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Dosimetry and Quality Assurance in Radiotherapy

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Annotation: Product quality is loosely defined as all the attributes and features of a product that influence its ability to meet the needs of the consumer. The term quality assurance or QA encompasses all of the practices, systems and criteria that ensure a product consistently meets the necessary quality requirements. In radiotherapy, the product being delivered is the intended dose to the patient. The assurance of this quality is typically achieved by the accurate, precise and reproducible execution of . The process of radiotherapy involves a series of complex processes and steps, including the architectural setting of the beam, the calibration of the treatment device, Imaging for the purpose of verification and localization, treatment planning, and finally the delivery of treatment. Each of the above-mentioned processes has the potential to introduce error and deviation in patient dose delivery. In order to ensure that patient safety is paramount and that the prescribed offering is delivered both accurately and accurately, good-quality quality assurance (QA) practices are needed. Furthermore, record and review the acceptability of each treatment field before the patient is treated. It is a guide before and during treatment to determine how well the planned therapy

session will be accurately and accurately administered. Two arms of this standard are the measurement of portal doses and the reconstruction of calculated doses (verifiable from portals). In this study, methods of dos variance detection of off-line portal doses were evaluated. In addition, the results of experiments investigating the portal dose were reported and compared with the results of such experiments in the literature; many of which are focused on planar dosimetric software analysis rather than the analysis of portal pixel values directly. Finally, the importance of seeds is lower and the seeds are high in beam orientations and the noise in the seed distribution is lower.

Keywords: treatment device, radiotherapy, seed, treatment planning, QA.

Introduction

1. Introduction to Radiotherapy

A comprehensive QA program should be in place in every radiotherapy department. Professional staff should have appropriate education and training. Staffing levels should be adequate to ensure safe and accurate delivery of the radiation doses. There are eight critical recommendations made by the [2]. These recommendations are intended to enhance safety by ensuring that the treatment dose to a patient is delivered as prescribed with minimal errors and maximum dose uniformity; therapy localization and verification are also essential for treatment safety.

The management of dynamic 3D conformal radiation therapy and intensity-modulated radiation therapy treatments using the dynamic MLC technique requires the machine QA of MLC related mechanical, dosimetric and dosimetric verification of individual fields and dose computation algorithm at all possible and critical field sizes and modulations. The twenty-two anisotropic analytic algorithm test plans and therapeutic test plans were used to verify the accuracy of the radiation treatments in four varieties of modern machines. The mean and standard deviations of the differences between the measured and TPS calculated doses for all the beams were found as 0.4% ± 1.4%, -0.6% ± 1.7%, 0.32% ± 0.6% and -0.18% ± 0.65% in Varian Clinac 21EX, 2100C and iX machines and 25EX machines, respectively. The observed deviations in the dose profile, output factors and PDD were well within the tolerance levels, which can be used to ensure the high confidence on the quality of oncology works [1].

Literature Review

1.1. History and Development

The delivery of a planned radiation dose to the tumour with less dose to normal tissues has become more achievable with the continued development of diagnostic imaging, treatment planning and radiation beam delivery technology. Most of the technological advances during the 20th century have been in linear accelerator technology. The technology of linear accelerators has progressed, partly because of the need to replace obsolete and used equipment and partly because the need for more specialized systems has emerged. This document is designed to indicate those key components or topics that should be covered when purchasing a radiotherapy system and to provide a template specification. It does not include a formal specification and should be used in

conjunction with available formal specifications [2]. Also included is a general overview on the history of radiotherapy, as the past has shaped current practices in the systems used, types of radiation in use and the configuration of treatments rooms. With radiotherapy rapidly growing in every region, it is essential that quality, safety and standards be maintained. It is expected that the typical reader of this document will be a physicist, oncologist or engineer with a role in radiotherapy, but it may also benefit health administrators, hospital managers and procumbent officers. The role of dosimetry audit in the implementation of radiotherapy is to ensure the successful transition of technical work and procedures into safe practice for the treatment of patients. This requires that the purchaser has appropriate equipment and facilities, equipment is installed and commissioned correctly, and professional staff are adequately educated and trained [1].

1.2. Basic Principles of Radiotherapy

Radiation therapy is the controlled use of high energy X-rays, gamma rays, particles or radiation that is targeted at a part of the body to treat a disease or condition. Radiation therapy may be used to cure or control primary disease, to improve the symptoms caused by the disease, or to provide palliation (relief of suffering) [2]. The intention is to disrupt the reproduction and spread of the abnormal cells, in this case the tumor. Radiation treatment can be given in a curative or palliative intention, either alone or in combination with surgery and/or other modalities such as chemotherapy. An important feature of the treatment is that the target (gross tumor volume) must be situated in structurally crucial sites in the body, such as in/around the base of the skull or in the spinal cord area. For this reason, a high precision during dose delivery is needed. Dose limiting organs at risk to be avoided are typically nerves such as the optic nerves, or normal brain and the brainstem. The precision of the treatment can be increased by using high-tech radiotherapy techniques involving precisely shaped fields and multiple treatment beams. Such advanced treatment techniques increase the complexity and the need for stringent QA procedures [1]. With the advent of new imaging techniques these are often incorporated to identify the target and the organs at risk. The combination of different imaging techniques for target visualization and the new radiotherapy techniques for dose delivery make the overall treatment highly complex. In addition, the treatments are more time consuming for the patient. The challenge is to guarantee an extremely high safety and quality level, even during daily routine delivery. Hence, procedures have to be put in place to ensure that all new equipment or procedures are safe and able to give the cure dose and function as intended. Three fundamental principles are needed to be applied to ensure the dose is given to the target with a high precision: correct diagnosis, correct treatment plan and correct dose delivery.

Materials and Methods

A radiotherapy treatment chain starts with patient referral and examination of the individual to see the clinical condition and to decide how the patient can be best treated. Following the diagnosis, careful treatment planning has to be done. The patient has to be carefully set up on the treatment table before the radiation treatment can start. Finally, the radiation dose has to be delivered as planned to the target with high precision. There are several developing modern radiotherapy techniques where an advanced imaging system is an intrinsic part of the system by which the beam is associated directly to the imaging system. This technique uses a combination of beam’s-eye-view portal imaging or volumetric image set and required to treat the disease site with a high accuracy. From all this technological advancement such as IGRT; IMRT; EPID; and DBSI are always an integral part. This in turn enhances the accuracy of dose delivery to the target and it influences the complicated setup verification and validation.

Results and Discussion

2. Dosimetry in Radiotherapy

Radiotherapy is widely used option to the management of malignant tumors. It has evolved from

conventional to sophisticated treatments. The advanced technological approaches require careful dosimetry before commencement of treatments. This paper discusses about the need for dosimetric verification, consistent with the recommendations of the ICRU report, and the dosimetry procedures adopted prior to the start of intensity modulated treatments with the aim of a subsequent smoothing of the verification workload. Detection of dose delivery deviations is essential and the recommended methods are common for radiotherapy. It is achieved through the use of routine monitoring and testing methods and aspects of clinical dosimetric QA common to all radiotherapy modalities.

A retrospective study has been done on the results of dosimetric quality assurance (QA) of 3127 modern image guided 3D-conformal radiotherapy treatments. In addition, a prospective study on machine and patient specific quality assurance of intensity modulated treatments for a patient number of 480 has also been carried out. Linear accelerator-based image guided radiotherapy treatments demand the highest level of accuracy in patient positioning as well as in the finished radiation dose delivery. Conversely, there are more opportunities for error introduction compared to conventional treatments. The most common faults are treatment delivery to a wrong patient or wrong part of the patient, and a change in the number of monitor units due to unequal field split, incorrect energy selection, MLC controller error or software error, especially in complex treatments [1].

2.1. Radiation Units and Measurements

Background to the modern external beam radiation therapy (RT) implies high technological development and complicated treatment delivery setups. Intensity modulated RT has brought in a whole new set of complicated equipment (multi-leaf collimators). As with any technical equipment, computerized or not, there will be limitations and issues with daily use. Because of the fact that RT can cause great good (cure tumors) or great harm (normal tissue damage), a precise quality assurance (QA) program is necessitated for all aspects of RT treatment to guarantee correct delivery of the intended dose to the right location at the accurate time [3]. This includes QC of the treatment machines, imaging and localization devices, treatment planning systems, dose delivery, as well as the treatment of the patient. There are well-established and published protocols for the majority of elements in a total QA Program, but in vitro means for the verification of the treatment planning systems' part in the chain suffer in the clinic – perhaps of the labor-intensive nature, or the fact that independent verification of the dose planning is hard, perhaps needs 3D treatment planning.

2.2. Treatment Planning Systems

For complex radiation therapy treatments, such as high-dose ablative treatments or highly conformal treatments such as volumetric-modulated arc therapy (VMAT), it is necessary to have confidence that the dose delivered to the patient is as prescribed in the treatment plan within the manufacturer specified mechanical and dosimetric tolerances. Quality assurance (QA) for radiotherapy equipment is an essential part of the delivery of high-quality and safe treatment to the patient. This requires use of various dosimetry, mechanical, and imaging-based procedures to validate the modeling in treatment planning systems. COMP recommends that in-depth quality control of treatment plans is performed at least annually [4]. Most modern commercial helical tomotherapy treatment planning systems (TPSs) can calculate and present IMRT QA plans. To validate the IMRT QA plan and delivery using phantom-based measurements, it is necessary to either purchase a phantom from the TPS manufacturer or clinically develop a means of dosimetric verification. There may also be limitations with commercial phantoms that give rise to inaccurate QA.

There are a number of small fields of treatment proposing to use the beam model, and the risks and challenges this entails. Apart from typical pretreatment patient-specific verification of monitor units (MU) or planned dose calculation, the accuracy of dose and place delivered and the modeling in treatment planning system (TPS or QA measurement hardware) require independent validation.

There are a number of complex patients that are either high-risk treatment or very high (or low) dose per fraction that would benefit from independent validation of the treatment plan. Monte Carlo simulations are considered the 'gold standard' for 3D dose validation on dose studies done retrospectively [5].

3. Quality Assurance in Radiotherapy

Quality assurance (QA) in radiation therapy is defined as the set of procedures, which when applied appropriately, will assure a consistent and safe fulfillment of a radiation oncologist's prescription to a target volume with the maximum sparing of normal tissues [6]. This goal can be achieved only through a system approach that encompasses the patient therapeutic process in an extensive and exhaustive manner. Every step included in the process may introduce a systematic error that could hamper reaching the final goal. Thus, QA should play a significant role at all points. Though its importance is widely recognized, both its extent and practice can vary widely.

AAPM's Report No. 13 defined radiation therapy as consisting of two different but closely linked components: Clinical component and Technical component. Clinical aspect addressed such issues as therapy implementation, therapeutic prescription, patient conditions, and response to therapy. Physical aspect dealt with the "means" by which the clinical component was delivered, stating the machine characteristics, beam calibration, dose computation and treatment geometry. Since the publication of this report, radiotherapy has undergone a remarkable evolution. Nevertheless, the physical part of the report remains the sole document issued by AAPM to date; thus, focusing the physical tests and procedures necessary for the delivery of the prescribed dose. Providing a coherent revision of patient management, set-up and immobilization procedures, CT-simulation compliance, etc., was beyond the scope of the AAPM document. It must be always recalled that a thorough QA document shall also embrace several clinically relevant recommendations: those regarding the clinically acceptable uncertainties in dosimetric procedures, as well as those concerning the tolerances for both the mechanical alignment of the treatment equipment and the general compliance with the treatment planning criteria.

3.1. Equipment Calibration and Commissioning

Dose delivery accuracy in intensity modulated radiotherapy (IMRT) can be affected by many inter-related factors such as leaf positioning, dose computation algorithm, multi-leaf collimator (MLC) transmission, dose rate, delivery time, gantry angle and patient movement. To ensure a high level of confidence in the performance of medical linear accelerators for the intended purpose, there is an obligation to verify the quality of dosimetry system. The Code of Practice has recommended that medical linear accelerators for photons and electrons are to be calibrated initially under reference conditions and that the delivered absorbed dose to water can then be derived. This Code of Practice is a revision of a previous Code of Practice for the same radionuclides. However, besides calibrations, the Code of Practice also defined the additional parameters that related to specification by manufacturers of inadequately designed beam characterization data. A result of the co-structuring of polymer gels is the production of macromolecular weight polymers. This qualitative discussion suggests that a one-stage process has only a calibration parameter, but one could still proceed with spatial dose response calibration and use the analytical method described here for evaluating the dose response of subsequent samples. In the workplace, where hazards cannot be eliminated, arrangements should be made for monitoring the health of the workers, whether this is done through established health infrastructure or through medical surveillance programmed by the relevant authority. Any proper operation, maintenance or calibration of equipment should be recorded and aggregated data should be statistically analysed; the results of analysis should be used as the basis for remedial actions. Measures should be taken to ensure that doses are within the specified limits and that protection standards are not exceeded. Efforts should be made to minimize background radiation and occupational exposure; workers and pregnant women who could be at risk are limited. The results of the monitoring should be reported to the competent authority and communicated on an individual basis between the licensee and the

workers; their family members should receive counselling and training when appropriate.

3.2. Patient-specific QA Procedures

Pretreatment patient-specific quality assurance (PSQA) protocols are an integral component when proton therapy facilities plan to treat their first patients. A simpler phantom-based approach is typically used to rapidly verify the output of the system, but this does not ensure accurate dose deposition at the distal end of the proton beam. More advanced patient-specific checks ensure independent verification of the dose distribution on the treatment plan and the detector according to the patient during and after treatment. The formalism used to independently verify the calculated dose is important. Ongoing dose verification comparisons demonstrate that the Monte Carlo dose calculations used at this institution are approximately 3% accurate. Most proton treatment planning systems use analytical dose calculations, which makes PSQA based on measurements at the treatment isocenter more critical than for photon therapy. Careful experimental verification is required to guarantee the precision of the spot position handed by log files [7].

Proton therapy has been shown in many cases to reduce the risks of late effects of normal tissues due to its ability to deliver high selective doses to tumors, while simultaneously decreasing the dose to surrounding normal tissues. However, compared to photon therapy, due to the physics of dose deposition, proton therapy is generally more sensitive to anatomical changes and is more challenging in calculation and delivery. For combined photon-proton plans, errors specific to the proton plan may not be detected during the validation of the hybrid. Discovering an undesired discrepancy after the patient has already started treatment, will interrupt an ongoing fraction on their treatment schedule. This will lead to reduce the accuracy of the treatment delivery, increasing the risk of complications, and potentially reducing the patient's chance of a cure. For these reasons, it is important to develop an efficient and effective pretreatment QA program [8].

4. Emerging Technologies in Radiotherapy

Introduction. Rapid technological advancements in radiotherapy have made treatment delivery more complex and precise. Along with these improved treatments, new systems have been developed to verify the accuracy of treatment planning and delivery. One such system, the helical tomotherapy quality assurance device (HT-QAD), was recently commercialized. Other devices currently used for verification of intensity-modulated treatment delivery are the heliodosimetry verifiers, film dosimetric verification systems, and the ArcCheck™ diode array. However, these devices only verify the static dose distribution for one static beam angle at a time. Modern treatment delivery, such as state-of-the-art technologies like RapidArc™ intensity-modulated arc therapy (IMAT), volumetric modulated arc therapy (VMAT) and statseodynamic (helical) treatments, deliver dose over an extended period and/or over several beam angles. There is currently no commercial device for the verification of such dynamic delivery for the new generation of radiotherapy systems.

Initial investigations. [9] The 4DIMRT/SBRT QATD prototype was composed of a mouse phantom mounted on a piezoelectric vibration platform that was connected to a pressure belt that monitored longitudinal respiratory motion. Tomotherapy treatment plans were delivered to the phantom, and time-resolved absolute dose was measured using an ionization chamber and time-binned measurements with a diode detector that were moved in synchrony with phantom motion. Subsequently, absolute dose was determined for motion-inclusive composite two-dimensional detector arrays. Plans were generated for helical tomotherapy treatments using a phantom with and without programmed motion in the SI direction. However, CNR was created on the phantom using a docking structure to test other LINAC-based 4D IMRT/SBRT.

5. Future Perspectives in Dosimetry and QA

Since the 1970s, the use of radiation therapy in the fight against cancer has been continuously increased in industrialized countries. The introduction of external beam accelerators which combined with modern image guidance and treatment planning systems have increased the

accuracy and allowed complex treatments able to maximise the tumour control and minimise the dose to the healthy tissues. These treatments, which can be still modelled and improved, are essentially mathematically calculated treatments. The availability of the big computational capacity and 3D medical image capable of representing with great accuracy the internal human body allowed the development of treatment planning systems capable of plan and complex treatment in very few minutes. The delivery of these computed treatments involves complex machines that during the process of irradiating a patient could encounter a failure causing a potential severe situation. The scientist calls these situations systemic errors or undesirable variances and the complex interactions between the organs and the therapy delivery can create a large spectrum of cases [2]. A variety of documentations of such happenings have been collected from the 2000s. Summing them, a couple of lessons learned are worth mentioning. These might prompt to a further development and optimisation of the control and verification of the dose delivery, and to avoid potential severe promises for the client. Actions are essential for progress of performance. Every failure, even if successfully managed, should be analysed at a profound level of detail in order to understand the root causes and how the safety provisions were activated. It is worth to notice that the thorough analysis of such occurrences often results in the finding of severe shortcomings.

6. Conclusion

Appropriate dose planning and accurate dose delivery is necessary for successful radiotherapy treatment. However, success of treatment will not be achieved where the prescribed dose does not conform to the intended dose plan. This in turn depends on appropriate standards of quality assurance of the radiotherapy treatment process, its planning and delivery [2], and on the accurate calculation and delivery of the radiation dose, verification of treatment and the correct set up of treatment fields and patient.

There are different methods of dose delivery for radiotherapy and the quality assurance program should minimally include all the methods of dose calculation and delivery. An important part of the quality assurance program is the verification of the accuracy and reliability of dose calculations, particularly by treatment planning systems. The proper dose planning and accurate dose delivery are necessary for effectiveness of radiotherapy. “Radiation dose” in radiotherapy commonly refers to the absorbed dose, which is defined as a quotient of dEtiny (energy released per unit mass) by dm (mass of irradiated body). It should determine the total energy deposited in a system by the absorption of ionizing radiation with their unit mass. An “appointment dose” is a sum of the dosages. Clinical practices are based on the prescribed appointed dose with the objective of specifying the time, target area and dosage level. The prescribed dose is an integral part of radiotherapy prescription. The adherence of treatment system to the dose prescription should be monitored on both spatial and temporal base, and accuracy of the dose delivery should be verified when radiation is given to patients. Many radiotherapy treatments involve highly complex radiation fields. Appropriate confidence that both the intended dose distribution and the applied method of treatment are evidence-based and tumor specific can generally be achieved by independent dose verification. Inter-comparison of the independently achieved results was an important part of the verification process. The search for an appropriate method of dose verification led to the procurement of a diode dosimetry system, the development of in-house software to undertake the predicted dose distributions and the construction of phantoms for data acquisition of the dosimetric characteristics of the linear accelerator.

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