1
	Affiniti 30	-	C6-2	-
	Epiq Cardiac CVx 3D	-	-	X5-1
		-	-	X7-2
		-	-	S8-3
		-	-	S12-4
	Lumify 72 SMT-T590	-	-	S4-1
	Lumify 91 SMT-T590	-	C5-2	-
	Lumify 86 SMT-T590	L12-4	-	-
	Lumify 87 SMT-T590	L12-4	-	-
	Lumify 89 SMT-T590	-	-	S4-1
	EPIQ Elite 5G	L12-3	C5-1	-
		L15-7io	-	-
	CS50 POC	L12-3	C5-1	-
Canon	Aplio i800	i18LX5	-	-
	Aplio a550	-	8C1	-
	Aplio a450	-	6C1	-
		-	11C3	-
	Aplio a	-	8C1	-
		11CL4-LA	11CL4-CA	-
Toshiba	Aplio300	14L5	6C1	-
	Aplio a400	-	6C1	-
	Aplio 500	14L5	-	-
GE	Vivid iQ	12L-RS	-	-
	Voluson S6	-	EndoVaginal	-
	Voluson S10	-	Transvaginal I9-RS	-
Esaote	X7	L4-15	-	-

C. Data Analysis Technique

The data analysis techniques used were based on what was commonly implemented in the literature. For this reason, three particular methods were investigated. These include the evaluation of the gamma of the system, the IC and the CNR. All of these approaches were considered to provide a better insight into the US system and probe's overall performance.

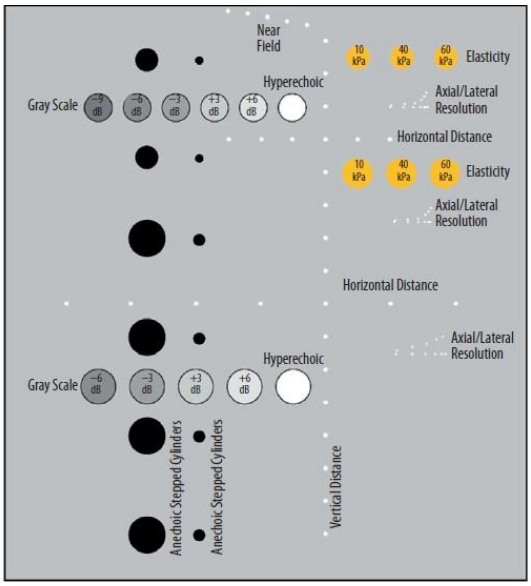

Fig. 4. A schematic for the phantom model CIRS 040GSE, Fabiszewska et al. (2017)

For data to be extracted, the stored DICOM images were uploaded to the open-source software ImageJ. A circular selection tool was used to draw a ROI on the targets. As shown in Fig. 5, the circular selection is represented in yellow. Data provided from the ROI includes the circular area, mean pixel value (MPV), SD, the maximum pixel value and the minimum pixel value. Four other ROIs were drawn around the target's background, and data was recorded for each ROI, as shown through Fig. 6, also in yellow. For most probes, this process was repeated for the targets at the depths of 3 cm and 11.5 cm within the phantom. Shown in Table III, the five data sets were noted for each target. The first one is that of the target itself, and the remaining four refer to data points of the target's background.

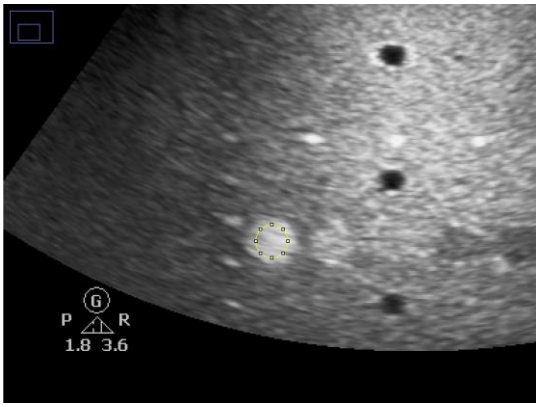

Fig. 5. Circular selection of a target at a depth of 11.5 cm in Image J

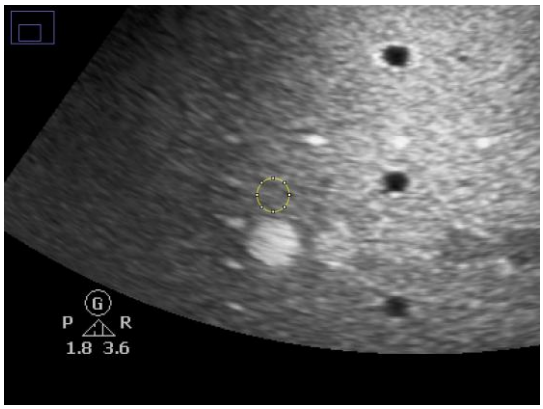

Fig. 6. Circular selection outside a target at a depth of 11.5 cm in Image J

Table III: Data of a curvilinear probe obtained through ImageJ Method 1 - Gamma Method:

Manufacturer and Model:	Philips Sparq
Probe Type and Name:	Curvilinear - C5-1
Probe Central Frequency:	2 MHz

Depth (cm)	dB	Area	Mean	SD	Min	Max
		328	129.665	10.302	98	156
		328	173.259	13.884	141	201
11.5	-6	328	153.003	16.765	115	201
		383	146.65	13.414	118	181
		383	145.509	14.134	106	182
		328	147.238	11.261	116	169
		328	185.073	12.132	161	220
11.5	-3	328	175.506	14.495	141	209
		328	160.207	14.053	126	206
		328	152.939	17.332	116	206
		384	180.656	10.961	156	208
		384	182.383	13.287	154	220
11.5	3	384	173.982	15.177	133	209
		384	161.964	12.678	134	204
		384	176.458	16.024	135	209
		384	184.711	10.629	151	205
		384	165.807	14.131	125	204
11.5	6	384	163.385	18.277	124	213
		384	153.016	15.709	122	214
		384	174.453	14.727	133	209
		384	198.294	8.807	169	218
		384	139.763	11.183	103	175
11.5	15	384	133.812	12.854	102	166
		384	106.552	13.183	78	156
		384	163.266	20.19	118	214

For this method to be explored, the MPV of each target, that is, the first MPV entry from Table III, was plotted as shown in dark blue in Fig. 7. In this way, the gradient, representing the gamma value, was obtained together with the R^1 value.

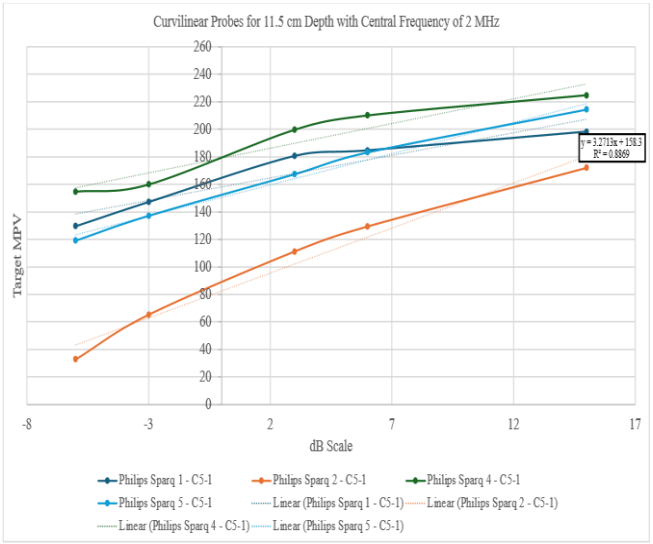

Fig. 7. A graph which represents the results of the gamma method for four curvilinear probes

Method 2 - IC Method: In the IC method also analysed by Gibson et al. (2001), the ratio of the mean of pixel values within the contrast region to those outside the contrast region was evaluated. Using the mean column in Table III, the IC for each target was calculated. As a result, the data as shown in Table IV was generated for each probe and depth.

Method 3 - CNR Method: For the CNR to be evaluated as suggested by Sanchez et al. (2009), the following equation was used.

$$\mathrm{CNR} = \frac{|(\mu_B - \mu_L)|}{\left|\sqrt{\sigma_B^2 + \sigma_L^2}\right|} \qquad (3.1)$$

From equation (3.1), $\mu_{\$}$ and $\mu_{\%}$ refer to the mean values of the background and target or lesion, respectively, whilst $\sigma_{\$}$ and $\sigma_{\&}$ represents the variance of the background and target/lesion, respectively. The CNR data also found in Table IV was obtained for a curvilinear probe at a depth of 11.5 cm.

This process was also repeated for every probe investigated. In hand with this, graphs similar to the one in Fig. 8 were generated for the remaining probes under investigation.

Table IV: The IC and CNR values for a curvilinear probe

Manufacturer and Model:	Philips Sparq
Probe Type and Name:	Curvilinear - C5-1
Probe Central Frequency:	2 MHz
Depth	11.5 cm

dB	IC	CNR
-6	0.839	1.399
-3	0.874	1.154
3	1.040	0.386
6	1.125	1.083
15	1.460	3.708

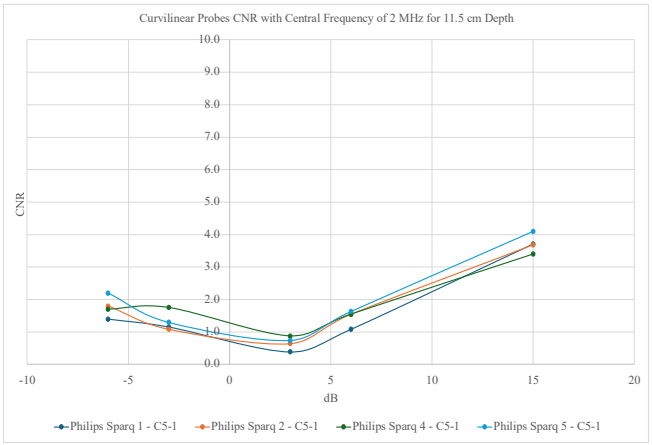

Fig. 8. A graph which represents the CNR of four curvilinear probes

III.RESULTS & DISCUSSION

From the results generated, it is important to note that the linear probes under investigation were not evaluated at a depth of 11.5 cm. As highlighted by Vanderland and Kumar (2021), linear array probes operate at high frequencies and have a narrow beam, allowing detail to be achieved only at shallow depths. This is because, for deeper structures, less sound energy will be received due to the weak intensity echoes received by the transducers.

The contrast resolution was first investigated across different frequencies at the near field and far field zones. For the near field, at a depth of 3 cm, the linear, curvilinear and sector probes established distinctive features, even though in general, high IC was achieved in the hyperechoic structures. This relationship was also established in the study by Gibson et al. (2001). The IC values for the linear probes were similar across different central frequencies. With regards to the curvilinear and sector probes, even though the IC varied from 0 to 3, a steeper gradient was achieved in the sector probes. On the other hand, at a depth of 11.5 cm, the curvilinear probes with various central frequencies achieved better linearity except for the 5 MHz probe at the -6 dB (hypoechoic) target. Figs. 9 to 13 represent the abovementioned.

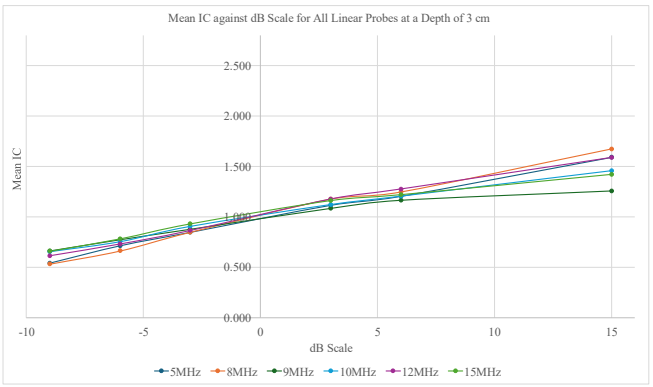

Fig. 9. Mean IC against dB scale for all linear probes at a depth of 3 cm

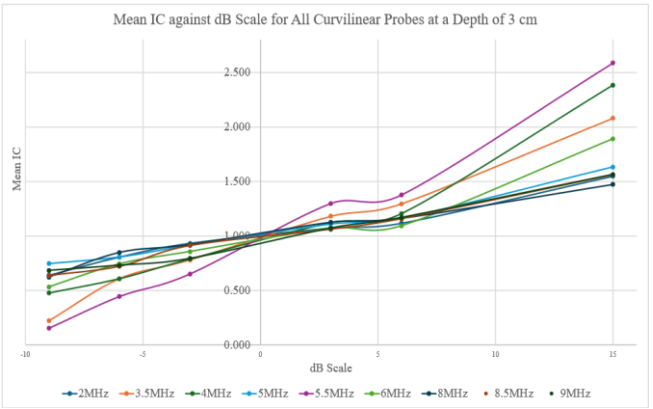

Fig. 10. Mean IC against dB scale for all curvilinear probes at a depth of 3 cm

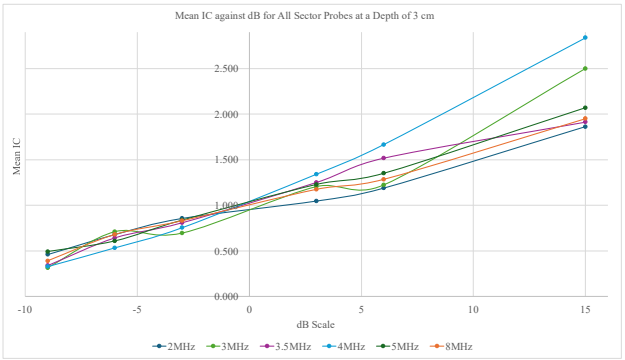

Fig. 11. Mean IC against dB scale for all sector probes at a depth of 3 cm

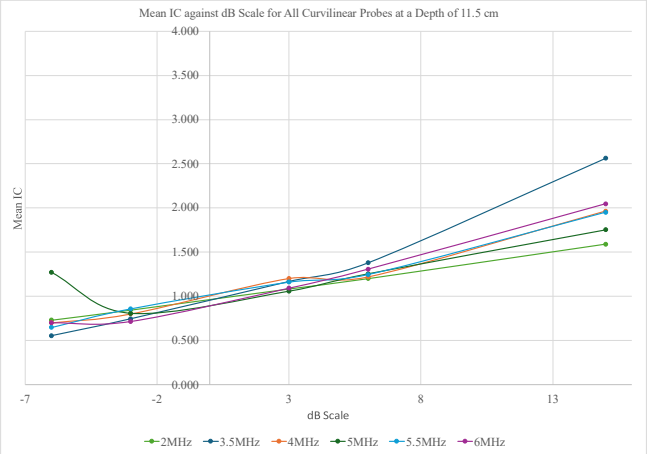

Fig. 12. Mean IC against dB scale for all curvilinear probes at a depth of 11.5 cm

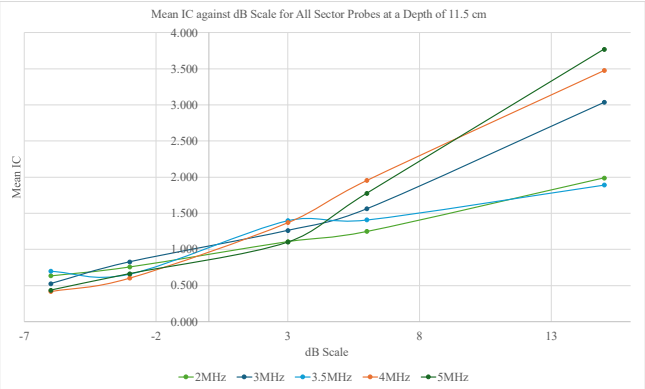

Fig. 13. Mean IC against dB scale for all sector probes at a depth of 11.5 cm

Since a limited number of probes were tested and averaged, improvements could have been made by taking repeated measurements. Moreover, since acceptance test images were subjectively obtained, different settings were used to achieve an optimized image which might have been affected by the amplification gain, TGC and focus.

With regards to the gamma of the system, as implied by Sharawy et al. (2016), if a large gamma value is obtained, a wider range of echo intensities are present within the available greyscale spectrum. This would lead to an increased contrast resolution.

Conversely, if a small gamma value is obtained, a narrower range of echo intensities are spread out across the greyscale spectrum, hence leading to poor contrast resolution. This explains why for both the near and far field, the sector probes established the best contrast resolution. On a similar note, no pattern was in general established on how the average gamma value varies across different frequencies.

For the $R^{!}$ value, given that most probes had values between 0.800 and 1.000, it ensures that the predictions are identical to the observed values. However, for the curvilinear probes with frequencies of 4 MHz and 8 MHz, an $R^{!}$ of approximately 0.700 was obtained, which could have been improved by taking repeated values. A summary of these values can be found in Tables V and VI.

Table V: A table summary of the gamma and $R^{!}$ values of all the probes investigated at a depth of 3 cm

Average Gamma Value and Average		**for All Probes at 3 cm Depth!!**	
	Central Frequency (MHz)	**Gamma Value**	!!
Linear	5	3.554	0.934
	8	4.398	0.954
	9	2.949	0.858
	10	3.113	0.968
	12	4.611	0.948
	15	1.919	0.905
Curvilinear	2	3.562	0.867
	3.5	4.254	0.917
	4	2.069	0.718
	5	3.463	0.934
	5.5	4.355	0.999
	6	5.010	0.983
	8	4.004	0.770
	8.5	2.788	0.962
	9	2.700	0.979
Sector	2	5.086	0.977
	3	4.755	0.950
	3.5	3.937	0.996
	4	6.186	0.971
	5	4.672	0.955
	8	4.907	0.887

Considering the CNR investigated at a depth of 3 cm, the results generated for the linear probe imply that the higher the frequency, the smaller the CNR is across the echoic targets. A similar situation was achieved for the curvilinear probes; however the 6 MHz frequency achieved the lowest CNR at the +3 dB target. This is in agreement with Sassaroli et al. (2019). However, given that there was only one probe with such a frequency investigated in comparison to the majority of the curvilinear probes, some discrepancies might

have resulted. Therefore, considering more probes will further confirm or deny such a statement. For the sector probes, the hypoechoic targets at high-frequency probes achieved a higher CNR but for the hyperechoic targets, no pattern was identified. In general, the sector probes established higher CNR values. At the far field, the sector probes yet again achieved higher CNR values in comparison to the curvilinear probes. Moreover, the sector probes allowed a better indication of how the CNR varies with higher frequencies at different targets. Except for the 3.5 MHz probe (in which only one probe was tested at this frequency), the CNR seemed to increase with increasing frequency. In the study by Sassaroli et al. (2019), it was also concluded that in the probes investigated (linear and convex), the CNR was better for the hypoechoic targets. The graphs generated for this method are represented through Figs. 14 to 18.

Table VI: A table summary of the gamma and $R^{!}$ values of all the probes investigated at a depth of 11.5 cm

Average Gamma Value and Average		**for All Probes at 11.5 cm Depth**	
	Central Frequency (MHz)	**Gamma Value**	R^2
Curvilinear	2	4.487	0.940
	3.5	5.509	0.964
	4	3.719	0.973
	5	5.034	0.989
	5.5	6.675	0.987
	6	4.264	0.995
Sector	2	5.892	0.983
	3	5.193	0.957
	3.5	4.085	0.969
	4	8.588	0.988
	5	6.540	0.917

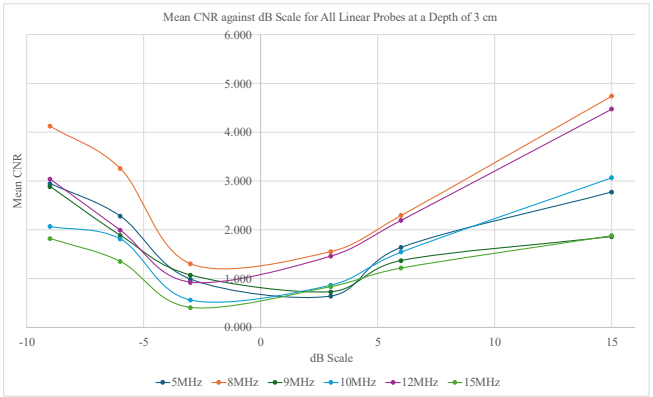

Fig. 14. Mean CNR against dB scale for all linear probes at a depth of 3 cm

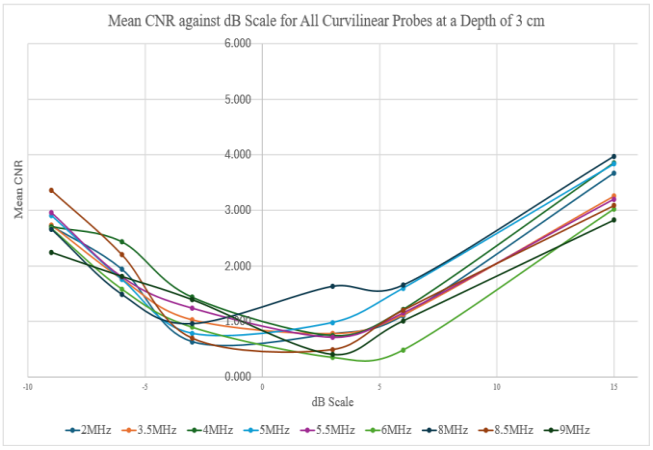

Fig. 15. Mean CNR against dB scale for all curvilinear probes at a depth of 3 cm

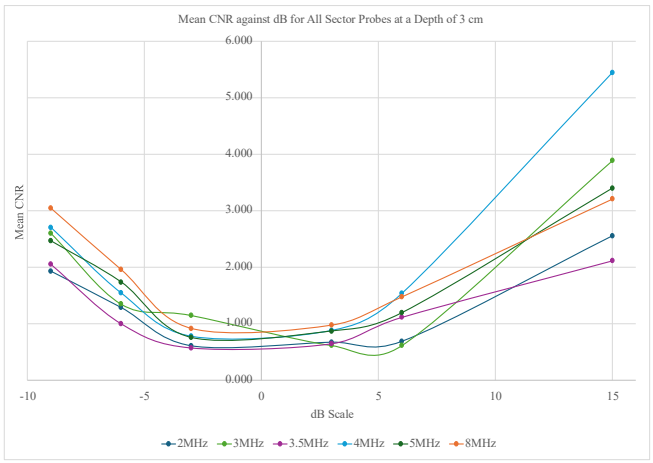

Fig. 16. Mean CNR against dB scale for all sector probes at a depth of 3 cm

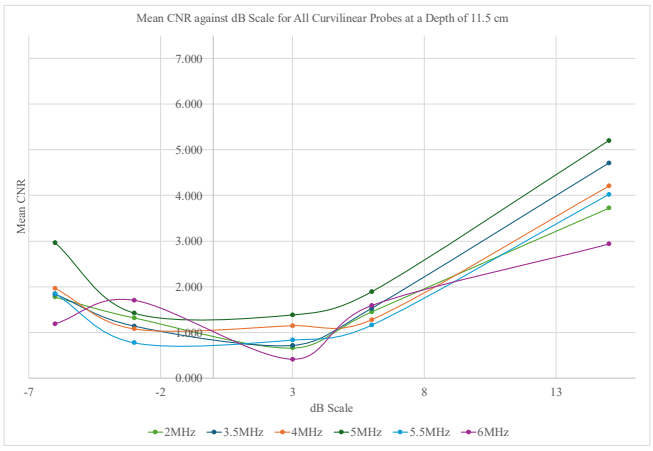

Fig. 17. Mean CNR against dB scale for all curvilinear probes at a depth of 11.5 cm

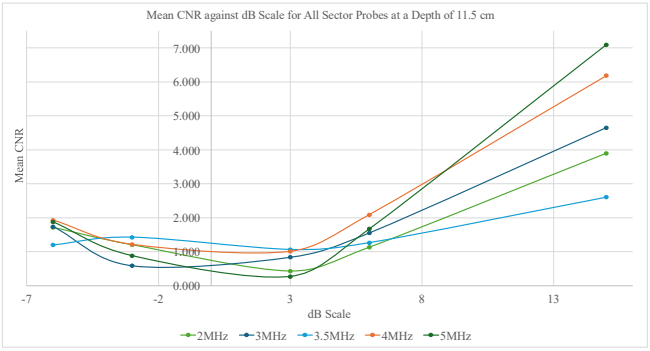

Fig. 18. Mean CNR against dB scale for all sector probes at a depth of 11.5 cm

The contrast resolution was then investigated across different transducers. This was done by taking a common frequency across all probe types, which was 5 MHz. The IC at the near field is quite similar for all probes. However, the 5 MHz curvilinear and sector probes established different characteristics for the far field zones as shown in Figs. 19 and 20.

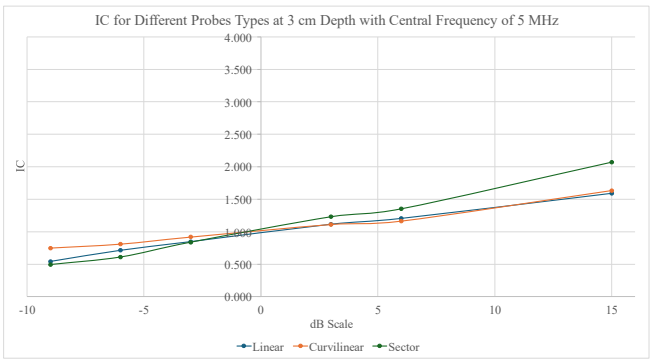

Fig. 19. Mean IC against dB scale for different probes with a common frequency of 5 MHz and at a depth of 3 cm

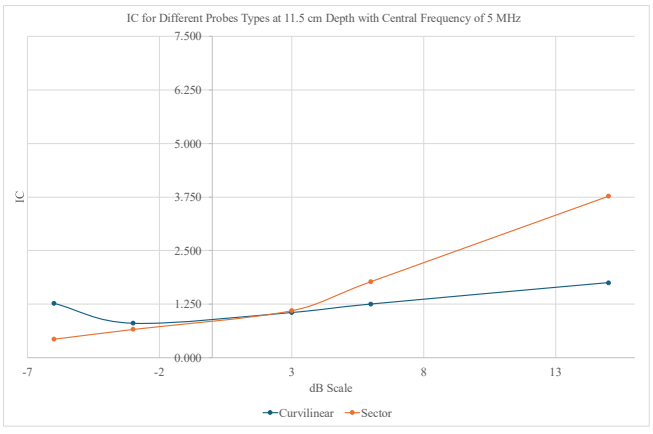

Fig. 20. Mean IC against dB scale for different probes with a common frequency of 5 MHz and at a depth of 11.5 cm

The curvilinear probes established a linear relationship from -3 to +15 dB targets whilst for the sector probes, a sharp gradient was achieved between the +3 dB and +6 dB targets. Through Tables VII and VIII, higher gamma values were obtained at 11.5 cm, indicating good contrast resolution.

Table VII: Gamma and R^2 values for different probes with a common frequency of 5 MHz and at a depth of 3 cm

Average Gamma Value and Average	**for the 5 MHz Probes at 3 cm Depth**	
Probe Type	**Gamma Value**	R^2
Linear	3.554	0.934
Curvilinear	3.463	0.934
Sector	4.672	0.955

Table VIII: Gamma and R^1 values for different probes with a common frequency of 5 MHz and at a depth of 11.5 cm

Average Gamma Value and Average	**for the 5 MHz Probes at 11.5 cm Depth**	
Probe Type	**Gamma Value**	R^2
Curvilinear	5.034	0.989
Sector	6.540	0.917

However, with regards to the R^1 values, all values were greater than 0.900. The CNR as shown in Figs. 21 and 22, established a similar shape. But, for the 11.5 cm depth, the sector probes established a steeper gradient between the +6 dB and +15 dB targets.

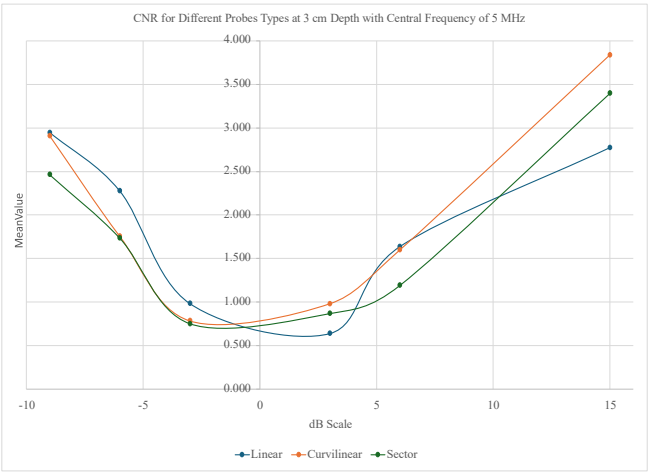

Fig. 21. Mean CNR against dB scale for different probes with a common frequency of 5 MHz and at a depth of 3 cm

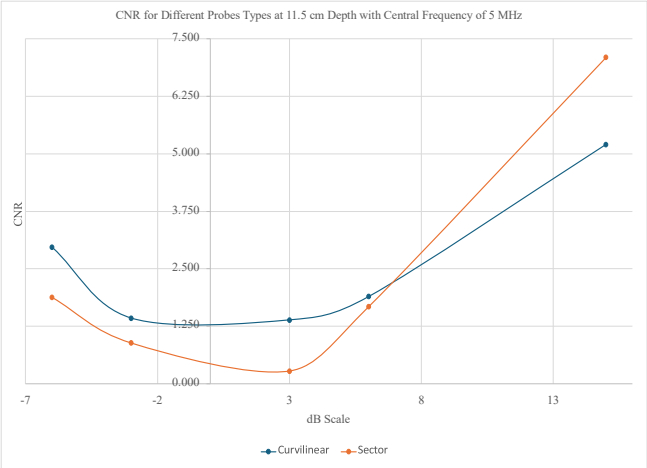

Fig. 22. Mean CNR against dB scale for different probes with a common frequency of 5 MHz and at a depth of 11.5 cm

Lastly, the contrast resolution was investigated by plotting Figs. 23 and 24, respectively. In both graphs, it was found that the values of the IC and CNR were higher at the 11.5 cm depth when compared to the 3 cm depth. With regards to such a characteristic, no literature was found. On the other hand, with regards to the gamma and the R^{l} values, the same concept applies as discussed earlier.

Overall, the values obtained were quite consistent with the literature. With regards to the sector probes investigated in this study, steeper IC gradients and sharper U-shaped plots for the CNR were obtained. This is because the majority of the sector probes tested can operate in 3D. On a different note, it was noted that hyperechoic targets have higher contrast. Such a result was also achieved by Gibson et al.

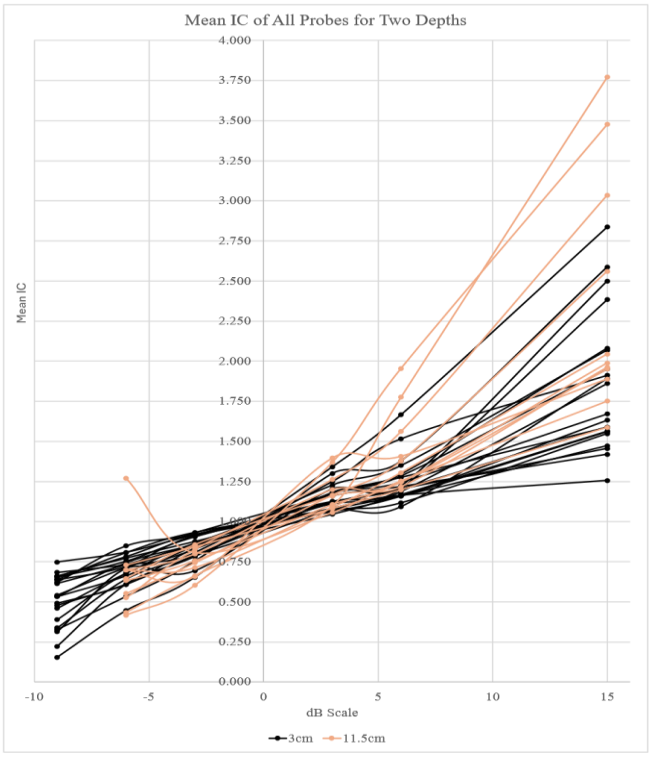

Fig. 23. Mean IC against dB scale for all probes at two different depths

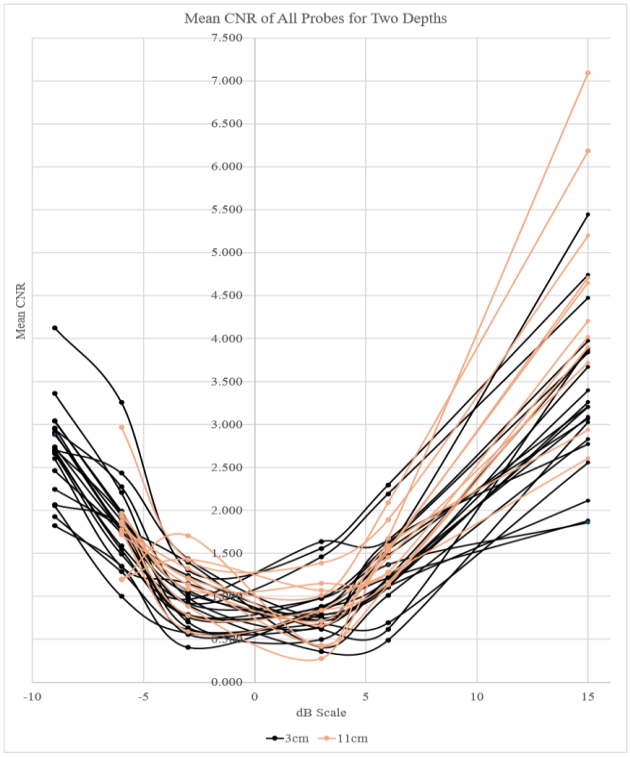

Fig. 24. Mean CNR against dB scale for all probes at two different depths

(2001). From the above-mentioned, it can be deduced that the gamma of the system does not depend on the frequency but rather on the probe.

Regarding the current guidelines established by the AAPM and IPEM 102, they do not provide any recommended action levels. Having said that, improvement and revision is necessary to minimise subjectivity and ensure that better protocols are in place.

Although this study thoroughly investigated three quantitative methods, there is still room for improvement. By considering more US systems and probes, better averaged data would be obtained, in turn offering better indication of how the contrast resolution varies with different frequencies and probes. On another note, upon selecting the ROIs on ImageJ, having equal areas will ensure that the data extracted is more precise and accurate, ensuring repeatability. The study could also be improved by investigating how different US systems establish different IC, gamma and CNR values. This would allow the MPs to compare which system performs better, which in turn can help them in the procurement process and testing.

IV.CONCLUSION

The main conclusions of the study were:

- For all transducer types, it was noted that the IC increases with hyperechoic structures, establishing a linear relationship.
- All transducer types established characteristic U- shaped scatter plots for the CNR which is in agreement with Sassaroli et al. (2019).
- All probes had varying gamma values. However, it was noted that it depends on the type of transducer, not on the frequency.
- Overall, the sector probes established a better contrast resolution performance for both the near and far field zones.
- From most data plotted, it was noted that the contrast resolution is not frequency dependent.

Suggestions for further research are:

- Repeating the study with more US systems and US probes will allow the full frequency range at which the US systems operate to be investigated.
- Equal areas of circular selection will increase repeatability.
- Besides using images from acceptance testing, images from various QC procedures can be investigated to evaluate thoroughly how the US systems and probes perform over the years.

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IMPACT OF DIFFERENT VARIABLES ON DOSIMETRIC LEAF GAP MEASUREMENT IN ROUNDED LEAF END MLC SYSTEMS

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Abstract: **This research aims to evaluate the dosimetric leaf gap (DLG) utilizing Integral sliding fields doses with varying gap widths for linear extrapolation to zero dose and intersection at the gap width axis. The study employs a 0.13 cc ionization chamber, Dose-1 electrometer, and water equivalent slab phantom. Experiments are conducted on a Varian True Beam linac equipped with the 120 Millennium MLC and Eclipse™ Treatment Planning System (TPS), examining different depths, photon beam energies, Source to Surface distances (SSDs), chamber orientations, and dose rates. Findings indicate that the DLG value remains consistent regardless of measurement orientation from the sweeping beam direction. The standard deviation (SD) values for varying SSDs, dose rates, and measurement depths are 0.061758%, 0.104595%, and 0.057940% respectively. DLG increases with higher photon beam energies, measuring 1.14537 mm, 1.27057 mm, and 1.30293 mm for 6 FF MV, 10 FF MV, and 15 FF MV respectively. Accurate DLG values within the TPS are crucial for precise dose calculations, particularly when applied to small targets using the DMLC delivery technique in IMRT, IGRT, SRS, and SBRT.**

Keywords: **dosimetry leaf gap, treatment planning system, leaf transmission, DMLC**

I. INTRODUCTION

The primary objective of radiotherapy is to deliver radiation to a target area while minimizing exposure to healthy tissues. Beam shaping plays a crucial role in reducing radiation absorption by healthy cells and vital organs. While conventional collimator jaws create rectangular treatment fields, additional shaping is necessary as treatment volumes are not typically rectangular [1]. Linear accelerators utilize Cerrobend blocks attached to the treatment head beneath a standard collimating system. However, beam blocks have several drawbacks, leading to the revolutionary introduction of multileaf collimators (MLC) since the late 1980s. The multileaf collimator is an important new tool for radiation therapy dose delivery [2]. MLCs aim to provide conformal therapy and enhance treatment delivery effectiveness, resulting in improved outcomes. An MLC is a beam-limiting device comprising numerous collimating leaves that can be independently and automatically controlled to generate any desired field shape. MLC field shaping is expected to reduce patient setup time during treatment and lower operational costs. This technology results in rounded leaf-end transmission [3] when the leaves are fully closed.

In the IMRT plan's leaf ordering process, the Leaf Motion Calculator (LMC) transforms the optimal fluence into a sequence that can be achieved by [4] the multileaf collimator (MLC). During this process, a parameter known as the Dosimetric Leaf Gap (DLG) is used to account for the disparity between dosimetric and geometric field widths caused by partial transmission through two adjacent rounded leaf ends of the MLC [5,6]. The DLG represents the gap between the physical leaf end and its dosimetric counterpart.

The Varian Eclipse dose calculation requires [7] this parameter to accurately simulate field modulation. Varian linear accelerators utilize rounded MLC leaf ends [8] to enhance off-axis dosimetric characteristics. The treatment planning system (TPS) approximates the MLC as having straight edges and accounts for the actual rounded leaf end transmission by retracting the leaf end by half the DLG value. MLC-formed fields exhibit specific penumbra compared to jaw-formed fields. The rounded leaf end structure influences the lateral penumbra, while the tongue and groove structure affect the longitudinal penumbra [9]. The measured DLG addresses the lateral penumbra, but the longitudinal penumbra has minimal impact on this DLG due to the larger field size in this direction [10]. However, typical IMRT/VMAT patient plans often include segments with small longitudinal field sizes. A precise DLG value could compensate for both the dose from the leaf gap to the longitudinal penumbra and the dosimetric inaccuracies associated with small fields (gaps).

In contrast, the Eclipse system's AAA photon dose calculation algorithm only requires two parameters per energy for its calculations [8]: (1) the Dosimetric Leaf Gap (DLG) and (2) the mean transmission factor through closed leaves, which encompasses both interleaf leakage and leaf transmission [11]. As a result, minor changes in MLC gaps (DLGs) could lead to significant discrepancies between the TPS calculated dose and the actual dose delivered to the patient [12]. Consequently, the optimal DLG value is integrated into the Eclipse TPS to ensure accurate dose calculations. This parameter is crucial for the Varian Eclipse dose calculation to precisely model field modulation.

The dosimetric leaf gap (DLG) is affected by X-ray transmission [13-15] through the rounded leaf ends, with its value contingent on beam quality and multi-leaf collimator (MLC) type. Typically, DLG values are established for each beam energy during the commissioning process. Multiple studies indicate that the DLG is dependent on various factors, including [16]: 1) MLC leaf positioning precision: Deviations in leaf positions can lead to discrepancies

between planned and delivered doses. 2) Beam energy: The DLG is affected by X-ray transmission via the rounded leaf ends, making its value dependent on beam energy [17]. 3) Radiation field dimensions and configuration: The size and shape of the field can impact the DLG. 4) Measurement technique: Different methods, such as ionization chamber or diode measurements, can be employed to determine the DLG, and the chosen method may influence the resulting value.

Dosimetric impact of the DLG:

The dosimetric impact of DLG in treatment planning systems and the experimentally determined DLG value demonstrate significant variations, deviating from the two expected outcomes.

1) If $DLG_{Measured} < DLG_{TPS}$; so MLC pull back is slowly so the measured dose is less than the TPS calculating dose.
2) If $DLG_{Measured} > DLG_{TPS}$; so MLC pullback is highly and the resultant wider effective MLC opening so the measured dose is greater than the TPS calculating dose.

Adjusting the measured physical DLG values proved crucial for reducing dose calculation errors within the investigated system.

II. MATERIAL AND METHOD

The research was conducted using a VARIAN LINAC True Beam SN4378 at The Gujarat Cancer and Research Institute in Ahmedabad. This machine features a millennium 120-leaf MLC. The most convenient method for Varian systems to determine the DLG is the sweeping gap technique, as outlined in Varian Medical System's documentation [14,18]. The DLG was derived using this technique, employing a CC13 ion chamber, DOSE-1 electrometer, and slab phantom. The calculation of DLG values followed the methodology described by LoSasso et al [14]. However, in this study, measurements were taken using a CC13 ion chamber and Varian-provided DICOM files for the sweeping gap measurements [19].

1. Open the DICOM plan file for the energy, primary fluence mode, and MLC model.
2. Measure leaf Transmission including both banks.
   - Extend Bank A fully and measure the MLC transmission through Bank A ($R_{T,A}$).
   - Extend Bank B fully and measure the MLC transmission through Bank B ($R_{T,B}$).

   Calculate the average transmission reading R_T.

   $$R_T = \left(\frac{R_{T,A} + R_{T,B}}{2}\right) \quad (1)$$

   Where $R_{T,A}$ is transmission through Bank A and $R_{T,B}$ is transmission through Bank B.
3. Measure sliding window fields of various gap sizes.
   - This is a dynamic delivery with a consistent gap formed by the MLC bank.

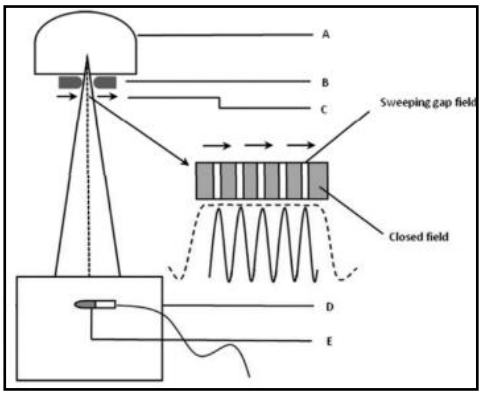

Figure 1: Schematic diagram of DLG measurement using ionization chamber.

(A) Gantry (B) MLC (C) Direction of sweeping beam. The magnified image shows the dose being delivered at different instances of the sweeping beam. A uniform dose is achieved as the result of an integrated dose. (D) Tissue equivalent water slab phantom (E) ionization chamber [4].

- Measurements of integral ionizations were conducted for various nominal gap widths, including 2, 4, 6, 10, 14, 16, and 20 mm. The gap, which swept from −60 mm to +60 mm, maintained a uniform velocity. (refer to Figure1

- To quantify the ionization exclusively resulting from the sweeping gap field, it is essential to eliminate the MLC transmission reading during slit motion, since the chamber was protected by the leaves. Compute the average MLC leaf transmission's influence on the gap reading (RgT) for every gap g calculated from given formula Shende et al. [20]. The transmission's contribution to the gap reading is characterized by:

$$R_{gT} = R_T\left[1 - \frac{g(mm)}{120\ (mm)}\right] \quad (2)$$

Where R_T is average transmission reading.

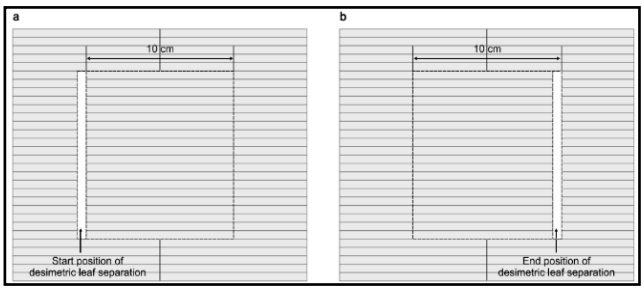

Figure 2: Start (a) and end (b) position of the 10 mm sliding slit movement for dosimetric leaf separation file.

4. Calculate the corrected gap reading for each gap (g) is R_g' using equation (2)

$$R_g' = R_g - R_{gT} \quad (3)$$

Where R_g is electrometer reading at gap g and R_{gT} is contribution of transmission to gap reading (g).

5. Determine a linear equation g(R'g) = aR'g + b that aligns with the data points representing the gap size g and the adjusted gap measurement R'g.'.

6. The measured DLG can be determined by graphing the MLC leaf gap in millimeters on the x-axis and the corrected gap reading Rg' in nanocoulombs on the y-axis. The DLG value is represented by the point where the plotted line intersects the horizontal axis.

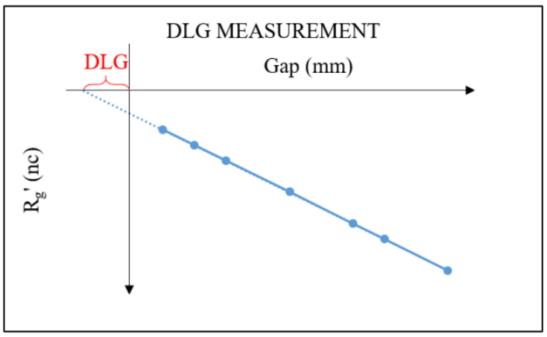

Figure 3: A pictorial representation of DLG measurement as per step 6.

Parameter effect on DLG measurement:

1) To verify the effect of Different orientations of the chamber on DLG measurement:

The CC13 ionization chamber was utilized for DLG measurements in two orientations: perpendicular and parallel to the sweeping beam's direction. Due to slab phantom constraints, the chamber couldn't be physically positioned in the first orientation; instead, the collimator was rotated 90°. Measurements were taken using the SAD technique at a 10 cm depth, delivering 100 MU with a 400 MU/min dose rate. The field size was set to 10 × 10 cm^2, employing 6 FF MV, 10 FF MV, and 15 FF MV photon beam energies. The DLG was calculated using the previously described method. Table (1) illustrates the effect of chamber orientation on DLG measurements.

2) To verify the effect of Different photon beam energy on DLG measurement:

The CC13 ionization chamber was utilized to record DLG measurements, with the linac's photon beam energy potentially influencing dose measurement and, consequently, the DLG value. To investigate the effect of photon beam energy on DLG determination, measurements were conducted using the CC13 ionization chamber at various photon beam energies: 6 FF MV, 10 FF MV, and 15 FF MV. The ionization chamber was positioned at a depth of 10 cm, with a source-to-axis distance (SAD) of 100 cm. A total of 100 MU was delivered at a dose rate of 400 MU/min, with a field size of 10 × 10 cm^2 at the isocenter. The DLG measurement was computed using the previously described method. Table (1) and Figure (1) illustrate the impact of different linac photon beam energies on DLG measurement.

3) To verify the effect of DOSE RATE on DLG measurement:

The CC13 ionization chamber was utilized to record DLG measurements. Since the leaf speed increases with higher dose delivery rates for constant MU settings, the photon beam energy dose rate of the linac could affect dose measurement. Consequently, it is crucial to examine how dose rate impacts DLG. To investigate the effect of photon beam energy dose rate on DLG determination, measurements were conducted using the CC13 ionization chamber. A 6 FF MV photon beam energy delivered 100 MU at dose rates of 400 MU/min and 500 MU/min. The ionization chamber was positioned at a depth of 10 cm, with a SAD of 100 cm and a 10 × 10 cm^2 field size at the isocenter. The DLG measurement was computed using the previously described method. Table (2) illustrates the influence of various photon beam energy dose rates from the linac on DLG measurement.

4) To verify the effect of Different SSDs on DLG measurement:

The source-to-surface distance (SSD) of a linear accelerator can affect dose measurements, consequently impacting the determination of the dosimetric leaf gap (DLG). To investigate how different SSDs influence DLG values, measurements were conducted using a CC13 ionization chamber. The chamber was positioned at a depth of 10 cm, with SSDs of 90 cm and 100 cm. A 6 FF MV photon beam delivered 100 monitor units (MU) at a rate of 400 MU/min. The DLG was calculated using the previously described

method. Table (3) illustrates the effect of varying linac SSDs on DLG measurements.

5) To verify the effect of Different depths of measurement on DLG measurement:

The CC13 ionization chamber was utilized to record DLG measurements. The measurement depth of this chamber could potentially impact the dose measurement and, consequently, the DLG value. To investigate the effect of measurement depth on DLG determination, measurements were conducted using the CC13 ionization chamber at various depths. Specifically, the chamber was positioned at 5 cm and 10 cm, with SSDs of 90 cm and 100 cm, respectively. A dose of 100 MU was delivered at a rate of 400 MU/min using a 6 FF MV photon beam. The DLG measurement was then calculated using the previously described method. Table (4) illustrates the influence of different measurement depths on the DLG.

III. RESULTS AND DISCUSSION

DLG vs Energy vs Orientations

For the 6 FF MV photon beam energy, the DLG values derived from the plotted figure were 1.14537 mm for parallel orientation and 1.15844 mm for perpendicular orientation relative to the sweeping field direction, using the CC13 ionization chamber. In the case of the 10 FF MV photon beam energy, the DLG values were found to be 1.27057 mm for parallel orientation and 1.24710 mm for perpendicular orientation. For the 15 FF MV photon beam energy, the DLG values were determined to be 1.30293 mm for parallel orientation and 1.30288 mm for perpendicular orientation, both in relation to the sweeping field direction.

Table 1: Calculate the standard deviation of the CC13 ionization chamber During DLG measurement in the Perpendicular and parallel direction of the sweeping beam for 6 FF MV, 10 FF MV and 15 FF MV photon beam energy.

Chamber orientation	Perpendicular to sweeping beam direction	Parallel to the sweeping beam direction	SD (%)
Photon beam energy	DLG (mm)	DLG (mm)	
6 FF MV	1.15844	1.14537	0.009241
10 FF MV	1.24710	1.27057	0.016595
15 FF MV	1.30288	1.30293	0.000035

DLG vs Energy

As illustrated in the Figure 4, the DLG values obtained using different energy levels of 6 FF MV, 10 FF MV, and 15 FF MV are 1.14537 mm, 1.27057 mm, and 1.30293 mm, respectively.

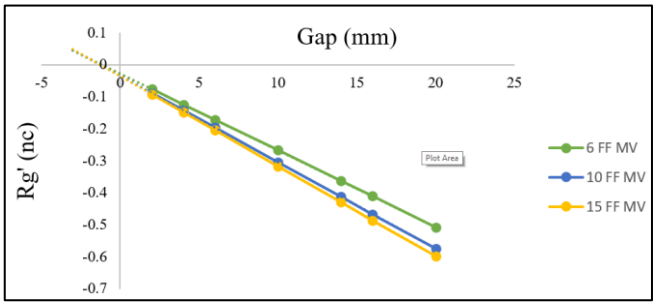

Figure 4: graphical representation of the variation of DLG versus 6 MV, 10 MV and 15 MV photon beam energy.

DLG vs Dose Rate:

The DLG values derived with different dose rates like 400 MU/min, and 500 MU/min, are 1.14537 mm and 1.27057 mm with respectively.

Table 2: DLG value for 400 MU/MIN and 500 MU/MIN photon beam dose rate.

MLC parameter	Dose rate		
	400 (MU/MIN)	500 (MU/MIN)	SD
DLG (mm)	1.14537	1.29329	0.104595

DLG vs SSD

Additionally, the DLG was evaluated at a depth of 10 cm with an SSD of 90 cm and contrasted with a standard SSD of 100 cm to examine the impact of minor alterations in detector distance. A small increase in the distance to the detector did not substantially influence the DLG measurements.

Table 3: DLG value for 90 cm and 100 cm SSD.

MLC parameter	SSDs		
	90 cm	100 cm	SD (%)
DLG (mm)	1.14537	1.05803	0.061758

DLG vs Depth

As shown in Table 4, the DLG values for depths of 5 cm and 10 cm exhibited a slight increase with depth [21], consistent with findings by Zygmanski et al. However, the standard deviation of 0.057940 mm indicated that the difference between depths was insignificant, thus validating the D_{max} measurement.

Table 4: DLG value for 5 cm and 10 cm measurement depth.

MLC parameter	Depth of measurement		
	5 cm	10 cm	SD (%)
DLG (mm)	1.0613	1.14537	0.057940

IV. DISCUSSION

Inaccurate accounting of the DLG can lead to discrepancies between the planned and delivered doses, potentially resulting in under-dosing or over-dosing of the target area and subsequent treatment complications [6]. Underestimating the DLG may reduce the delivered dose to the target, diminishing tumor control probability. Conversely, overestimating the DLG could increase the delivered dose, heightening the risk of radiation toxicity in nearby healthy tissues and organs. As shown in Table 9, DLG characterization is not affected by measurement orientation relative to the sweeping beam direction, variations in source-to-surface distance (SSD), measurement depth, or dose rate. However, it does increase with beam energy due to increase in transmission through the leaf end of MLC [22]. Table 13 demonstrates that when using the CC13 ionization chamber, DLG values rise as photon beam energy increases. Furthermore, MLC systems with reduced scattering and transmitting radiation tend to have smaller DLG values [17].

Although most DLG values reported in literature range from 1.05803 mm to 1.30293 mm, Clark et al. have documented lower values of 1.05 mm and 0.97 mm. Ning Wen et al. employed a hybrid approach to optimize DLG settings for a True Beam linac [17]**.** Baseline DLG values were measured according to vendor-provided guidelines and similarly optimized in Eclipse [17].

V.CONCLUSION

To ensure accurate dose delivery and prompt detection and correction of discrepancies, the accuracy of the measurement method should be verified by comparison with other independent methods. Ion chamber measurements provide low uncertainty, and a DLG difference of less than 0.2 mm may maintain PTV dose variation within 1% [17]. Thus, we have confirmed that changes in DLG as a function of depth, SSD, dose rate, and photon beam energy do not need consideration in a TPS, despite DLG values being dependent on depth and field size.

More accurate and optimal DLG minimizes uncertainty in dose calculations and provides additional confidence in clinical practice of DLG. More accurate and optimal DLG minimizes uncertainty in dose calculations and provides additional confidence in clinical practice of DLG [22].

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HOW TO

DEVELOPMENT AND EVALUATION OF IMRT TECHNIQUE FOR CRANIOSPINAL AXIS RADIOTHERAPY PLANNING

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Abstract- **This study aimed to evaluate and compare the dose distribution of the CSI technique using Helical IMRT with conventional LINAC_IMRT and VMAT. Five patients diagnosed with Medulloblastoma (High and Medium Risk) were treated with Craniospinal Irradiation at our institute by Helical Tomotherapy (V3.3.1.3). The plans were replanned for conventional techniques, IMRT, and VMAT using Eclipse V15.6. The prescribed dose was 36 Gy in 20 fractions for high risk and 23.4 Gy in 13 fractions for medium risk. For planning, PTV was split into two parts, one in PTV-Brain (cranial contents) and the second in PTV-Spine (inferiorly from C1) to improve dosimetry. As per our studies, for *Spine*- the mean values of D_{max}, $V_{107\%}$, $V_{95\%}$, CI, HI in case of IMRT were 37.985 cGy, 0%, 97.625%, 0.765, 0.0725; for VMAT were 38.135 cGy, 0%, 97.325, 0.967, 0.0725; and for IMRT_HELICAL were 38.72cGy, 0.025%, 96.35%,0.96, 0.0975. Similarly, for *Brain* - the mean values of D_{max}, $V_{107\%}$, $V_{95\%}$, CI, HI in case of IMRT were 38.4025 cGy, 0%, 98.225%, 0.977, 0.0625; for VMAT were 38.375 cGy, 0%, 96.575%, 0.965, 0.1125; for IMRT_ HELICAL 39.34, 0, 98.275, 36.55, 0.98, 0.077. For *Brainboost* - the mean values of D_{max}, $V_{107\%}$, $V_{95\%}$, CI, HI in case of IMRT were 18.875 cGy ,0%, 97.875%, 0.975; for VMAT were 19.1075 cGy ,0%, 98.075%, 0.9725, 0.0775; for IMRT_HELICAL 19.24 cGy, 0%, 98.7%, 1.0125, 0.3275 respectively. The D_{max} for serial OARs for *IMRT* technique ranges from 25 - 40 Gy for Eyes, 6.5 - 8.2 Gy for Lens, 25 - 40 Gy for Optic Nerve, 54-56 Gy for Brainstem, 43-56 Gy for Chiasm and D_{mean} for parallel OARs ranges from 13-22 Gy for Parotids, 4-8 Gy for Lungs, 5-30 Gy for Esophagus, 4-13 Gy for Heart. For *VMAT*, D_{max} ranges from 22- 40 Gy for Eyes, 7.2-10 Gy for Lens, 27-41 Gy for Optic Nerve, 54-56 Gy for Brainstem, 30-50 Gy for Chiasm and D_{mean} ranges from 10-20 Gy for Parotids, 5-13 Gy for Lungs, 11-22 Gy for Esophagus, 4-14 Gy for Heart. For *IMRT_HELICAL*, D_{max} ranges from 16-32 Gy for Eyes, 4-6 Gy for Lens, 26-40 Gy for Optic Nerve 37-54 Gy for Brainstem, and 28-50 Gy for Chiasm and D_{mean} ranges 9- 19 Gy for Parotids, 4-8 Gy for Lungs, 5-22 Gy for Esophagus, 4-14 for Heart. Helical tomotherapy offers clear dosimetric advantages, good target coverage with high homogeneity and conformity, and OAR sparing. However, higher MU and longer beam-on time mean a potentially higher risk of secondary malignancy.**

Keywords- **Craniospinal Axis Irradiation, HELICAL IMRT**

I. INTRODUCTION

Craniospinal irradiation encompasses radiation therapy aimed at the entire craniospinal axis to eliminate tumor cells found in the cerebrospinal fluid. Craniospinal irradiation (CSI) is indicated in patients with malignant central nervous system (CNS) tumors that tend to develop cerebrospinal fluid (CSF) dissemination [1-3].

This advanced radiotherapy (RT) technique targets the cranium and spinal cord, involving the movement of junctions along the lateral brain and spinal fields. It is highly complex technically because it requires encompassing a challenging clinical target volume that includes the entire brain, the full length of the spinal axis, and the surrounding meninges.

Under current practice, when combined with chemotherapy, the radiotherapy dose is 23.4 Gy for the craniospinal axis standard-risk medulloblastoma and 36 Gy for those with high-risk disease. In both cases, it is followed by a conformal boost to the posterior fossa, up to a total dose of 54 Gy. Conventionally, the brain is treated with lateral opposed fields, and a direct posterior field is used for the spine.

Currently, CSI is the main treatment option for patients with *medulloblastoma*, a particular type of CNS tumor that can spread into the craniospinal fluid of the neural axis. Long-term side effects associated with the treatment of the brain include neurocognitive deficits, hearing impairment, growth hormone deficiency, and cataracts [4-9]. CSI plays a very important role in the treatment of medulloblastoma and is often required for cases involving germ cell tumors, non-Hodgkin lymphoma, or anaplastic ependymoma with spinal metastasis.

A. Patient positioning and Immobilization for treatment:

Mostly, CSI is delivered to patients in the prone position using lateral opposed fields covering the whole brain and upper cervical spine matched to a direct posterior field that extends inferiorly to cover the caudal extent of the thecal sac [and to confirm the isocenter position and field junction on the skin. However, the prone position is often discomforting for the patient and can cause significant patient movement at times during prolonged treatment. Supine position allows easy access to the oral cavity and airway when general anesthesia (GA) is required and is more comfortable for most

patients, making the position easier to hold throughout treatment, which reduces the risk of intra-fraction motion [10,11]. Weekly junction displacements, known as feathering, by moving the treatment field junction weekly, have been adopted to reduce the larger over- or underdose in the junction areas.

B. Treatment Planning:

Defining a volume is a prerequisite for meaningful 3D treatment planning and accurate dose reporting (dose uniformity within 7% and 5% of the dose delivered to a well-defined prescription point). Treatment plan acceptance is largely based on dosimetric data such as dose-volume histogram (DVH) statistics for targets, normal tissues, and isodose line distributions.

The basic Fundamental treatment planning of CSI includes the use of lateral parallel opposed fields for the cranium and upper cervical spinal cord, and the use of a matching posterior spinal field to the cranial field, including the full spinal subarachnoid space. The treatment volume for CSI includes the entire CNS subarachnoid space, and the inferior border is extended below S2 to include the thecal sac. As there is a large percentage of the patient's anatomy that is exposed to some level of radiation dose, it can only produce good effects if it is delivered in an appropriate clinical context.

Feathering after 5 to 7 fractions smoothies out any overdose or underdose over a longer segment of the cord. It is relatively simple and easy to verify the delivery of CSI in the prone position due to direct visualization of the field light on the patient's surface. Over the last decade, many techniques for CSI have evolved to decrease the dose to the organs outside the target volume, in particular, the thyroid, heart, and intestines.

C. Various types of Treatment Modality:

To achieve the basic fundamental treatment planning, the 2D technique is most commonly used in centers that lack advanced linear accelerators for conformal treatment planning. The 2D approach results in dose inhomogeneity, especially at the beam junction(s), and a significant dose anterior to the spinal target volume. Traditionally, the 3D conformal radiotherapy (CRT) technique is applied for CSI by using two lateral opposed photon beams for the brain and matching one or more posterior photon beams for the spine. However, this method has a few drawbacks; the large dose gradient between each treatment field, even small errors in positioning, can result in unintended high or low doses to the spinal cord. Also, 3DCRT usually sets up the patient in the prone position to confirm the isocenter position and field junction on the skin, which is discomforting for the patient that causing significant patient movement at times during prolonged treatment. Manual shifting of field junctions between fractions is complex and increases set-up errors and the entire treatment time.

It has been demonstrated that IMRT can produce better results than conventional and simple conformal radiation therapy techniques, due to a significant reduction of radiation dose and toxicity delivered to the critical organs. It is different from the conventional techniques that lean on a single plane matched junction in the neck region with a "gapped" junction in the spine, in which very high- and low-dose regions are produced in the treatment volume. Apart from IMRT benefits, the segmented and overlapping fields created by IMRT and the resulting dose distribution are complex. Increase the prescription dose to the target and achieve a better sparing of the surrounding critical tissues than traditional 3D CRT, but the dosimetric information alone does not always point out the radiobiologically superior treatment for the patient.

RapidArc is a type of volumetric modulated arc therapy (VMAT) that provides intensity-modulated radiation therapy (IMRT) with multi-leaf collimator (MLC), dose rate, and gantry speed modulation. For Complex techniques like CSI, with the innovative VMAT technique, a homogeneous and conformal dose to the brain and spinal canal could be achieved, while limiting the dose to the relevant OARs. By using RA, the field junction matching difficulties were alleviated with the use of overlapping fields/arcs, where the dose contribution from each arc was automatically calculated during the optimization process.

The tomotherapy unit delivers a continuous, helical-shaped beam, using a single isocenter, no field junctions, and no gaps or overlaps within the entire irradiated volume, which leads to highly homogenous dose distribution, thus increasing the chances of disease control and lowering the toxicity risk. Daily patient position can be verified using megavoltage computed tomography (MVCT) at every treatment fraction.

Moreover, HT also involves setup uncertainty due to the relatively short range of MVCT compared to the long range of the treatment field in the craniocaudal direction required for CSI using HT. The main disadvantage is that the part of the abdomen containing the small intestine might be irradiated due to the anterior fields in our technique, although no distinct toxicity of gastrointestinal organs, such as enteritis, has been observed during treatment or on follow-up.

II. MATERIAL AND METHODS

A. Patient selection

For this study, five patients diagnosed with medulloblastoma (High and Medium Risk) were previously treated with CSI at our institute by helical tomotherapy were retrospectively replanned with conventional techniques; Intensity Modulated Radiation Therapy (IMRT), Volumetric Modulated Arc Therapy (VMAT) using Eclipse V15.6 (3DCRT), Intensity Modulated Radiation Therapy (IMRT), Volumetric Modulated Arc Therapy (VMAT) using Eclipse

V15.6. For planning, PTV is split into two parts, one in PTV-Brain (cranial contents) and the second in PTV-Spine (inferiorly from C1) to improve dosimetry.

B. IMRT Planning

Craniospinal irradiation (CSI) using the conventional linear accelerator (IMRT_LA) technique involves the combination of two separate treatment plans - one for the brain and another for the spine and a separate booster dose for the brain (if required) - delivered using 6 MV photons on the Eclipse Treatment Planning System (TPS).

The spinal planning target volume (PTV_spine) was planned and treated, including five fields like 40º,130º,180º, 235º,320º, using inverse planning technique. If the length of the patient is tall and if the spine is not covered by a single isocentre, then two isocentres in the spine are used with the same beam angles. The isocentre was positioned at the geometric centre of the PTV_spine along the cranio–caudal (Y) axis and midplane at the level of the C2–C3 vertebral body. A total dose of 36Gy was prescribed and normalized to the spinal isocentre. Optimization using Anisotropic Analytical Algorithm was carried out to reduce doses to organs at risk (OARs) without compromising target coverage or creating excessive hot spots.

A separate plan was created for the cranial PTV (PTV_brain). The isocentre for the cranial fields was set at the most inferior slice of the PTV_brain, while maintaining the same lateral (X) and depth (Z) coordinates used in the spinal plan. The beam orientation consists of 7 beams: 220º, 260º, 300º, 350º, 30º, 70º, 110º. Appropriate collimator angles were chosen to align the cranial dose gradient with that of the IMRT spinal plan.

This plan used lateral opposed, half-beam blocked fields, each conformally shaped to the target using MLCs based on the beam's-eye-view. A uniform 1 cm margin was applied around the PTV_brain in all directions except caudally, where the margin was reduced to account for the penumbra effect and enhance target coverage. The dose distribution was calculated and normalized to a reference point at the geometric centre of the PTV_brain. Finally, the spinal and cranial plans were combined dosimetrically to generate the composite IMRT_LA plan for the entire craniospinal axis.

Generally, in medulloblastoma, the most common site of origin is the Posterior Fossa. So, to reduce the recurrence, a booster dose is given to the posterior fossa. The beam orientation for booster dose includes bilateral field and a posterior field along with angles like 135º and 225º.

C.VMAT Planning

Volumetric Modulated Arc Therapy (VMAT) plans were created with three isocenters—two for Phase 1 (covering the brain and spine) and one for Phase 2 (brain boost). To treat the upper part of the planning target volume (PTV), which includes the brain and upper spinal cord, two coplanar arcs were used with opposing rotation directions (clockwise and counterclockwise). A single partial arc was used to treat the lower spinal regions. For lower region of spine, two full arcs with opposite rotation directions were used to cover the lower spine regions.

For Brainbooster, two full arcs with opposite directions were used for the Posterior fossa to reduce the recurrence. Several Beam-blocks were applied to prevent beam entry through sensitive structures such as the eyes, optic nerves, arms, and lungs. Collimator angles were alternated to reduce the tongue-and-groove effect of the MLC leaves.

Upper and lower arcs were optimized simultaneously using dose–volume constraints for the PTV, organs at risk (OARs), and the ring structure. The optimization process continued until the plan met the defined criteria, ensuring that at least 95% of the PTV received the prescribed dose, while keeping doses to surrounding normal tissues within acceptable tolerance limits.

D. Tomo Planning

Helical TomoTherapy-based IMRT employed a fan beam thickness (FBT) of 2.5 cm, a pitch value of 0.3 or 0.43, and a modulation factor of 2.5-3.00. The prescribed total dose was 36 Gy to both the PTV_brain and PTV_spine.

The optimization algorithm Convolution Superposition used in the TomoTherapy system and Eclipse TPS is different, so identical dose–volume constraints could not be directly transferred. Nonetheless, similar constraint parameters were adopted to the extent possible. Optimization proceeded until further reduction in organ-at-risk (OAR) doses could no longer be achieved without compromising target coverage or inducing unacceptable dose inhomogeneity (i.e., hot spots).

Given TomoTherapy's capacity for continuous delivery over extended lengths, the spinal component (PTV_spine) was planned as a single uninterrupted volume. The directional blocking feature was employed to selectively limit beam entry through critical OARs, including the eyes and kidneys, thereby enhancing normal tissue sparing while maintaining adequate dose conformity to the target volumes.

E. Plan Evaluation:

The dosimetric outcomes of VMAT, IMRT_LA, and IMRT_Tomo were compared qualitatively and quantitatively using PTV dosimetry and dose to OARs. PTV dosimetry includes maximum dose (D_{max}), minimum dose (D_{min}), mean dose(D_{mean}) to the PTV target, volume of PTV receiving atlleast 95% of the dose($V_{95\%}$), volume receiving 107% of the dose($V_{107\%}$), Homogeneity Index(HI) that characterizes the uniformity of the absorbed dose distribution within the target,

$$HI = \frac{D_{2\%} - D_{98\%}}{D_{50\%}}$$

Where $D_{2\%}$ is the dose received by 2% of the volume, $D_{98\%}$ is the dose received by 98% of the volume, which is

used to assess minimum dose to the target and D50% is the dose received by 50% of the volume (Median Dose).

Conformity Index, which defines the degree of dose conformity of the Target Volume to the PTV volume, can be evaluated and defined as

$$CI = \frac{\text{Dose to 95\% of volume}}{\text{Prescribed Dose}}$$

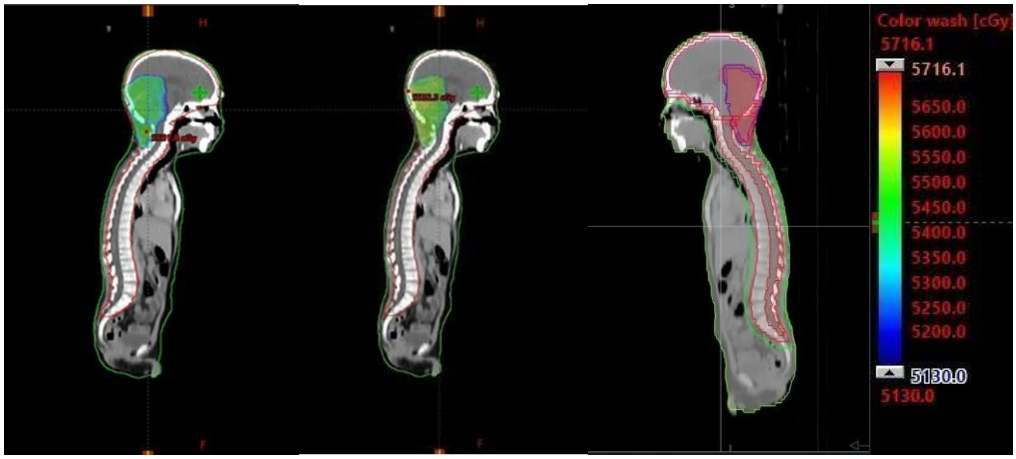

Figure 1: Colourwash representation of the dose fluence distribution across the entire PTV for different treatment techniques: IMRT_LA, VMAT, IMRT_HT

III. RESULT

A.PTV Dosimetry, Homogeneity & Conformity Index:

The figure shows the colourwash representation of the dose fluence distribution across the entire PTV of one patient for each treatment technique. Dosimetric parameters related to coverage, homogeneity, and conformity for all the three different techniques are shown in the table below. For all three dosimetric data, they are described as the mean for all datasets along with the standard deviation (SD). The target volume coverage, which is described by $V_{95\%}$, was >95% for all the plans. The best target coverage was seen in the TOMO plan with the mean dose of 98.275% for PTV_Brain,98.35% for PTV-Spine, and 98.7% for PTV_Brainboost. The high dose volume within the target, V107%, was almost 0 for PTV_Brain, PTV_Spine, and PTV_Brainboost for all the techniques. All plans had comparable mean dose (Dmean) for PTV_Brain (36.04 cGy), PTV_Spine (36.03 cGy), and PTV_Brainboost (18.5 cGy). The intermediate dose; D50% for PTV_Brain (35.7), PTV_Spine (35.9) and PTV_Brainboost (36.01) were also almost same.

Table 1: Dose-Volume relation for the 3 different treatment techniques. All values represent the mean of five patients (SD-Std. Deviation)

	PTV_Brain			PTV_Spine			PTV_Brainboost		
	IMRT_LA	VMAT	TOMO	IMRT_LA	VMAT	TOMO	IMRT_LA	VMAT	TOMO
D_{max}(cGy)(SD)	38.40(0.41)	38.37(0.40)	39.34(1.11)	35.985(0.7)	37.135(0.37)	39.73(0.69)	16.87 (0.27)	17.1 (0.34)	19.24(0.69)
D_{min}(cGy)(SD)	13.17(2.42)	12.01(0.69)	11.64(6.7)	24.37(0.32)	26.23(2.05)	24.79(4.2)	5.34(0.29)	6.3(3.55)	9.83)(2.3)
D_{mean}(cGy)(SD)	35.99(0.33)	35.87(0.15)	34.40(0.28)	35.75(0.33)	35.93(0.17)	36.4(0.087)	18.01(0.24)	19.08(0.82)	17.4(0.17)
$V_{95\%}$(%)(SD)	95.225(1.96)	96.575(1.16)	98.275(1.3)	97.625(1.35)	97.325(1.82)	98.35(1.7)	95.875(0.85)	97.075(1.33)	98.7(1.25)
$V_{107\%}$(%)(SD)	0(0)	0(0)	0(0)	0(0)	0(0)	0.025(0)	0(0)	0(0)	0(0)
$D_{50\%}$(cGy)(SD)	35.6(0.31)	35.090(0.09)	32.55(0.28)	35.83(1.04)	36.01(1.99)	36.5(0.12)	16.09(0.14)	16.23(0.16)	18.26(0.13)
$D_{98\%}$(cGy)(SD)	34.34(0.68)	34.21(0.49)	33.75(0.53)	31.77(1.25)	32.08(2.33)	33.74(0.09)	16.87(0.24)	16.08(0.36)	17.26(0.8)
$D_{2\%}$(cGy)(SD)	36.45(0.41)	36.96(0.46)	36.91(0.42)	36.46(0.75)	36.19(0.53)	37.32(0.28)	18.07(0.61)	18.57(0.18)	18.15(0.31)
$D_{95\%}$(cGy)(SD)	35.21(0.86)	34.64(0.41)	35.50(0.93)	34.81(1.4)	34.61(1.3)	34.92(0.55)	17.52(0.42)	17.48(0.59)	17.92(0.42)
HI(SD)	0.0625(0.012)	0.1125(0.015)	0.047(0.012)	0.065(0.017)	0.0725(0.025)	0.0975(0.03)	0.0635(0.78)	0.0775(0.12)	0.3275(0.56)
CI(SD)	0.977(0.017)	0.965(0.01)	0.98(0.012)	0.765(0.01)	0.94(0.04)	0.96(0.01)	0.975(0.97)	0.9725(0.33)	1.0125(0.88)

Table 2: The dose statistics in terms of maximum (D_{max}) and mean (D_{mean}) dose for all treatment techniques

	D_{max}(cGy)			D_{mean}(cGy)		
	IMRT_LA	VMAT	TOMO	IMRT_LA	VMAT	TOMO
Esophagus	3338	3362.45	3290.6	2168.9	1956.8	2368.7
Heart	2401.6	2298.8	1863.3	797.8	748.125	406.78
Lung_L	3531.975	3439.05	3152.5	1097.52	1063	651.25
Lung_R	3597.6	3469.75	3294	1138.7	1091	661.25
Brainstem	5489	5479.9	4506	5145.5	5230.12	4130.8
Chiasm	4515.05	4727.8	4167.25	4206	4418.9	3952.75
Eye_R	3551.9	3675.675	2300	1382	1802	1041.75
Eye_L	3691.75	3634.8	3328	1698.5	1731.3	1005.75
Lens_R	692.8	915.15	505	632	776.725	540
Lens_L	740.9	912.75	611.25	618	793.5	583.7
Larynx	3040.1	3157.5	2972.5	1549.7	1510.65	1632
OpticNerve_L	3810.5	3342	3731.5	2944.5	2789.6	3214
OpticNerve_R	3972.5	3806.8	3779	2802	2770	3305
Parotid_L	3697	4251.8	3142	1078.47	2400	1496.5
Parotid_R	4008.1	3918.05	3059	1811	2259.7	1439

In case of homogeneity index, PTV_brain, PTV_Spine and PTV_Brainboost shows highest Homogeneity for TOMO plans. The conformity index for Tomo Plan. in PTV_Brain (0.98), PTV_Spine (0.96), PTV_ Brainboost (1.01), shows better conformity than IMRT_LA (PTV_Brain-0.97, PTV_Spine-0.765 and PTV_Brainboost-0.97) and VMAT (PTV_Brain-0.965, PTV_spine-0.94 and PTV_Brainboost-0.97)

B. Dose to OARs:

The dose statistics in terms of the maximum (D_{max}) and mean (D_{mean}) dose for each OAR from the three planning techniques of IMRT_LA, VMAT, and IMRT_Tomo are shown in Table 2. The IMRT_Tomo plan was better for the reduction of doses (both D_{max} and D_{mean}) to all OARs. For OAR-like lens D_{max} for Tomo plan is 2-4% less(5cGy) than modern techniques like IMRT_LA(7Gy) and VMAT (9Gy). Similarly, for parotid, D_{mean} is 3-4% less than IMRT_LA (40Gy) and VMAT (40Gy). Also for Heart, which is 4-5% less than IMRT_LA(8Gy) and VMAT(7Gy). So, Tomotherapy has better OAR sparing capacity, followed by VMAT and IMRT.

IV. DISCUSSION

Homogeneous dose distribution in CSI is one of the most complicated techniques with excessively long fields and complex shapes of the target volume. With rapid development in the technique from classic 2D planar imaging to modern Helical IMRT technique, the radiotherapy technique evolves in terms of normal tissue sparing, target coverage, homogeneity, as well as conformity. (12,13). As per our studies, for both IMRT (D2% = 36.45 Gy, D98% = 34.34 Gy) and VMAT (D2% = 36.19 Gy, D98% = 32.08 Gy), the near minimum (D98%) and near maximum dose (D2%) fell within the recommended PTV dose constraints of 95% and 107% for all the five patients from our case study. This analysis showed that the only the difference between the IMRT and VMAT D2% data was significant. In clinical practice, the reason for using more conformal techniques is better sparing of healthy tissue outside the planning target volume. However, it should be mentioned that knowledge of the uncertainties related to possible motion of the target and correct target volume delineation is prerequisite for highly conformal techniques. Initially, CSI was planned with two collimated lateral cranial fields modified with MLCs or conformal blocks, which are connected geometrically onto the beam divergence of the direct posterior spinal field. The junction of the cranial and spinal fields, which is at the C2–C3 level, is generally junctioned to minimise over- or underdose across the junction field. For 2D, field shaping and matching are done on the bony landmarks seen on the real-time fluoroscopic images on a conventional simulator. The pros of CT simulators and virtual simulation allow better field definition for improved coverage and sparing of OARs. This procedure Although the patients were treated for several years, refrained from giving data for dose–volume relationships of targets and OARs, as long-term side effects become a growing concern for the paediatric population, that are necessary to be evaluated by dose-volume data. According to our modern technique study, regarding the dose to OARs (Heart lungs, kidney, Optic Nerve, etc.), almost all of them were in favour of Helical IMRT and VMAT (For

example, Lens). The recommended dose constraints of 20 Gy for the eyes, 6Gy for the lenses were exceeded for all techniques. Although the dose to OAR was least in the VMAT technique, even than that of the developed technique like Helical Tomotherapy. The finding that VMAT and IMRT_HT spared the OARs better than IMRT_LA is attributed to the number of subfields or partial arcs and their geometric setup, as well as the TPS optimization algorithm (For Helical IMRT). In case of Homogeneity and Conformity, better conformity among the modern techniques is observed in VMAT AND HT, whereas helical shows more accuracy. The HI was somewhat similar (not exactly) for all the techniques when considering the range of data per technique. However, better HI values for PTV_spine were observed with modern radiotherapy techniques.

For techniques like CSI, approximately 4-5 hours were needed to complete the procedure from contouring, planning, evaluation, quality assurance, to perform fraction treatment delivery for CSI patients, with the VMAT duration being the shortest by approximately an hour or two. Generating the treatment plans was faster for IMRT (4 hours) and VMAT (3 hours) because plan templates were created for these techniques and loaded as a planning starting point. For Tomotherapy, lying in supine position is the most convenient position for simulation and treatment delivery, without the need to move them during the treatment (single isocentre) and facilitating a smoother process for anaesthesia and/or sedation when needed, as opposed to standard techniques which require prone positioning and several field junctions.

Patient positioning is simple and reproducible, further supported by daily IGRT using the built-in MVCT increases treatment precision. However, despite the convenient treatment planning and dosimetric benefits, Tomotherapy comes with a significantly longer beam-on-time, and this might be limiting for patients with poor compliance, low performance status, or experiencing pain, or those who need anaesthesia or sedation during radiotherapy. However, this could be mitigated by employing several strategies, such as projecting movies on the tube ceiling, thus increasing compliance, especially in children.

V. CONCLUSION:

Due to the development and the evolution of various techniques, there is constant growth in the field of radiotherapy treatment, especially in specialized techniques like CSI owing to patient comfort and homogeneity. The increasing development in radiotherapy techniques, Helical Tomotherapy plans provided a better dose conformity, homogeneity, and OARs sparing at the expense of exposing larger volumes of tissue to lower dose and longer beam-on time compared with the other techniques.

If considering only LINAC-based technique, then RapidArc-based plans seem to be ideally suitable to plan such long and complex target volumes, owing to lower integral dose to normal healthy tissues, followed by IMRT_LA. All the modern techniques are better in terms of tissue sparing, but Helical Tomotherapy is better in terms of accuracy and Homogeneity. Thus, helical tomotherapy offers clear dosimetric advantages, good target coverage with high homogeneity and conformity, and OAR sparing. Although combined with the higher MU and longer beam-on time, this means a potentially higher risk of secondary malignancy in specific patients, such as patients at a very young age and with a genetic predisposition to certain cancers.

The preference to use this technique should be made case to case, taking into consideration both technical and clinical feasibility and relevance.

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QUALITY ASSURANCE OF MEDICAL LINEAR ACCELERATOR USING TG-142

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Abstract— **Quality control (QC) is a process that focuses on detecting mistakes, errors, or missed requirements in a medical linear accelerator. AAPM Task Group-142 (TG-142) is a collaborative effort established by the American Association of Physicists in Medicine (AAPM). The primary purpose of TG-142 is to develop and publish guidelines for Quality Assurance (QA) of medical accelerators used in radiotherapy.**

Keywords— **Multi-Leaf Collimator, Quality Assurance, Cone Beam CT, Electronic Portal Imaging Device**

I. INTRODUCTION

Quality Assurance is defined as a process through which the actual performance of the equipment is measured and compared with the existing standard or reference value (baseline value), and actions necessary to keep or regain uniformity with these standards are taken. The primary purpose of TG-142 is to develop and publish guidelines for Quality Assurance (QA) of medical accelerators used in radiotherapy. Quality Assurance is a broad process for preventing quality failures. The QA team is involved in all product development stages, production, testing, packaging, and delivery.

The AAPM TG-40 report, published in 1994, is widely used as reference document that includes recommendations for general quality assurance (QA) tests for medical linear accelerators. Since the publication of TG-40, several new technologies have been developed and are now commonly used in clinical practice. These technologies include Multi-Leaf Collimation (MLC), asymmetric jaws, dynamic and virtual wedges, and electronic portal imaging devices(EPIDs). Image guidance devices such as cone-beam CT(CBCT), static kilovoltage (kV) imaging, and respiratory gating were rarely used in 1994. The purpose of this report is to build upon the recommendations of TG-40 for QA of medical linear accelerators, including the aforementioned technologies (MLC, newer wedge systems, asymmetric jaws, imaging systems, and respiratory systems) and procedures such as SRS, SBRT, TBI, and IMRT. During the development of this report, an investigation of technologies that deliver MLC-based IMRT with simultaneous gantry rotation had just begun, and therefore, QA for these technologies is not included in the report.

The need for TG-142 arose from the recognition that medical accelerators play a crucial role in radiation therapy. Precise and accurate delivery of radiation to target tissues is essential for effective treatment while sparing healthy surrounding tissues. Any errors or malfunctions in medical accelerators can have serious consequences for patients' safety and treatment outcomes. Therefore, AAPM Task Group 142 was convened to create a comprehensive set of guidelines and recommendations for the Quality Assurance of Medical accelerators.

The ultimate goal of AAPM TG-142 is to enhance patient safety and treatment efficacy by establishing standardized QA protocols that medical physicists and radiation therapy teams can follow to ensure the reliable and accurate performance of medical accelerators.

The recommendations of this report are summarized in tables. The first three tables, Table (daily), Table (monthly), and Table (annual). Each table has specific recommendations based on the nature of the treatments delivered on the individual machine. The tables are differentiated into non-IMRT or non-Stereotactic machines, IMRT machines, and IMRT/ stereotactic machines. Three additional tables were created for Dynamic/ Virtual/ Universal wedges (Tables), MLC (Tables), and Imaging (Tables). This task group (TG) considers that all of the tests included in the tables are important for ensuring the equipment is suitable for high-quality and safe radiation treatments. A consistent beam profile is an important quantity for accurate and reproducible dose delivery in radiotherapy. Beam uniformity was addressed in TG-40 with flatness constancy.

The expansion of tests is also justifiable because, since TG-40 and post-IMRT, the selection of available QA tools makes annual testing less burdensome; these tools range from 3D water scanning tanks to large area detector arrays. The proper tools should be chosen by matching the detectors and software to the needs and sensitivity requirements.

This study aimed to perform and analyse a medical linear accelerator's Quality Assurance (QA) test using TG-142. TG-142 aims to ensure the entire radiation therapy process, from imaging to treatment delivery.

II. MATERIALS AND METHOD

The study was performed on the True Beam Varian Medical System (SN-4378) machine with photon energies 6MV, 10MV and 15MV (6FFF, 10FFF), and electron energies 6MeV, 9MeV, 12MeV, 15MeV, 18MeV and 20MeV.

Dosimetry checks for daily QA were performed in the slab phantom, monthly in the water phantom (30×30×30 cm^3), and annually in RFA. Other equipment are ionization chambers, electrometers, dosimetry phantoms, lasers and alignment tools, beam quality analyzers, imaging devices, phantom positioning devices, water tanks, multi-leaf collimator (MLC), radiation detectors and probes, radiation survey meters, software systems, thermometer, barometer, spirit level.

Daily QA Set-up:

Daily QA focuses on quickly verifying the overall functionality and stability of the treatment delivery system. It ensures that the treatment machine is in a suitable condition for patient treatments each day. It helps catch any sudden malfunctions or changes that could impact treatment accuracy. The daily QA typically includes checks on basic parameters such as beam output, beam symmetry, and mechanical stability.

Fig. 1: Set-up for daily QA

Monthly QA Set-up:

Monthly QA comprised gantry, collimator and table (couch) spoke test; Radiation and light field congruence; X-ray output constancy and electron output constancy; and Beam quality index measurement.

Fig. 2: Set-up and images for monthly QA

Annual QA RFA Set-up:

The annual QA measurements include bean quality index, PDD curves, MLC and imaging tests, leaf test, output calibration, beam profile, dose rate – gantry speed test.

NOTE: This QA report is as per the recommendations of AERB Safety Code No. AERB/RF-MED/SC-1(Rev.1) March-2011 and AAPM Report TG-142.

Fig. 2: Set-up and images for annual QA

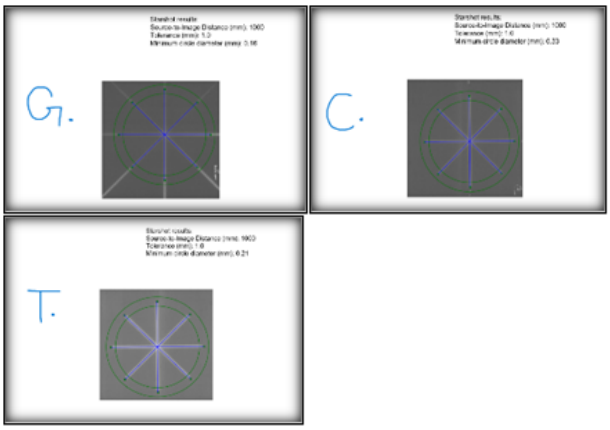
III. RESULTS AND DISCUSSION

Daily output consistency:

	Energy	MR (nC)	CORR. MR(nC)	DEV (%)
Output Consistency Photons	6 X	17.89	18.01	1.01%
	6 FFF	17.45	17.57	1.27%
	10 X	19.20	19.33	1.20%
	10 FFF	18.64	18.77	1.18%
	15 X	19.67	19.81	1.07%
Output Consistency Electrons	6 E	20.49	20.63	1.13%
	9 E	19.94	20.08	1.41%
	12 E	20.85	20.99	1.30%
	15 E	21.98	22.13	1.28%
	18 E	22.93	23.09	1.09%
	20 E	23.32	23.48	1.25%

Monthly QA:

Gantry, collimator and table (couch) spoke test:



Radiation and light field congruence:

Energy	Optical F.S.	Radiation F.S.	% Difference
6 MV	10×10 cm2	10×10 cm^2	0.0

X-ray and Electron output constancy tests

Energy	Measured Output	Base Line	% Deviation
6 MV	101.62	100cGy/100MU	1.62
10 MV	101.82	100cGy/100MU	1.82
15 MV	101.87	100cGy/100MU	1.87
6 FFF	101.76	100cGy/100MU	1.76
10 FFF	101.56	100cGy/100MU	1.56
6 MeV	100.45	99.10cGy/100MU	1.36
9 MeV	100.62	98.36cGy/100MU	2.29
12 MeV	100.08	98.63cGy/100MU	1.46
15 MeV	100.00	98.56cGy/100MU	1.45
18 MeV	100.02	99.20cGy/100MU	0.87
20 MeV	101.17	99.04cGy/100MU	2.146

Beam Quality Index Measurement:

Energy	6 MV	10 MV	15 MV	6 FFF	10 FFF
Baseline	0.665	0.739	0.763	0.630	0.707
MR@20cm Depth	11.03	13.80	14.88	9.823	12.43
	11.01	13.78	14.88	9.822	12.42
	11.01	13.74	14.86	9.823	12.42
Avg.	11.01	13.77	14.87	9.822	12.42
MR@10cm Depth	16.59	18.68	19.55	15.69	17.68
	16.60	18.66	19.53	15.68	17.66
	16.60	18.67	19.54	15.65	17.67
Avg.	16.59	18.67	19.54	15.67	17.67
TPR20/10	0.663	0.735	0.761	0.626	0.703

Annual QA:

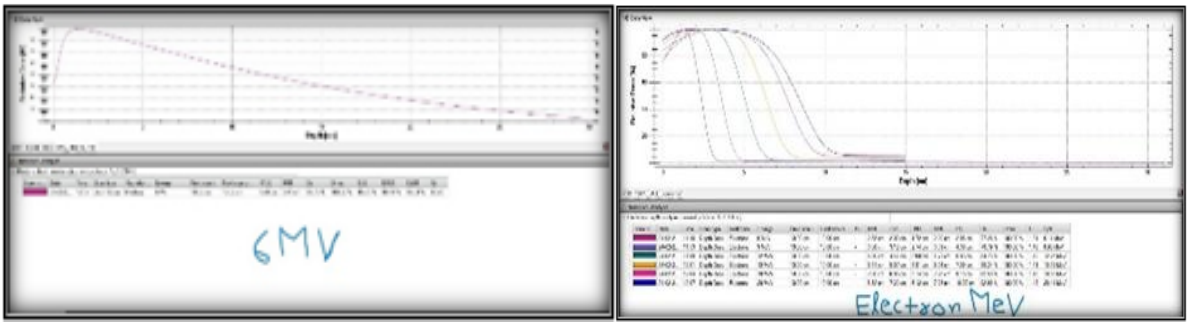
Beam Quality Index

Energy	TPR10 (10cm depth)	TPR20 (20cm depth)	TPR (20/10)	Reference	Tolerance (from baseline)
6 MV	16.83	11.17	0.664	0.665	±1%
10 MV	19.01	14.01	0.736	0.739	± 1%
15 MV	19.54	14.87	0.761	0.763	± 1%
6 FFF	15.673	9.822	0.627	0.630	± 1%
10 FFF	17.67	12.425	0.703	0.707	± 1%

PDD Curves:

Photon PDDs					
Energy	Dmax	D_{10}(cm)	Q index	Reference	Tolerance
6 MV	1.48	66.14 %	0.575	1.6±0.15	± 1mm
10 MV	2.34	73.83 %	0.631	2.4±0.15	± 1mm
15 MV	2.83	76.92 %	0.651	2.9±0.15	± 1mm
6 FFF	1.38	63.14 %	0.547	1.5±0.15	± 1mm
10 FFF	2.23	71.36 %	0.606	2.34±0.15	± 1mm

ELECTRONS Pdds						
Energy	Dmax	R_{50}	Tolerance	R_{90}	R_{80}	Z ref
6MeV	1.29	2.33	± 5 mm	1.72	1.92	1.30
9MeV	2.02	3.56	from	2.74	3.00	2.04
12MeV	2.86	4.99	Base line	3.90	4.26	2.89
15MeV	3.58	6.31		4.91	5.39	3.69
18MeV	2.75	7.60		5.74	6.40	4.46
20MeV	2.74	8.32		6.12	6.92	4.89



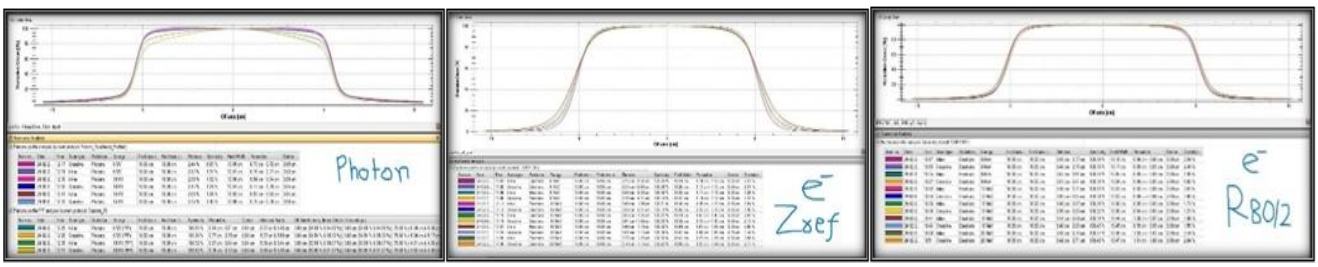
Leaf Speed Test:

Image Analysis Using (10 cm × 0.5 cm) ROI					
Leaf Speed Test					
Band No.	-4.5 cm	-1.5 cm	1.5 cm	4.5 cm	Threshold
R(ls)	0.171	0.17	0.17	0.17	
R(open)	1.232	1.25	1.25	1.23	
R(corr.)	13.88	13.86	13.86	13.79	
Diff(X)	0.07	0.13	0.18	-0.39	<±3%
Average of Absolute Deviations [Diff.(abs)]				0.19	<1.5%

Output Calibration (TRS-398):

Energy	K q q_o	Kt p	Ks	Kpol	Avg. MR (nC)	PPD at 10 Cm %	Ndw x10^8 Gy/C	O/P Dmax %	% Variation
6 MV	0.996	0.999	1.0	1.0	13.83	66.3	4.82	100.4	0.42
10 MV	0.985	0.999	1.0	1.0	15.53	73.7	4.82	100.3	0.37
15 MV	0.980	0.999	1.0	1.0	16.24	76.8	4.82	100.5	0.51
6 FFF	0.998	0.999	1.0	1.0	13.11	63.2	4.82	100.4	0.45
10 FFF	0.991	0.999	1.0	1.0	14.75	71.2	4.82	100.4	0.41
6 MeV	0.94	1.0	1.0	1.0	11.95	99.8	8.84	99.96	0.04
9 MeV	0.92	1.0	1.0	1.0	12.22	99.9	8.84	100.3	0.31
12 MeV	0.91	1.0	1.0	1.0	12.35	99.9	8.84	99.98	0.02
15 MeV	0.90	1.0	1.0	1.0	12.42	99.6	8.84	99.98	0.02
18 MeV	0.89	1.0	1.0	1.0	12.33	98.1	8.84	99.99	0.01
20 MeV	0.89	1.0	1.0	1.0	12.30	96.9	8.84	100.5	0.55

Beam Profile:



Energy	Separation between IPL & IPR cm	X - 90% cm	X-75% cm	X - 60% cm	Symmetry %	Left Penumbra (cm)	Right Penumbra (cm)
6 FFF (In plane)	10.84	4.04 4.02	5.12 5.12	5.30 5.28	0.91	0.85	0.82
6 FFF (Cross plane)	10.88	4.09 4.09	5.10 5.10	5.32 5.32	0.62	0.78	0.75
10 FFF (In plane)	10.86	3.19 3.16	4.87 4.63	5.21 5.19	0.38	0.87	0.84
10 FFF (Cross plane)	10.82	3.15 3.21	4.87 4.90	5.22 5.23	0.75	0.79	0.77

Dose Rate- Gantry Speed:

Image Analysis Using (10 cm × 0.5 cm) ROI								
Dose Rate- Gantry Speed Test								
Band No.	-6cm	-4cm	-2cm	0.0cm	2cm	4cm	6cm	Threshold
R(dr gs)	0.60	0.61	0.61	0.61	0.61	0.61	0.60	
R(open)	4.08	4.19	4.19	4.19	4.20	4.20	4.06	
R(corr.)	14.90	14.67	14.70	14.72	14.73	14.7	14.8	
Diff(X)	0.92	-0.62	-0.38	-0.25	-0.22	0.08	0.64	<±3%
Average of Absolute Deviations [Diff.(abs)]							0.45	<1.5%

The results for daily output photon constancy were 1.15±0.11% (mean ±SD), and daily output electron constancy was 1.24±0.13 (mean ±SD). The measured values for monthly output photon consistency were 1.73±0.13% (mean ±SD), and monthly output electron consistency was 1.60±0.53 (mean ±SD). The results for annual output photon consistency were 0.43±0.05% (mean ±SD), and annual output electron consistency was 0.16±0.22 (mean ±SD). The calculated values for Beam Quality Index (TPR20/10) were 0.70±0.05 (mean ±SD) of annual & monthly. MLC leakage test and MLC leaf speed test were calculated as Max 2.91% (Tol: ±5.0%) and average of absolute deviations 0.19% (Threshold: ±1.5%), respectively.

All results are within tolerance limits as per TG-142 protocols. Machine performance data are in the tolerance range.

IV. CONCLUSION

These records show the activities conducted and serve as a reference to follow up on any changes and issues that may affect patient care.

V. ACKNOWLEDGEMENTS

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1. TG-40, TG-100, TG-142. Eric E. Klein (Washington University, St. Louis, Missouri), Joseph Hanley (Hackensack University Medical Center, Hackensack). TG-142 was constituted by the AAPM-Science Council-Therapy Physics Committee-Quality Assurance and Outcome Improvement Subcommittee.

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DEVELOPING KNOWLEDGE ON PRACTICES FOR IMAGING IN RADIOTHERAPY THROUGH ICRP MENTORSHIP PROGRAMME

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Abstract– **Task Groups of the International Commission on Radiological Protection (ICRP) publish reports giving recommendations and guidance on the safe use of ionising radiation in a variety of applications. For the preparation of reports background material and information on current radiological practices need to be gathered from around the world. Sometimes the feasibility of new techniques for use in different locations may need to be investigated. ICRP launched a mentorship programme to enable early career radiation scientists to participate in this preparatory work and broaden their experience in radiological protection. Task Group 116, which is concerned with imaging in radiotherapy, assembled a group of mentees from 22 countries throughout the world. The mentees have participated in a variety of projects involving surveys of current practices, literature searches and reviews, experimental measurements to investigate dosimetry techniques, computer modelling and data analysis. Many young enthusiastic medical physicists eager to participate in improvement projects are often working at hospitals in countries where medical physics is still at an early stage of development and so have more limited professional support. The mentorship programme provides research opportunities with scientific backup through virtual meetings at which mentees can discuss findings from their projects with more experienced scientists and researchers. This enables them to obtain advice on the analysis of results, highlight issues that arise and air new ideas and suggestions. This paper describes the evolution of work by the mentee network linked to TG116. Initiatives of this type can promote the involvement of early career medical physicists in implementing medical developments with support from virtual forums, demonstrating the value of the scientific approach of medical physicists in healthcare.**

Keywords— **Mentorship, ICRP, cone beam computed tomography, imaging, radiotherapy**

I. INTRODUCTION

The International Commission on Radiological Protection (ICRP) has the mission to provide recommendations and guidance on radiological protection based on an understanding of the science of radiation exposures and effects, and value judgements taking account of societal expectations, ethics, and experience. Reports are prepared by Task Groups (TGs) set up to address specific topics and often require a significant amount of background investigation into the current state of knowledge and radiological practices around the world. In 2019, ICRP launched a mentorship programme to assist TGs in carrying out the background work required when getting ready to assemble a report. The programme provides opportunities for emerging radiation scientists worldwide to broaden their experience in the field of radiological protection through participation in the work of ICRP TGs and also provides mentees with an opportunity to gain insight into ICRP processes. In this way the programme can help to strengthen expertise in radiological protection, a need identified in the ICRP Vancouver Call for Action [1] supported by 19 other international organizations [2]. Moreover, the programme is able to attract and involve early-career medical physicists from a wide geographic range, many of whom have limited contact with radiation scientists in their own country, especially in Asia, Africa, and South America where numbers practicing in some scientific professions are limited. The wide geographic distribution of mentees enriches the work of the TGs and assists in ensuring the relevance of recommendations in a global setting. The link with ICRP is helpful in encouraging support from employers and national organizations, as well as providing a way for ICRP experts to assist with initiation and follow-up of the introduction of recommendations. The programme can provide early-career scientists with an opportunity to

carry out investigations, which can then be discussed with experienced scientists and researchers in a virtual forum to assist in interpreting results and identifying problems. After a brief overview of the mentorship programme, this paper describes the development of a project linked to a TG in imaging in radiotherapy involving a survey of practices, followed by development of an experimental technique, and finally a survey of patient imaging doses.

II. THE ICRP MENTORSHIP PROGRAMME

The mentorship programme is designed to offer applicants with appropriate backgrounds and experience from any educational, governmental, private or other organization a part-time voluntary position as a mentee. There are no fees and the mentee's home organization bears all costs associated with the mentorship, but the programme provides an opportunity to work as part of an international team broadening their experience in the field while contributing to the background knowledge necessary for writing the reports. Mentees are assigned a specific role, task, or project that is defined in advance, but this can be developed during the mentorship period with the agreement of mentor and mentee, as knowledge of the topic evolves and needs of the TG change. Examples of typical projects that have been undertaken by medical physicists are:

- Carrying out background literature searches and reviews
- Making measurements such as on medical equipment performance or dose levels.
- Carrying out computer calculations or simulations.
- Participating in the organisation of surveys, data collection, and analysis.

Mentorship positions are advertised on the ICRP website (https://www.icrp.org/page.asp?id=465) and persons interested must submit an application, setting out their expertise and explaining why they are interested in the specific project. They must also include a letter of support from their employing organization. The assignment is for a pre-set initial period, typically one year but can be renewed as the project develops. Selection of mentees is based on expertise of the applicant as well as consideration of diversity and regional representation. The mentor is normally a member of the TG and is responsible for providing guidance and support to the mentee. At the end of the mentorship period, the mentor and mentee each submit a brief confidential report about their experiences and these are being used to gradually improve the mentorship programme. Renewal of the mentorship for a further period depends on requirements of the TG and will take account of the mentee's performance.

III. THE USAGE OF IMAGING IN RADIATION THERAPY

A. Improvements in radiotherapy treatments

Improvements in the capability of linear accelerators to conform radiotherapy treatments to tumour targets have created a need for additional imaging at the time treatments are delivered to achieve the necessary accuracy. The use of image guidance has increased substantially in the last decade and the delivery of more focused radiation treatments has led to better patient outcomes [3] and is regarded as essential for some treatments [4]. ICRP, aware of the increased use of image guidance, set up TG 116 to prepare recommendations and guidance on the radiological protection aspects of imaging in radiotherapy in 2018. The aim is to prepare a report giving an overview of the use of imaging in radiotherapy and provide guidance on optimization of radiological protection aspects related to imaging practices. Most imaging is undertaken with kV X-ray imaging systems incorporated into linear accelerator radiation treatment machines that can be used in a stationary position for plain radiographic images or with the imaging system rotated around the patient for cone beam computed tomography (CBCT). Imaging may be carried out at every fraction for many treatments and the increased use of x-ray imaging exposes normal tissues in the region surrounding a tumour to more radiation. As a result, there are risks, firstly that doses to organs lying near the boundary of the planned target volume may rise above respective tolerance doses [5], and secondly that second primary cancers may be initiated in tissues within the larger volumes surrounding the targets included in images [6]. There is evidence of an association between malignancy in children having CT scans at organ dose levels below 100 mGy [7].

B. A survey of the use of imaging in radiotherapy

The TG decided to advertise positions for mentees for two tasks 1) to carry out a literature survey of imaging practices in radiotherapy and 2) to undertake Monte Carlo simulations to evaluate dose levels from CBCT imaging systems. The call for mentees yielded ten applicants from a broad range of countries with low-, medium-, and high-income levels distributed across six continents. Most of the applicants had medical physics experience, although few had relevant computing experience or access to computing facilities that would enable them to carry out Monte Carlo simulations and several applicants were from countries that did not have well-developed medical physics communities. Since development of knowledge and skills, especially among early career medical physicists in countries such as those from which applications had been received, was a key objective of the mentorship programme, TG members were reluctant to reject these applicants. When reviewing the literature available on image guidance in radiotherapy, it

had become apparent that the radiotherapy centres covered were almost exclusively in more developed nations and the TG members realized that it would be useful to have more information about imaging practices in radiotherapy for countries such as those from which mentee applications had been received. Therefore, a new project was set up for the mentee applicants to survey imaging practices in radiotherapy in their own countries. The aim was that each would participate by carrying out a survey of practices in as many radiotherapy centres as they were able to persuade to participate. Periodic virtual meetings were arranged to provide information and discuss results. These were irregular in the early stage but have now settled down at a frequency of about every two months.

The survey would be conducted online, and a questionnaire was developed with the Survey Monkey ® platform by a sub-group of medical physicists within the TG. The TG was ambitious about the amount of information that could be gathered since there would be a mentee with local knowledge and contacts based in each country. The survey comprised a mixture of numerical questions about radiotherapy treatment and imaging equipment and practices, and free text fields for comments on reasons for choices, modifications made to protocols, and the use of national or international guidance documents. The finalized questionnaire contained 130 separate items on practices in each centre and some of these aspects are summarized in Table 1.

The nine mentees appointed contacted groups of radiotherapy centres within their countries and asked each centre to identify a representative to take responsibility for completion of the survey questionnaire. This was done largely through the mentees' contacts, but in higher-income countries, the national medical physics societies helped by providing contacts. Participation in the survey was organized in two parts. Mentees were provided with a link to send to the representatives at each centre, through which they could register and opt into the survey. The initial contact link explained the purpose of the survey, sought agreement that the centres were willing to participate, and collected the representative's email addresses to which links to the full survey were sent. Since the survey was relatively long, the individual links were left open, so that representatives could complete the various sections over several sessions.

The mentees liaised with the different centres, following up on any questions and providing clarification of the requirements. Since only countries with a mentee participated, the survey could only give a snapshot of practices, but it enabled a substantial amount of information to be gathered. The survey was left open for 3½ months, between August and November 2020, and as the deadline approached mentees reminded centres with incomplete submissions and encouraged them to finish the questionnaire. A total of 143 centres registered an initial interest, and 100 completed the full questionnaire in nine countries. Each mentee was responsible for collating the data for their country in an Excel spreadsheet, investigating unexpected responses, and calculating percentages of centres with specific types of facility or carrying out particular practices. Results from the survey were collected centrally and analyzed. Results were discussed with the mentees in several ZOOM meetings and have been reported in the literature [8].

Table 1. Information requested in the questionnaire completed by radiotherapy centres

Pages	Information requested	No. of questions
1-3	General facility information • Facility and local contact details • Type of facility: Public / Private / Academic • Number of patients treated per month • Percentage of treatments using image guidance • Availability of imaging physicists for consultation	22
4	Imaging equipment used for planning • CT Systems (Makes and number) • Other imaging modalities (Types and number)	9
5	Treatment machines and associated imaging facilities • No. of linear accelerators (Makes and dates of commissioning) • No. of Cobalt-60 treatment units • No. of linacs with kV imaging capabilities	8
6	Types of imaging used during treatment • Types of imaging procedures used • Types used for paediatric treatments	18
7-12	Imaging during six specific types of treatment • Imaging modalities used • Frequency of imaging for radical treatments	30
13-16	Optimization undertaken for different X-ray imaging modalities • Use of protocols as supplied by the manufacturer • Adaptation of protocols for individual patients • Recording of dose quantities for individual patients	29
17	Additional information • Types of QC performed on imaging systems • Frequencies for performing QC	14
	Total	130

The survey showed that radiotherapy centres in all countries employed image guidance, but the number of units with kV imaging facilities available and the frequency of imaging were lower in low- and middle-income countries. The imaging technique used most frequently immediately prior to treatment was kV cone beam CT (CBCT) imaging, where this was available. Relationships between practices and the income and development of the countries in the survey were investigated through comparisons with the Human Development Index (HDI) value as defined by the United Nations Development Programme [9]. The HDI

combines indices of life expectancy, education, and per capita income with values increasing with the level of development to a maximum of 1.0. The survey revealed that irrespective of their level of development, countries outside Europe recorded little or no information on patient doses from imaging used for treatment guidance. This was despite full CBCT scans being acquired at the start of each fraction of most radiation treatments, potentially including 30-40 fractions [8]. Equipment operators need to have a knowledge of the dose levels used to allow them to assess the impact of any change in practice. If the dose levels are not apparent from the clinical images, optimization will not be possible. This proved to be important information for finetuning the scope and recommendations in the TG 116 report to improve optimization of radiological protection for imaging in radiotherapy.

C. kV cone beam CT dosimetry project

Following the findings of the initial survey of imaging practices, a second mentee project was started in 2022 to investigate dose levels for kV-CBCT systems incorporated with linear accelerator treatment machines. This was to identify suitable dose quantities that could be measured and used for assessing patient doses and look into the feasibility of radiotherapy centres across the world carrying out surveys [10]. Another call was made for ICRP mentees in 2022, and the number was increased to 22 to extend the project to more countries with the hope of eventually initiating surveys of imaging doses in radiotherapy centres around the world. Patient dose audit is a process, widely used in diagnostic radiology, whereby median patient doses for particular procedures are determined from surveys at each centre and compared against a standard [11]. The standards used for diagnostic medical exposures are called diagnostic reference levels (DRLs). They provide a dose benchmark, against which facilities can compare their practices and identify whether optimization of imaging protocols may be required [12]. Dose reference levels (DRL_{RTS}) for imaging used in treatment planning [13] and imaging prior to radiotherapy treatment [14] have in recent years been established in the UK from national surveys. Surveys across multiple countries should provide reference data for developing a dose audit programme that can be applied more widely.

The standard dosimetry quantity recommended by the International Electrotechnical Commission (IEC) for display on CT scanners is $CTDI_{100}$, which provides an indication of CT dose levels. The accepted tool for measurement is a 100 mm long pencil radiation detector measuring air kerma. The CTDI is the measurement normalized by the nominal width of the CT beam relative to the length of the detector. The pencil detector may be used free in air to assess the output of a CT scanner or within standard cylindrical phantoms made of polymethyl methacrylate (PMMA), 150 mm long, and 320 mm and 160 mm in diameter, representing the body and head, respectively. Since the distribution of CT radiation inside the patient's body is nonuniform, i.e. radiation intensity decreases as the beam penetrates inside the body, the pencil chamber is placed in holes in the phantoms' centres and at four positions at 90º intervals around the periphery to make dose measurements. A weighted value for the $CTDI_{100}$ measurements made in a phantom ($CTDI_w$) is derived to give an indication of the dose to tissues within the region scanned and takes the form:

$$CTDI_w = \frac{1}{3} CTDI_c + \frac{2}{3} CTDI_p$$

where $CTDI_c$ is the $CTDI_{100}$ measurement at the centre of the phantom and $CTDI_p$ is the average of the four $CTDI_{100}$ measurements made at peripheral positions. The CTDI concept to capture all the radiation within the narrow fan beams of conventional CT scanners is designed for beam widths of ≤40 mm [15], but cone beams used in radiotherapy equipment are wider than both the lengths of the 100 mm ionization chamber and the standard 150 mm long phantoms [16-18].

The IEC has defined a wide beam CTDI measurement ($CTDI_{w,IEC}$) as a standard quantity for display on cone beam CT systems [15, 19], which is a development of the $CTDI_{100}$ for narrow beam CT scanners. This is closely related to the weighted $CTDI_w$ for narrow beam CT scanners. A practical method for measurement of the $CTDI_{w,IEC}$ for wide beams using $CTDI_{100}$ dosimetry equipment has been described in IAEA [19] and is based on the acquisition of $CTDI_{100}$ measurements for a reference beam of width ≤40 mm within the standard PMMA CT phantoms with a correction factor equal to the ratio of $CTDI_{100}$ measurements free in air for the wide beam of interest and the reference beam [15, 19, 20]. Calibration of the displayed quantity should be verified to enable imaging performance to be compared against national or international reference data. However, display of the wide beam CTDI on clinical linac CBCT systems has so far been variable, so its use as a dose audit quantity for large scale surveys of patient doses is impractical at the present time. Moreover, the calibration check requires a series of measurements for each kV / filter combination being used that are not straightforward. Looking towards the future, all CBCT systems should aim to display the $CTDI_{w,IEC}$ values. However, for the purposes of carrying out a dose survey at the present time, an alternative approach was required. Moreover, to enable centres to contribute dose measurements for multiple systems, this needed to be relatively straightforward, and a plan was developed (table 2).

A dosimetry quantity called the Cone Beam Dose Index (CBDI) has been proposed by Amer et al. [21]. The CBDI relates to the level of dose to the patient capturing the effect of kV and filtration. The CBDI involves measurement of the cumulative dose for a CBCT scan with a 100 mm pencil detector within standard cylindrical PMMA CT phantoms, but with the 150 mm long phantom lying entirely within the cone beam. Dose measurements are made at the centre and periphery of the phantom and combined to give a weighted

value $CBDI_w$ as for the standard $CTDI_w$ (equation 1). This method has been applied in clinical practice [22-24] and the recent UK study of CBCT doses has demonstrated the feasibility of applying the method in a patient dose survey [14], so this approach was adopted as the measurement to be used.

Initial discussions with the mentees revealed that few radiotherapy centres had access to 100 mm pencil detectors or standard cylindrical PMMA CT phantoms. A small survey of the availability of radiation measurement instruments and phantoms showed that less than 50% of centres in the mentees' home countries had access to CT measuring equipment. However, almost all centres had 0.6 cc Farmer ionization chambers and slabs of solid water or similar phantom material with holes to take a Farmer chamber that were used for dosimetry on radiation therapy beams [25]. A cubic phantom measuring 300 × 300 × 300 mm^3 comprised of slabs of solid water or similar material could be assembled with slabs containing holes for the Farmer chamber at the centre and two others at the top and bottom of the pile. The slabs are taped together to enable measurements to be made in different orientations to replicate measurements with the cylindrical CT body phantom. The equivalent diameter of the phantom averaged over a 360º rotation is approximately 337 mm and so is similar in attenuating properties to the 320 mm CT body phantom. This method could be developed as a first line of attack, where the recommended CT measurement equipment was not available. The $CBDI_w$ for cylindrical phantom and 100 mm detector was chosen as the standard to be taken forward, with other approaches being designed to give a measurement that could be compared with the standard in the early stages of the project (table 2).

Table 2. Steps in development of dose measurement method and initial patient data collection

1 Project design

Identification of a suitable quantity for measurement of cone beam dose

- Review of dosimetry quantities available and practicality of measurements
- Choice of cone beam dose index (CBDI) measurement with 100 mm detector inside a 32 cm diameter cylindrical phantom as method of choice

2 Survey of equipment available in RT centres

Survey of radiation dose measuring instruments and potential phantom materials available in radiotherapy departments

- 100 mm pencil radiation detectors
- 0.6 cc Farmer chambers
- Cylindrical CT PMMA phantoms
- Slabs of water-equivalent material

3 Selection of experimental method used by each centre

Identification of options for phantoms that all centres can use
Investigation into the use of phantoms measuring 300 mm x 300 mm x 300 mm constructed from water-equivalent slabs as an alternative to CT body phantom.
Comparison of measurements and determination of adjustment factors to give CBDI values with the following experimental configurations (by centres with different experimental equipment):

- Cylindrical 320 mm and 160 mm CT phantoms with 100 mm CT chamber
- Cylindrical 320 mm and 160 mm CT phantoms with 6 cc Farmer chamber
- Slab phantom measuring 300 mm × 300 mm × 300 mm with 6 cc Farmer chamber

Select experimental configuration to be used for measurements based on available equipment and take measurements at their own centres

4 Dosimetry measurements

Make measurements at other centres or ask colleagues to make measurements with the chosen method for each beam quality (kV and filtration) to be assessed.

- Applications may use different mAs values, but the same beam quality
- Single measurements can be used for different treatments with the same kV and filters.

Analyze results for normalized dose and compare different CBCT systems

- Analyse data calculating the doses per mAs
- Apply calibration / conversion factors
- Investigate reasons for differences based on kV, filtration, field size, etc.

Carry out Monte Carlo simulations of different experimental approaches and compare with experimental measurements

5 Patient dose assessments

- Collect data on standard treatment protocols for specified treatments
- Calculate cumulative doses for each application by multiplying by the mAs
- Collate results for different centres within each country
- Compare cumulative doses for each application at different RT centres
- Identify units for which doses are higher and try to identify reasons

Mentees were asked to take measurements at their own centres to establish the technique and would later ask colleagues to carry out similar measurements at other centres. Preliminary measurements were performed in most of the countries and results were reported in terms of air kerma per mAs (tube current exposure time product). Comparisons between measurements of the CBDI with 100 mm detectors in cylindrical phantoms and ones with Farmer chambers in slab phantom cubes were made in centres, which had both sets of equipment, to evaluate adjustment factors that could be used by the participants who did not have access to CT measurement equipment, so that correction factors could be developed using a combination of results from practical measurements and Monte Carlo simulations. One mentee undertook the role of creating spreadsheets for collection of the data to allow ready comparisons to be made, another carried out Monte Carlo simulations of the different experimental arrangements, and others investigated issues relating to calibration of Farmer chambers for kV x-rays and differences in CBCT systems such as collimation and filtration. Virtual meetings every two months were an important forum for educating mentees

on the principles and methods for patient dose surveys, sharing results, and discussing experimental methods, calibration of equipment, and progress in the project. This part of the project has just been completed and a paper submitted to a scientific journal [25].

D. Patient dose surveys

The next phase of the project involves collection of exposure factor data on standard treatment protocols for specified treatments at each centre. The protocol data are combined with the $CBDI_w$ data for each centre to provide information on cumulative patient dose levels used for imaging. This is the point at which doses linked to patient imaging can be compared to identify radiotherapy centres in which further optimization is required. The aim is to extend the survey through organizations within the mentees' countries and this has already been initiated via the Medical Physics Society in Poland. This project, which ultimately aims to implement national dose reference values for CBCT in Poland, is planned for a period of 2-3 years. During its course, it is planned to carry out a survey and dosimetry measurements at radiotherapy facilities in Poland in accordance with the guidelines and based on the results developed by the TG116 ICRP. The results obtained will serve as a basis for the national guidelines of the Polish Society of Medical Physics on the use of CBCT in radiotherapy and for the legal regulations on radiation protection in medicine.

The link with the ICRP has proved valuable in providing evidence of the wider scale of involvement in the projects, which has encouraged other centres to participate. In the initial stages, the dose reference level values based on $CBDI_w$ values determined in the UK survey [14] are being used as approximate comparators, until appropriate values are determined from the present survey. When analyses of the results identify centres where doses are higher, this may indicate that optimization is required, and here discussion among the mentee group and TG members will be crucial. This is the most important phase of the project and it is hoped that it will continue into the future. It will require the knowledge and experience of the TG 116 members involved and allow the mentees to develop their own expertise in the subject by carrying out investigations with TG member guidance. Cross fertilization of ideas between members of the mentee group is also proving to be an important component. The measurements proposed should give dose values suitable for benchmarking and comparing the performance of equivalent CBCT protocols for similar treatments.

IV. DISCUSSION

The ICRP Mentorship Programme has to date engaged 76 mentees worldwide across 13 TGs, with 65 currently active. TG116 mentees represent an age range of 25 to 62 years, with a median age of 33. While younger scientists are typically preferred, including older participants has expanded geographic reach and enabled the sharing of knowledge with younger colleagues in continuation of the work. This diversity enhances the programme's ability to address global radiological protection challenges.

The mentorship programme fosters a support structure for early-career scientists by integrating them into TGs initiatives that align with the ICRP's objectives. This collaborative model aids in developing new techniques, expanding knowledge, and addressing challenges specific to diverse socioeconomic and cultural contexts. It is important to emphasize that the mentorships are not a one-way process. For mentees, participation offers unique opportunities to contribute to meaningful projects, while for TGs, mentees' involvement enriches the development of their reports by providing insight from underrepresented regions and ensures broader application of recommendations.

TG116's mentorship initiative demonstrates how experimental measurements, computational analysis and international collaboration can address radiotherapy imaging challenges. For example, the evolution of the CBCT dosimetry project demonstrates the program's ability to adapt and respond to mentee's resource limitations. By engaging mentees in conducting surveys, refining dosimetry methodologies, and collecting imaging dose data, the program has provided actionable, practical, useful knowledge and recommendations about radiological protection practices across varying HDI levels. These findings have been included into TG-116's recommendations and highlighted areas for further optimization. Moreover, the mentorship model creates a dynamic feedback loop. Mentees experiences in experimental methods and surveys enable them to identify practical challenges, which TG members help address through iterative guidance via discussion of results through virtual meetings. For example, mentees' difficulty with accessing standard CTDI measurement equipment prompted the development of alternative methods using locally available resources, such as Farmer chambers, and water equivalent phantoms. This adaptability underscores the program's role in bridging resource gaps in low- and middle-income countries.

The mentorship initiative's impact extends beyond technical advancement. By connecting mentees through virtual meetings, the program cultivates a global scientific community, facilitating cross pollination of ideas and long-term collaborations. Several mentees have presented findings at national and international conferences, and co-authored several scientific publications [8, 10, 25], demonstrating the program's role in professional development. Additionally, ICRP's reputation provides mentees with institutional credibility, encouraging support from supervisors, employers and national organizations.

However, challenges remain. Limited resources in some regions constrain participation, and sustaining momentum

for long-term projects requires institutional buy-in. Addressing these barriers will be critical for expanding the programme's reach to low- and middle-income countries and ensuring its sustainability. Strengthening partnerships with international organizations such as the IAEA, IOMP and EURADOS could help scale mentorship opportunities and secure funding for follow-up initiatives.

Not surprisingly, the different TGs have varying needs for expertise, but the TG116 group mentees were predominantly medical physicists and the main requirements for participation were:

- Enthusiastic early career scientists seeking an opportunity to get involved in research and development;
- Participants having sufficient skill to carry out measurements or local supervisors to assist in measurements;
- A willingness of medical physics departments to allocate time for young staff to participate in a research project;
- An umbrella organisation with sufficient standing to provide credibility for any project;
- Medical physicists with sufficient experience, time, and willingness to act as mentors for applicants;
- Sufficient information technology facilities within the organisation to provide virtual communication facilities for meetings;
- Sufficient organisational flexibility to enable projects to evolve as knowledge and experience grow.

So, what are the benefits and why should people participate in the ICRP mentorship programme? These can perhaps be summarized as:

- Facilitating transfer of knowledge and experience to early career professionals;
- Giving the potential to create global scientific communities which could continue through the scientific careers of individuals in a diverse range of countries who may be able to aid and assist each other to develop and implement new ideas in the future;
- Allowing mentees to undertake measurements and generate data from institutions around the world that would be difficult or impossible through other routes.
- Overall, the ICRP Mentorship Programme exemplifies how targeted mentorship can advance scientific expertise, address global disparities in radiological protection, and inspire early-career professionals. By continuing to support mentee-driven projects and fostering international collaboration, the programme holds the potential to transform radiological protection practices worldwide.

V. CONCLUSIONS

There are many young, enthusiastic and motivated scientists around the world. The ICRP Mentorship Programme provides a valuable means through which these individuals can cooperate in carrying out tasks. Active participation in projects, especially ones that generate results from experimental measurements or computation, with back-up from a virtual forum of more experienced colleagues, can enable early career medical physicists, who may have limited contact with local medical physics colleagues, to develop their knowledge and scientific expertise. It is hoped that the ICRP mentee programme together with other strategies and initiatives can inspire the next generation of medical physicists, in geographical regions where their presence is most needed.

In the context of TG 116, the direct involvement in the process of delivering radiotherapy to patients and close collaboration with physicians means that many medical physicists are eager to participate in initiatives to improve the quality of treatment. The problem of taking account of dose from imaging is at the heart of the concerns of many radiotherapy facilities, particularly in the absence of national guidelines. The medical physics community needs to develop ways in which they can be involved in development and demonstrate the value of medical physicists in healthcare. One way of doing this is through initiatives such as those described in this paper.

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ESTABLISHMENT AND UTILISATION OF LOCAL DIAGNOSTIC REFERENCE LEVELS FOR COMMON SCAN PROCEDURES IN NUCLEAR MEDICINE

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Abstract– **The concept of Diagnostic Reference levels (DRLs) is an important tool use for optimization process in nuclear medicine procedures. Nuclear Medicine facilities are encouraged to set up their own institutional or local DRLs (LDRLs). This potentially could have a tendency of undermining radiation protection of patients undergoing nuclear medicine procedures. This study establishes LDRLs for bone, renal and thyroid scans, the three most common adult scan procedures performed in the facility. Quality control tests were first undertaken to assess the performance of the radionuclide dose calibrator and the SPECT Scanner. The International Commission for Radiological Protection (ICRP) recommended methodology was used to established the institutional LDRLs for the facility. The study established that there were 1,540 adult patients who were scanned with the SPECT system between the period January 2021 to December 2023 of which 1,240 (80.5%) were male and 300 (19.5%) were female. The study also found that the most commonly performed procedures were bone scan (1,250; 81.2%), renal scan (150; 9.7%) and thyroid scan (140; 9.1%), with mean radionuclide doses of 661±3.03 MBq, 175±1.17 MBq and 155±1.32 MBq respectively. The institutional preliminary LDRLs are proposed as follows: 483 MBq for bone scan, 133 MBq for renal scan and 86 MBq for thyroid scan. These data will guide the application of radionuclide dose levels in medical procedures at the hospital, thereby ensuring optimized procedures and improved patient protection. The Nuclear Regulatory Authority of Ghana is recommended to collaborate with relevant national professional bodies and policy makers to establish national DRLs based on the proposed LDRLs.**

Keywords— **Optimization, DRL, ICRP, LDRL, SPECT, Radionuclide, Dose, Calibrator**

I. INTRODUCTION

Nuclear medicine includes procedures for diagnosis, staging of disease, therapy, and/or tracking the progress of a disease process [1-4]. For either diagnostic or therapeutic purposes, the radiopharmaceutical given to the patient orally, intravenously, or by inhalation localizes in the target cells. One of the efficient strategies for improving nuclear medicine examinations while lowering patient exposure is the use of diagnostic reference levels (DRLs) [5]. In medical imaging, DRLs are used to show if a patient's dose or the amounts of radiopharmaceuticals utilized in a specific radiological technique are typically high or abnormally low for that radiological procedure under normal circumstances [6,7]. One of the processes in the overall optimization process is DRL setup.

DRLs are regular dose estimates for a "standard-sized patient" during a certain examination. Image-guided interventional radiology, diagnostic nuclear medicine, or treatments must abide by examination-specific criteria that are adapted to the size or age of the patient, the location of the imaging, and the therapeutic purpose in order to improve patient safety [7,8]. This guarantees that patient doses are kept as low as feasible in order to fulfil the study's clinical goal. DRLs should be defined for representative tests or processes carried out in the locality, nation, or area where they are employed

In nuclear medicine, DRLs are determined by the activity delivered per kilogram of body mass to the patient or other factors [5,9]. Therefore, the DRLs in nuclear medicine represent the degree of activity deemed appropriate for use during a typical patient assessment. DRLs are usually determined based on customary practice of administered activity at the practical levels. Hence DRL values have historically reflected the normal optimum values in this regard rather than expressing inquiry levels.

The ICRP [10] and the European Directive (2013/59/Euratom) [11] both support the establishment of DRLs to aid in the optimization of radiological investigation. Several studies have been done to establish preliminary local DRLs including a retrospective, cross-sectional investigation of various nuclear medicine procedures in southwest Nigeria which significantly improved dose optimisation in the facility as the established DRL were within the range of international best practices [12, 13]. A review of various studies on the establishment of DRL reported varied DRL values, for instance, data obtained from Gabon shows that the DRL values were greater than those from the UK but lower than those from Sudan, Kuwait, Nigeria, and Australia. However, these values were within accepted values as recommended by EU [11].

Regular monitoring, optimization and adherence to DRLs contribute to safer and more standardized approach to

medical imaging. Hence, the objective of the study is to establish local DRLs (LDRL) for common nuclear medicine imaging procedures (bone, renal and thyroid scans) at the Korle-Bu Teaching Hospital..

II. MATERIALS AND METHOD

Equipment

The study was performed at the Nuclear Medicine Unit of the Korle Bu Teaching Hospital. The equipment and materials used include dose calibrator, flood field uniformity phantom, quadrant bar phantom, Jasczcak phantom, planar sensitivity phantom and dual-head SPECT scanner. The phantoms were used to perform basic quality control to assess the performance of the equipment.

Sampling

Data of injected radionuclide activities for patients undergoing varied nuclear medicine procedures were retrieved from database of the hospital. Data on bone, renal and thyroid scans, were randomly selected for this study.

Retrieval of Research Data and Estimation of DRLs

Data on patients who had undergone the three scan procedures (bone, renal and thyroid examinations) between the period January 2021 to December 2023 were retrieved. The data covered patients' age, weight, height, scan procedure, administered radionuclide activity and gender. The study found that 1,540 patients underwent nuclear medicine procedures, of which 1,240 (80.5%) were male and 300 (19.5%) were female. Overall, data on 1,250 bone scan patients, 150 renal scan patients and 140 thyroid scan patients were retrieved.

The minimum, maximum, mean, median and upper quartile values from the collected radionuclide activity were estimated, tabulated and analyzed to determine the DRLs for the Nuclear Medicine department for the three scan procedures.

Inclusion criteria

Patients with complete data, both in the PACs and daily records were included. Both paediatric and adult patients' data were included in the study.

III. RESULTS AND DISCUSSION

Demographics of study

Figure 1 shows the percentage distribution of the Gender variation of the data collected. While Figure 2 shows that the most common protocol undertaken in the facility was bone scan (n =1250, 81.2%), followed by renal scan (n =150, 9.7%) and then thyroid scan (n =140, 9.1%).

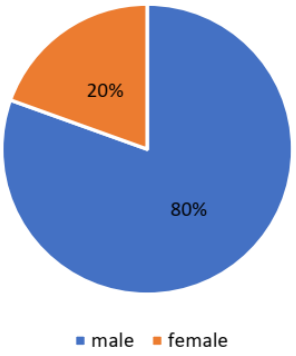

Figure 1: Percentage distribution based on Gender

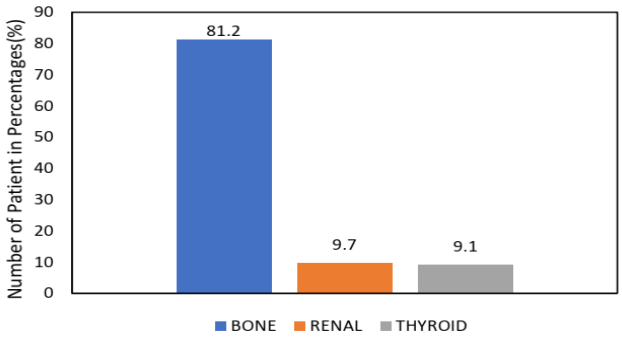

Figure 2: Percentages of Patient based on scan procedures

Figure 3 shows the attended rate of various age categories based on Adults (n =1540, 88.5%) and Paediatrics (n =200, 11.5%) distribution.

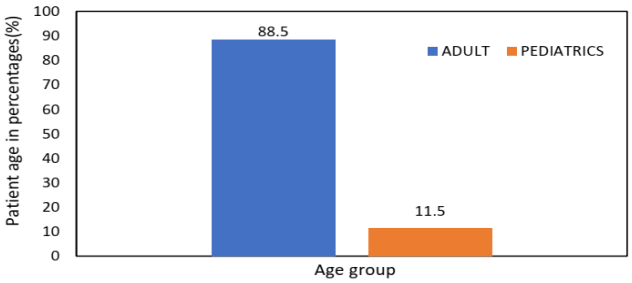

Figure 3: Percentages of Patients based on Adult (17-97 yrs) and Paediatrics (0-16 yrs)

Established DRLs

This section presents the results on age (adults and paediatrics) and administered activity for each of the protocols based on the median values.

Table 4: Radionuclide activity for common procedures

Protocol	Radionuclide Activity (mCi)							
	Adult				Paediatric			
	Min	Max	Mean	Median	Min	Max	Mean	Median
Bone scan	17.00	28.00	17.84±3.03	17.40	2.97	24.80	13.35±8.01	13.10
Renal scan	2.10	5.46	4.72±1.17	4.8	0.59	5.60	2.23±1.05	1.90
Thyroid scan	0.37	6.20	3.13±1.32	3.10	1.30	3.00	2.15±1.20	2.15

Table 4 shows the overall mean and corresponding deviation of the injected activity for both adult and paediatric patients based on the established protocols in the department. The mean adults and paediatric activity for bone were found to be 17.84 ±3.03 and 13.35 ±8.01, Renal were 4.72 ±1.17 and 2.23 ±1.05. while the Thyroid were 3.13 ±1.17 and 2.15 ±1.20 respectively. These results are comparable to a reference mean age of 17.0 ± 7.6 years for adult as published by ICRP 135, 2017 [5].

Figure 4 shows the comparison between the estimated mean administered activity of the Bone, Renal and the thyroid of adults and paediatrics patients. The results show adherence to the varied protocol of the paediatric and adult patients. In all the cases the adults mean activity were higher than those of the paediatrics patients.

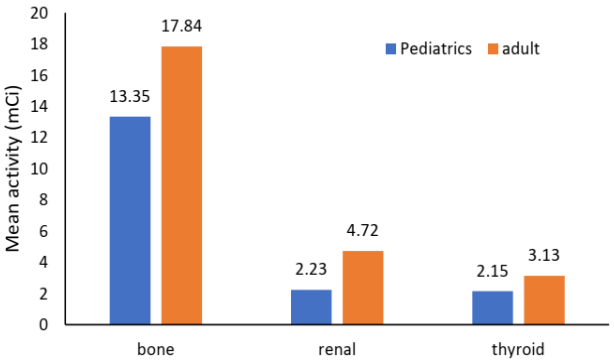

Figure 4: Comparison of mean administered activity of Adult and Pediatrics

Table 5: DRL(MBq) for most common nuclear medicine procedures in Ghana.

Procedure Name	Activity (MBq)				
	25th Percentile	75th Percentile	Max Value	Min Value	LDRLs
Bone scan	160.95	482.85	1036.00	629.00	482.85
Renal scan	44.40	133.20	555.00	77.70	133.20
Thyroid scan	28.67	86.02	229.40	113.69	86.02

From Table 5, the maximum and minimum values were found to be 1036.00 and 629.00 for bone scan; 555.00 and 77.70 for renal scan and 229.40 and 113.69 for the thyroid scan. Also, the 75th and 25th percentile values were calculated to be 482.85 and 160.95 for bone scan; 133.20 and 44.40 for renal scan and 86.02 and 28.67 for thyroid scan. Finally, LDRL values for each of the common procedures (bone, renal and thyroid scan) were found to be 482.85, 133.20 and 86.02 respectively.

The established DRL are comparable to other countries as the estimated values were within the recommended estimates. For instance, the mean activity for Bone was estimated to be 660 mCi, which is similar to published value in France 668 mCi. The estimated values were however lower than those published in Sudan, Brazil, Korea, and UNSCEAR, but was slightly higher than those published by IAEA Basic Safety Standard (BSS). Details of these are presented in Figure 5.

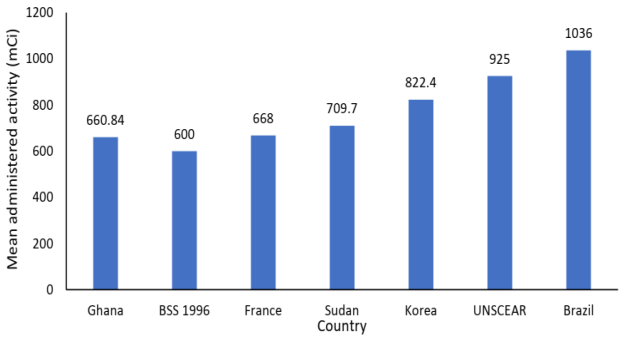

Figure 5: Mean administered activity (mCi) of 99mTc-MDP for bone scintigraphy in different countries.

Figure 5 shows that, the injected activity were within accepted range compared to other countries

The distribution in terms of 25th Percentile, 75th Percentile, Maximum, Minimum value associated with the DRL of administered activity are presented in Table 5.

Table 6: Proposed local DRL in comparison to DRLs from other countries

Protocol	DRL (MBq)								
	Ghana	Korea	Australia	Qatar	Kuwait	Japan	UK	USA	EU
Bone	483	945	920	740	944	950	600	848-1185	500-1110
Renal	133	185	200	101	200	210	80	189-289	70-183
Thyroid	86	217	215	195	185	300	80	-	75-222

Table 6 shows the 75th Percentile of administered radionuclide activity for scan procedures in Ghana as compared to other countries with administered activity for Bone, Renal Thyroid examination as 483, 133 and 86 MBq respectively. By comparison the values from Ghana were comparable to other international recommendations, for instance a recommendation from the US, proposed an administered to be within a range of 370 to 740 MBq (14) (ACR - SPR, 2014). These values are comparable to other countries including Korea, Australia, Qatar, Kuwait and Japan.

IV. CONCLUSION

The study is the first LDRL proposed for any nuclear medicine procedure in a medical facility in Ghana. The proposed DRL are Bone (483 MBq), Renal (133 MBq) and Thyroid (86 MBq). The proposed DRL values should be periodically reviewed and updated as recommended by the ICRP.

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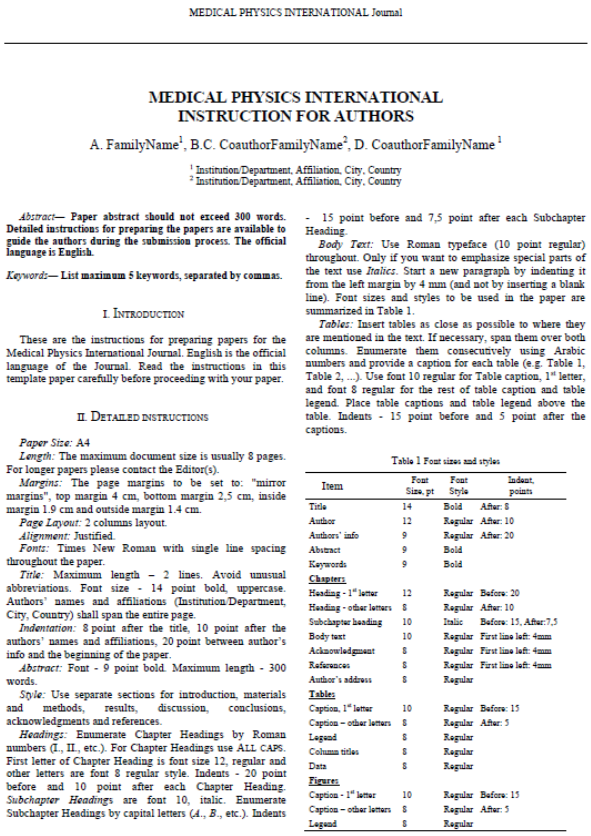

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Authors' info	9	Regular	After: 20
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Keywords	9	Bold	
Chapters			
Heading - 1st letter	12	Regular	Before: 20
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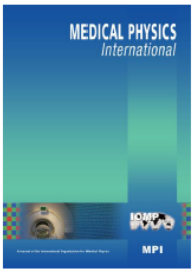

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