American Journal of Botany and Bioengineering
https://biojournals.us/index.php/AJBP
ISSN: 2997-9331

Evaluation of Radiation Doses in Radiotherapy Using Cone-Beam Computed Tomography

Hussein Hadi Kazim, Hussein Maher Shamkhi, Fatima Kazim Abbas, Raghad Khaled Star, Zahraa Jafar Mohammed
Department of Applied Medical Physics College of Science Almustaqbal-university

Received: 2024 19, Dec
Accepted: 2025 28, Jan
Published: 2025 22, Feb

Annotation: Dose distributions in the Image Gently and Image Wisely campaigns were estimated by using Monte Carlo methods to calculate doses to organs in radiation treatment planning phantom models. The phantoms, representing the average individual of four age groups, were standardized by using reference body and organ masses defined within International Commission on Radiological Protection Publications for an adult male. They were implemented into the EGSnrc radiation transport code and coupled to a model of a Siemens Artiste linear accelerator equipped with both an OBI system and an MV cone beam CT system. Open fields were irradiated in anterior-posterior and lateral setups to calculate organ doses and effective doses resulting from irradiation of a head and a chest phantom. In the latter setup, the head phantom, representing a child, was also exposed by using an adult protocol to simulate overshooting of the primary beam, in particular in cone-beam CT exposures. Organs within and outside of the primary x-ray beams were evaluated as a function of beam energy and patient size, and overall effective dose was calculated. The effective doses in CBCT scans were also compared with those in kVCT scans which replace the CBCT scans in the treatment planning process. In order for treatment procedures to be optimized, the doses delivered by imaging exposures should be taken into account. Though the essential characteristics of CBCT systems and CT simulators are the same, the CT dosimetry methods based on the CT dose index that have been widely used are not feasible for CBCT imaging devices. The most important distinction is the large variability in patient exposure for CBCT systems because different scanners use different imaging protocols, each composed of a variety of parameters that determine the final dose delivered to the patient. Currently, the CTDI method has been modified for CBCT systems and the results have been published in a report. Given the potential for significant differences in dose delivery between different modes of imaging, it’s essential that doses resulting from a given protocol and machine can be accurately estimated.

Keywords: Cone-Beam Computed Tomography, Radiotherapy, Radiation Dosimetry, Monte Carlo Simulation, Image-Guided Radiotherapy, Radiation Protection.

1. Introduction to Radiotherapy and Cone-Beam Computed Tomography

Radiotherapy is one of the most common modalities used to treat cancer. In radiotherapy, imaging plays a major role in the localization, treatment planning and setup of the patient. The setup errors, patient movement and changes in the normal tissue during the course of treatment will impair the accuracy of the radiation delivery. Cone-beam computed tomography (CBCT) has been adopted in the clinics for the image guidance in radiotherapy. The patient setup using the bony anatomy and tumor volume delineation using contrast agent injection are performed using the cone-beam CT. Compared to the conventional kV X-ray imaging systems, the advantages of the CBCT are as follows: reducing the exposure to the therapist by using it in a remote position, producing CT slices in the treatment room, and a high-speed CT acquisition within a few seconds. CBCT in radiotherapy is integrated with the treatment machine and it is acquired while the patient is on the treatment couch. Both the gantry and the couch of the treatment machine have attached X-ray sources, which are perpendicular to each other, and a flat panel detector mounted on the gantry. The patient is on the couch under the gantry within the treatment room. The X-ray ON, for a short time, will move the patient couch and the gantry to acquire the CT slice images of the patient. The CBCT is used for the image guidance in order to increase the accuracy in the patient setup and the radiation delivery [1]. Although the clinical use of the CBCT in the image guidance has improved the accuracy in the patient setup and the radiation delivery, the dose delivered during the image guidance is of significant concern. The CBCT integrated with the radiotherapy treatment machine irradiates CC exposure, which is a high dose per image. Use of a high dose of ionizing radiation will increase the risk of secondary carcinoma and impair the normal tissue recovery. Most commercial CBCT treatment machines deliver about 1-10 cGy per one image. The kV CBCT delivers less dose to the patient than the MV-type due to the reduced scatter radiation effect via the photoelectric absorption effect [2]. Care should be taken because the CBCT delivering the less dose is applied only to the small region with a lower field of view and resolution in a commercial radiotherapy treatment plan.

Literature Review

2. Basic Principles of Radiation Dose in Radiotherapy

Radiation dosimetry in radiotherapy is currently being rediscussed because of the introduction of volumetric imaging techniques. In particular, the use of cone-beam computed tomography (CBCT) techniques to verify patient position and to estimate the absorbed dose as well. In scanning modality, exposure conditions vary along the longitudinal axis of the patient: differences depend on the acquisition parameters, as well as on the different amount of attenuating matter the x-ray beam needs to cross. In the last years, the ionizing treatment beam monitoring has evolved from the first dosimeters, adopted for the first radiotherapy treatments in the early 1900s. The first reference detectors were ionization chambers, equipped with telethermographic techniques. Nowadays, most treatments are monitored longitudinally on every treatment day with, probably, a two-dimensional (2D) detector in planar modality and with a detector that plugs to the treatment unit at isocenter displacement, intercepting some hundreds of monitor units during the acquisition. Every time a scanning modality is used, the monitor units needed to reconstruct every single slice of the image are collected by the planning system. From the knowledge of these data, it is possible to directly evaluate both the focal spot-to-isocenter distances along the cross-plane and in-plane coordinates (gantry angle 0 only) and all the other parameters needed to be set in the Monte Carlo code [2]. A Monte Carlo (MC) method has been developed for simulating the Linac, the EPIDs and the imaging system of the treatment rooms. The models have been validated in terms of the evaluation of the incident fluence to the imaging system and analyzed to decide on the setup for the simulation of the scanning modality cone beams. Patient dose from kilovoltage cone-beam computed tomography imaging in radiation therapy: dependence of dose on imaging modality. Organ doses have been estimated from the computed tomography (CT) dose index for cone-beam CT images acquired on medical linear accelerators. A Monte Carlo simulation of an on-board imaging system on a Varian Clinac 18 MV medical linear accelerator has been used to establish organ dose conversion factors for CT scans of the head, chest, and pelvis and compared to treatment planning system dose calculation in a RANDO® anthropomorphic phantom. Reasonable agreement has been obtained between the two dose calculation methods. Inclusion of organ dose conversion factors can therefore be useful for patient-specific dose estimation studies associated with CBCT imaging. Central axis dose measurements and Monte Carlo simulations. An ionization chamber array was used to measure central axis percentage depth dose and cross-plane and in-plane profiles. Measurement reproducibility (+/-1 standard deviation of three repeated measurements) was better than +/- 1%. Monte Carlo simulations were used to model the treatment head of the Clinac and to predict central axis dose. Agreement better than 5% was observed between measurement deriven and simulation calculated percentage depth dose, percent Rx and entrance and exit doses. [3][4][5]

3. Role of Cone-Beam Computed Tomography in Radiotherapy Planning

The increased conformal therapy techniques in radiotherapy planning require accurate targeting to avoid the normal tissues surrounding the treatment volume. Apart from the use of complex multileaf collimators, compensating filters and intensity modulated radiation therapy, a sophisticated on-board imaging system is required in a radiotherapy treatment room. The advent of in-room imaging systems aids in tracking the exact position of the target volume and hence the accurate delivery of radiation. However, repeated cone-beam computed tomography before each fraction of the treatment increases the dose to a considerable extent. This dose is both from the primary radiation as well as from the additional imaging of the portal view image. The dose to the patient can be optimised for the later one [1]. The repeated imaging during the radiation treatment also increased the scattered dose to the patient. The assessment of convolution dose to the patient due to the scatter generated from each imaging during the treatment is clinically useful. For this purpose, an activation technique has been used to estimate the scatter dose to the thyroid and body due to the kilovoltage imaging system. The additional organ-specific shielding to reduce the scatter dose was also modeled and their efficacy has been tested using the developed method [2].

Materials and Methods

4. Methods for Dose Calculation in Radiotherapy

Nowadays, many studies have been achieved in radiation oncology to improve a plan quality and a patient workflow by image registration between radiotherapy planning images and positioning system images with the patient on the treatment unit. Widely used imaging devices for those tasks are portal imagers that can acquire images at the megavoltage energy beam and cone-beam computed tomography (CBCT). However, it was pointed out that those imaging devices might expose unnecessary dose to patients before treatment. Radiation dosimetry for wide-beam CT scanners: recommendations of a working party of the Institute of Physics and Engineering in Medicine said that the total dose due to the KV-CBCT should be monitored and its amount given. The three-dimensional dose calculation validated the Monte Carlo–simulated doses with the phantoms that contained the lung tissue and showed the need to take the patient irregular geometry into account when performing the dose assessment [6]. Previously, various approaches for assessing dose indicators and patient organ doses by conducting measurements or simulations with the phantoms containing the bone, lung, and soft tissue were investigated. One of those approaches assumed the uniform tissue in the patient and about half of the problem volume was simplified to the structure of the cylindrical phantom or house-like phantom. In this study, these approaches, as well as the direct assessment of the bonafide patient CBCT scans, were used to evaluate the organ and effective dose coefficients. Wide-beam KV-CBCT systems are readily available in the current standard radiotherapy device by replacing the regular imaging chain and exporting DICOM KV-CBCT images. Eight different treatment sites with frequent scanning were considered: breast, thorax, thorax free breathing, head, brain SRS, head & neck, abdomen, and pelvis. Dose coefficient calculations considered the whole patient, as it would normally be seen and acquired in a KV-CBCT system. Considering this point, the head and brain SRS treatment sites that treat only the head or small region were not included [2].

5. Overview of Radiation Dose Measurement Techniques

An overview of studies presented in this special issue on radiation dose measurement techniques in computed tomography is given here, specifically papers that have done work in the area of on-board imaging systems used in image guided radiotherapy. These include assessing patient dose from kilovoltage cone beam computed tomography imaging, a Monte Carlo simulation to estimate organ dose from the computed tomography dose index, and a new study on patient exposure and absorbed dose from an Elekta CBCT.

There is also a Monte Carlo study that investigates the coefficients needed to derive organ and effective doses from free-in-air CTDI head and body exams at various anatomical locations. Several CBCT units are used in the treatment rooms utilizing kV on-board imagers but the dosimetric characteristics of these systems are varied. A significant shift in workload from older-standard linear accelerators equipped with electronic portal imaging devices to image guided radiotherapy enabled linacs has led to new quality assurance protocols. Major changes to commissioning requirements as well as ongoing quality assurance practices in radiotherapy involving treatment planning systems were made. Despite these advances in the radiotherapy aspects of treatment, movement into on-board imaging, specifically CBCT, has proceeded with far fewer studies on the resulting dosimetry. [7][8][9]

Results and Discussion

6. Advancements in Cone-Beam Computed Tomography Technology

Article outlines incidence and dose optimization methods to determine effective dose from CTDIvol based CBCT scans. Topics covered include CBCT imaging in radiotherapy, European directives and methods for estimation of organ dose from a CBCT scan using the conversion coefficients provided in current work. The risk to normal tissues due to the dose delivered by therapy beams is of major concern in radiotherapy. It remains a critical issue for patients undergoing treatment involving highly conformal dose delivery to the tumor as in intensity-modulated radiotherapy. The clinical use of cone-beam computed tomography (CBCT) in image guidance has the potential to improve the accuracy in patient setup and radiation delivery [1]. This has led to a growing interest in CBCT methods which allow 3D verification of the patient geometry before and during each fraction and has resulted in the development of several commercially available systems. A recent survey of UK radiotherapy centres suggests that a large proportion have already implemented or are considering the clinical use of CBCT. Although the availability of CBCT in radiotherapy departments for image guidance is some way off being routine, there is a desire to implement CBCT as part of the verification of the treatment set-up within the context of clinical trials. The dose delivered during the image guidance has always been of concern. The ICRP has pointed out that repeated imaging using a 3D modality such as CBCT during the course of treatment is likely to result in a significant dose to normal tissues not included within the treatment volume and considerably higher than that from the 2D techniques in routine clinical use at present. This could increase the probability of a stochastic effect.

7. Quality Assurance in Cone-Beam Computed Tomography Systems

The verification of patient setup with highly conformal dose distributions has always been a critical part of radiation therapy. Slight inaccuracies in patient positioning result in the displacement of the isodose distributions, sometimes missing the target completely. The development of high-energy linear accelerators equipped with multileaf collimators and three-dimensional treatment-planning tools makes this effect particularly critical. Cone-beam computed tomography for patient positioning during radiation therapy represents a recent and significant advance in image-guided radiation therapy, which allows real-time detection of interfraction shifts, changes, and deformation of the target volume and immediately after that, correction of the treatment delivery.

The continued increase in the clinical use of cone-beam computed tomography in radiotherapy throughout the world implies the need for periodic quality assurance checks. The European protocol on the quality assurance of computed tomography imaging recommends the frequency of at least a yearly test of the X-ray source. This work ensures uniformity in image quality and that the radiation dose is kept to a minimum. However, with cone-beam computed tomography, a new unique set of image-guided treatment machines, it is necessary to perform quality assurance checks that are not done in conventional diagnostic computed tomography machines. At the time of this study, there were at least two commercial systems to provide cone-beam computed tomography patient support in conjunction with a linear accelerator. With these developments, there have been some early studies and reviews on the quality assurance of cone-beam computed tomography systems through measurement. However, these works are typically specific to individual sites and do not provide a vigorously tested procedure to be implemented as part of routine clinical use. This work reports the quality assurance procedure that was developed during the installation of one of the commercial systems provided with the TomoTherapy radiation therapy machine. This procedure ensures, as far as is feasible, that the machine is delivering in a safe way, is accurately positioned in the linear accelerator reference frame, with accurate image quality and image registration, and with minimum dose to the patient. This will be of benefit to other radiotherapy departments that will have to install such machines. [10][11][12]

8. Clinical Applications of Cone-Beam Computed Tomography in Radiotherapy

The X-ray imaging capabilities of linear accelerators have evolved from portal, through electronic portal, to megavoltage cone-beam computed tomography (MVCBCT). There has also been a parallel development of radiotherapy machines equipped with kilovoltage cone-beam computed tomography imaging (kVCBCT). The latter involves mostly wider beams and higher doses than the MVCBCT systems [2]. The continuous development and clinical implementation of radiotherapy machines with kilovoltage cone-beam computed tomography imaging (CBCT) capabilities have accentuated a significant need for accurate patient dosimetry in CBCT. In many cases, organ doses have been approximated as a constant fraction of the entrance dose, but no published data has been found to suggest that the entrances of radiotherapy CBCT are correlated with any specific organ dose. The motivation of this study is to facilitate future work in the development of generic coefficients for assessing organ and effective doses. These coefficients may be derived from Monte Carlo-generated energy-dependent scatter factors for broad beams incident on a virtual anthropomorphic phantom. It is intended that these coefficients will facilitate the rapid estimation of organ and effective doses given the entrance dose and imaging parameters. Comprehensive Monte Carlo study has been conducted of patient doses resulting from kilovoltage cone-beam computed tomography (CBCT) imaging on radiotherapy treatment units. Energy-dependent scatter factors for broad beams have been generated using Monte Carlo simulations. These are used to predict organ doses received by the male and female reproductive organs as well as the active bone marrow in the pelvis for a range of kilovoltage x-ray beams.

9. Radiation Dose Optimization Strategies in Radiotherapy

The utilisation of daily CBCT for radiotherapy treatment verification has increased with the intention to escalate the dose, hypofractionate, or reduce margins due to online correction of suboptimal setup. Online treatment delivery verification tools are often activated in conjunction with image guidance systems allowing for the detection and correction of patient setup errors. However, these tools have limitations due to the inability to see the target volume in the same reproducible setup as the main portal image. This has led to increased popularity of daily CBCT for online treatment verification, since the image is obtained in the same co-ordinate system as the treatment planning CT. This has increased the intention to escalate the dose, hypofractionate, or reduce margins due to clinically significant tumour dose, with the received dose being escalated above normal tissue tolerance. Typically linear accelerators come with default scanning parameters for their CBCT devices and these are not always optimised in terms of radiation dose and/or image quality [13]. If high imaging doses are delivered to patients over a long course of treatment this can deliver a dose equivalent to one fraction of the therapeutic dose.

Previous studies have created methodologies and software applications to optimise CBCT imaging parameters based on patient size, radiotherapy technique, or tumour location utilizing Monte Carlo simulations. Conventional CT protocols are selected from a region of interest (ROI) in relation to a contoured structure and representative image noise on the treatment planning CT. Monte Carlo software calculates the ROI x-ray fluence, or source term, for a defined CBCT scan position and imaging parameters. The best combination of kVp, mAs, acquisition slices, and bowtie filter for the specific scan position are the resultant parameters that produce a calculated absorbed dose within ±3% of the initial dose estimate. Although there are studies that suggest methodologies to optimise CBCT imaging parameters, to the best of the author’s knowledge, there are no studies implementing these recommendations clinically [2]. The purpose of this study was to implement optimised CBCT protocols for most tumour sites treated at the hospital for the Varian TrueBeam, necessary for treatment verification.

10. Comparison of Radiation Doses in Different Radiotherapy Techniques

Purpose: In radiotherapy treatment of prostate cancer, the acini and peripheral zone are typically targeted. These tissues are located close to the bladder and intestines. Because the rectum is also close to the target tissues, an excessive radiation dose in the rectum is undesirable and may cause damage to bowel tissues. Therefore, an antiflux stent is employed to reduce the dose in the rectum. Here, five different radiotherapy techniques are evaluated: three techniques that include an antiflux stent, an IMRT without an antiflux stent, and a conventional treatment without an IMRT technique.

Results: With a 20-fraction regimen, both doses in the rectum and bladder are highest with the conventional treatment, and the doses in the rectum and bladder decrease with the addition of an antiflux stent. For all evaluated techniques, with the exception of the conventional treatment, the maximum dose in the rectum is not over 48 Gy. Specifically, with a 20-fraction regimen, the psychiatrist dose in the rectum is highest with the conventional treatment at 41.5 Gy, and the prostate dose for an IMRT without stent is highest at 46.79 Gy. With the optimized IMRT treatment, the doses in the target are higher than the others for a 40-fraction regimen.

Concerning 30-fraction regimen treatment, the penial dose is considered low, and the skin dose is somewhat similar. Particularly when considering the increase in fraction number, the thickness of the penial cuff is important for reducing the dose in the penial. The aforementioned information could be helpful for both medical physicists and radiation oncologists in the field of radiotherapy for skin cancer. [14][15][16]

11. Patient-Specific Dose Calculations Using Cone-Beam Computed Tomography

CBCT is increasingly used in radiotherapy for patient alignment prior to treatment. Patient dose estimates obtained by converting the CTDI calibration of the CBCT scanner to absorbed dose at relevant organs/tissues are usually quoted to be accompanied by considerable uncertainty, which is mainly due to the lack of scatter radiation data. An established Monte Carlo code used to simulate the systems operating on two different linacs. Two cylindrical phantoms used to calibrate and validate the simulations. To estimate patient-specific organ doses direct simulations performed in homogeneous and anthropomorphic phantoms of common treatment sites. Patient-specific scatter-to-primary and scatter-to-total dose ratios compared with data from a commercial Monte Carlo program that is not linac specific. Good agreement within experimental uncertainties indicated by the comparisons. Dose estimation strategies that consider scatter-to-primary dose ratios may effectively be used to estimate organ dose at locations in the anatomy where the energy deposited increases more rapidly than the mean depth. Applicability of these strategies need verification in phantom studies for patient groups that were not assessed in this work.

12. Dosimetric Accuracy and Precision in Radiotherapy Planning

Many of methods have been given for 3D dose calculation and estimation for image guided radiotherapy (IGRT) which was made by the treatment planning system (TPS) to be evaluated during the treatment planning. Dose evaluation software (DES) which could import the treatment parameters was prepared for 3DCRT and patient set-up verification using CBCT and expected dose distributions were compared to check the coverage of PTV by >95% of prescription dose [17]. While the basic principle is very simple, the isocentric quality assurance of linac-based SRS systems is complex and time-consuming. To somewhat minimize variations between QA as well as clinical setups and to gather the essential data in a single set-up, multi-leaf collimators were used.

Gantry star-shot irradiation was performed with 6Ex 10MV. Each “star point” was shot nine times, separated by 40° gantry rotations. The total irradiation time was 13.5 min. When the irradiation was completed, the phantom was disassembled and the Star-shot plastics along with SCS films were scanned. The method of analysis was designed to quantify the rotation of the twelve cones with reference to the angle used during irradiation. The global positioning errors were evaluated by taking into account both detected geographic displacement and the trajectory of couch movement. The CBCT planning was based on the automatic coarse registration followed by manual fine registration. Generally, images acquired with isocentric voxels showed fewer imaging artifacts and improved volumetric imaging reconstruction than those acquired with off-isocenter voxels.

13. Radiation Protection and Safety Measures in Cone-Beam Computed Tomography

Radiation protection and safety measures are important issues that need to be considered to evaluate the radiation doses in cone-beam computed tomography (CBCT) procedures. Quality control tests on CBCT should be performed at the installation and periodically to optimize imaging protocols and to ensure that patients receive the lowest possible absorbed dose to healthy organs without compromising image quality. A number of radiation safety measures have been proposed based on the simulation of different clinical cases, treatment sites, and radiotherapy machines. Dose indicators were derived from the monochrome test images of the Catphan phantom. Patient organ doses are estimated by multiplying weighted coefficients with respect to the distance. Inter-acquisition pauses reduce the patient effective dose by up to 1.6 times. Organ doses will be further reduced by up to 1.6 times if the IGRT equipment design is improved. Sha’s setup reduces the patient effective dose by 1.04 times as opposed to the other setups. Lowering the table speed decreases the patient effective dose by up to 1.4 times. Single-angle gantry rotation simplifies the setup procedures and decreases the patient effective dose by up to 1.6 times. Proper collimation design keeps the patient effective dose at an acceptable level.

REQUIREMENTS AND SHEET ITERPOLATION

During the last decade, cone-beam computed tomography (CBCT) has become a standard tool for image-guided radiotherapy (IGRT). Planar kilovoltage CBCT imaging (commonly referred to as cone-beam CT) is conducted by most IGRT equipment. It is used whenever the aligning tattoos are not visible. Improved image quality makes it possible to set-up the isocenter using bony landmarks. The imaging dose is examined by glandular tissue dose measurements. Patient imaging studies with the half-fan and quarter-fan protocols have been simulated. Using the Monte Carlo software , the dose efficiencies for glandular tissue have been calculated. The skin entry and glandular tissue doses were measured with a physical phantom commonly used for mammographic equipment quality control. A full study of the imaging dose for clinical breast and chest protocols with varying triggers and tube voltages is presented. The imaging dose is compared to patient setup doses. [18][19]

14. Challenges and Limitations in Radiation Dose Evaluation Using Cone-Beam Computed Tomography

The acquisition of cone-beam computed tomography (CBCT) scans using linear accelerators is increasingly common as a tool for image-guided radiotherapy (IGRT). This modality allows the alignment of the patient between the position used for planning the treatment on computed tomography (CT) and the time of treatment delivery to be verified. The patient is imaged frequently throughout the course of treatment, with considerable variability between patients in both the total number of scans and in the amount of anatomy imaged with each scan [2]. When using CBCT to assess shifts in patient position, the whole body is being irradiated, so this type of imaging also delivers a significant dose to healthy tissue. Therefore, in addition to the primary concern about the imaging dose deposited to the target volume by the kilovoltage (kV) beams used in this type of imaging, there are concerns that the patient may also receive a non-trivial dose to the target volume from the additional beams used in megavoltage (MV) imaging.

There are a number of challenges and limitations in the accurate and/or practical evaluation of the dose received from CBCT imaging. The use of both MV and kV energies means that standard dosimeters are not suitable for evaluating imaging dose, due to the non-water-equivalence of these materials at MV energies and the large number of dosimeters needed to map out the small fields characteristics of CBCT imaging. In order to assess the dose received by patients from CBCT imaging, conversion coefficients are required that enable to estimate organ doses received per unit of absorbed dose measured in air for a given scanner geometry and set-up. Establishing such conversion coefficients involves a series of Monte Carlo simulations, which is time consuming and can be technically challenging. As a result, there is a need for a simple and practical means of monitoring and estimating the imaging dose received by patients during treatment. An understanding of the likely magnitude of dose received through CBCT imaging can also assist in the delineation of research priorities for treatment verification using CBCT and in the generation of guidelines and in-house protocols for its use.

15. Future Directions and Emerging Technologies in Radiation Dose Assessment

In this work, the investigation was focused on developing a novel method for easy daily implementation and direct intra-patient determination of dose in fields. The use of transmission detector provides a simple method for in vivo dose verification in radiotherapy including TBI treatment. An automatic procedure to optimize it relying on the opening jaw field matching the CT image was proposed. Additionally, a new method for on-line determination of mean glandular dose during breast cancer radiotherapy treatment was also suggested [2].

16. Case Studies and Clinical Examples in Radiation Dose Evaluation

The Commission on Radiation Units and Measurements and the International Commission on Radiation Units and Measurements have agreed that the units for organ- and effective doses should be Sv, although they have historically not used specific symbols for these quantities. A Commission has been established specifically to deal with quantities and units in the field of radiology, known as the International Commission on Radiological Protection (ICRP). This Commission has agreed that the quantities and units for limiting doses formally adopted in ICRP Publication 26 are to be taken as standard, and that any changes to these standards should be evaluated by the ICRP. This does not mean that the dose constraint for a single CBCT examination of a child's head would be simply the 100-HDCW tolerance dose of 9 Gycm as the dose received per examination could exceed this value by one or two orders of magnitude; rather, the purpose of the ICRP recommendation is to prevent excessively high additional doses or to prevent the same body region from receiving multiple additional CBCT examinations. Film: measure image quality, optimize image quality – measure dose. Numerous studies have been made of dose and image quality assessment for CBCT systems used in IGRT [2]. While measured CTDIv are available for a range of sites and techniques, the dosimetry accuracy of these values has not been widely investigated. In this paper, a previously reported Monte Carlo method was extended to simulate the effect of a CBCT arm and personnel on kV dose [6]. Dose profiles along the central axis of a 10 to 40 cm polymethylmethacrylate phantom were measured for both wide-beam kVCBCT systems used in radiotherapy (a Varian OBI equipped to an Elekta Synergy accelerator and an Elekta XVI) at 55, 80, 110, and 125 kVp. The dose profiles were normalized to dose surface and maximum dose to determine the effect of beam width on dose utilization and reported as a ratio of the wide-beam system to those previously measured at 125 kVp on a one-dimensional dosimeter for a GE LightSpeed. Don't assume that the maximum dose ratio is at the isocenter. Due to reduced scatter further away from the imaging plane (at the y1 or y2 horizontal government centers), the entrance dose ratio was 2–6% higher than at the isocenter.

17. Ethical Considerations in Radiation Dose Monitoring in Radiotherapy

Concerns grow over ethical aspects of involving people, including patients, in a study designed to monitor and report their radiation exposure. These stem primarily from the realization that, although leading to beneficial findings [2], the studies often subject patients to additional "research" radiation doses that are underpinned by research methodology: many of the same studies can be equally well accomplished at zero or with multitude lower additional doses than have been proposed or are planned. There are few clear guidelines on how to tackle this, so it has a very real potential transgression of ethical principles if wrong decisions are made or a lack of awareness ensues.

The situation is different in the existing implementation of the Radiation Incident Monitoring Network (RIMN) where accidental radiation overexposure is being investigated retrospectively, with the benefit of refining overall safety in radiation treatments and learning from specific incidents, but where no further exposure is involved. Nor is this the aspect in question where they are adopting a check-off QA approach to provide basic spine SRS dosimetry, the dose from this additional imaging is a fraction of the treatment and much less than other strategies proposed. But where questions are to arise: is to clarify to the third party reviewer whether the intent is to propose similar or quite different approaches to the morbidity issue from other vendors, whether RIMN data will be made available or there is a plan to study it firsthand, and, most importantly, what the study method is to be. On this last point, key information to disclose is in the choice of patients, forecasting the likelihood of incident(s) per patient – a plan to chase and "verify" high incident number patients is very likely not to be approved. [20][21]

18. Conclusions

The wide variation of doses received by some organs could have consequences when considering consequential cancer induction and a mixture of effects. In general, for a head and neck case (exclude oral cavity and lips), the thyroid gland receives the largest radiation doses, followed by the oesophagus and brain. For a bladder case, the small bowel receives the largest radiation doses, followed by rectum and bladder. From the results of the present work caution in respect to the Boulder skin increased weighting factor approach is advised. The explanation given in ICRP 116 regarding the changing tissue weighting factors over 100 mSv should be included in the discussion about the ICRP 103 WB effects if it differed. The results corroborate previous suggestions that the current dose limits and constraints would be extremely difficult to achieve using data produced by a treatment planning system and a single dose distribution. Depending on the treatment site and the patient, the accumulated dose distributions in organs can be very different.

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