Radiotherapy Errors and Its Verification Approach

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Abstract - Radiotherapy is one of the main modalities of cancer treatment, either as a curative or palliative form, and also recommended as one of the best possible treatments for every patient with cancer by the ISCRO-USA and WHO. There were few inventions of radiotherapy in the beginning of the 20th century especially for the cancer treatment of breast, stomach, skin, and nose in America, France, Austria, and Sweden. Those inventions in radiotherapy paved for the discovery of the two main techniques of radiotherapy delivery, namely teletherapy (cobalt^{60} or linac) and brachytherapy. Further, the invention of the CT-Scan, followed by MLC device, help to improve the certainty of the irradiation targets and improve the accuracy of the radiotherapy delivery, without exceeding the tolerance dose of normal tissues. Yet, radiotherapy is still found as a high risks treatment procedure due to the complexity of its sophisticated technology development. Therefore, the objectives of this paper are two- folds:1) to study the type of errors that normally occur in radiotherapy; and 2) to analyze the existing approaches in verifying the radiotherapy errors to improve the certainty of radiotherapy delivery. Finally, the most significant errors and the gaps and limitations of current approaches to verify the errors are discussed.

Keywords- Cancer, radiotherapy, radiotherapy error.

1. INTRODUCTION

According to the American Cancer Society (ACS) report showed that cancer was at present the third cause of death in the world. It was noted that more than12 million new cancer cases and 7.6 million people in the world died by cancer in 2007.[1], [2]It is predicted in 2030, there will be about 26 million of new cancer cases and 17 million people died by cancer per year, which is more than a half of the incidences happens in low and middle income countries (LMIC).[1]–[6].

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Cancer is a multigenic and multicellular disease which arises from body cell and organ type due to multifactorial etiology and unability to control the aggression and metastasis to other body parts. In order to overcome the cancer's problem, radiotherapy is introduced.[2]

Radiotherapy is one of the main modalities of cancer treatment, either as a curative or palliative cost-effective form.[2], [5], [7]–[14].Radiotherapy is an injection of enormous-high energy (megavoltage) ionizing radiation into the cancer cell, then the ionizing radiation breaks the DNA molecular bonds of the cancer cell, either by the direct action from absorption of the ionizing radiation itself or by the indirect action from destroying by cytoplasma fluid of the cancer cell which is transformed its feature to be a strong free radicals, and thus stops the proliferation process of the cancer cell and finally brings to the cancer cell death [2]. Radiotherapy is recommended as one of the best possible treatments for every patient with cancer by the Inter-Society Council for Radiation Oncology (ISCRO) USA and the World Health Organization (WHO).[15], [16] Recommendation from The ISCRO-USA report shows that for every 120 thousands of population is included in 1 megavoltage radiotherapy machine service, and about 6250 treatment service will be given to every 250 new cancer patients per year.[16]Meanwhile, the data shows that radiotherapyis needed to treat at least for about 60% of the total number of new cancer cases in the LMIC which is take portion 82% of the population in the world[2], [4], [5], [7]–[12], [14], [16], [17].

There were few inventions of radiotherapy in the beginning of the 20th century especially for the cancer treatment of breast, stomach, skin, and nose in America, France, Austria, and Sweden. Those inventions in radiotherapy paved for the discovery of the two main techniques of radiotherapy delivery, namely teletherapy (cobalt^{60} or linac) and brachytherapy.[18]–[20] Further, the invention of the CT-Scan, followed by MLC device, help to improve the certainty of the irradiation targets and improve the accuracy of the radiotherapy delivery, without exceeding the tolerance dose of normal tissues.[2], [16], [18], [19], [21], [22]

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However, it is found that radiotherapy is a high risk treatment procedure due to many processes and staffs involved in the requirement of estimation, achievement, and maintanance of accuracy in its delivery remain the core of its treatment process [8], [23], [24]. Further, radiotherapy technology is sophisticated and its technique is very complex and complicated, which requires special knowledge and human expertise to operate it, hence increasing the risk for occuring the errors in radiotherapy [8], [9], [22]–[25].

Therefore, the objectives of this paper are to investigate the type of radiotherapy errors and to analyze the current approaches in verifying the radiotherapy errors to improve the certainty of radiotherapy delivery. This paper is organize as follows; Section 2 describe the method how the study is conducted and this is followed by section 3, describe on the type of errors and the type of existing verification approaches. Subsequently, Section 4 presents the discussion and results drawn from the study and we conclude the study in Section 5.

1.0 RESEARCH METHODOLOGY

The aims of this review are to investigate the type of radiotherapy errors and to analyze the current approaches in verifying the errors to improve the certainty of radiotherapy delivery. This review considers the concept of the type of radiotherapy errors and its related work on verification approaches. In this case, the related work on verification approaches, such as control factor, verification measurement, and radiotherapy delivery approach, were included in the investigation. Thus, we would like to investigate and analyse the radiotherapy errors including in each of their verification approaches. The following procedure was conducted as shown as Figure 1, to ensure that relevant literatures are included in the analysis.

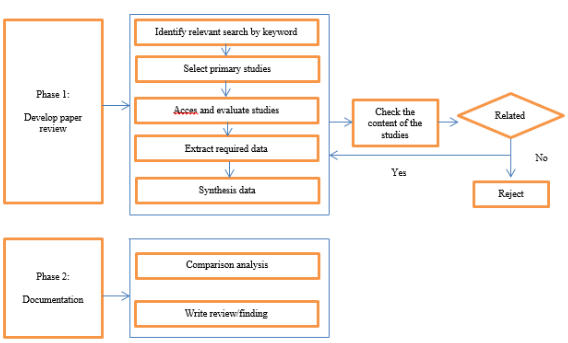

Figure 1: Methodology paper review

Based on the review paper shown in figure 1, there are two phases include for our literature search. In phases 1, review papers was formulated and develop specified to our literature search in the field of online family business. The empirical studies ware search by using search engine like SCOPUS, IEEE explore, ACM, ELSIVER and Google Scholar database. The search keyword uses “radiotherapy”/ “radiotherapy error” to ensure all related the paper is included. As the initial search based on the keyword radiotherapy and radiotherapy errors has resulted 25900 papers. By examining the title and abstract of the primary identified studies. There are 5770 studies during the second activity of selecting primary atudies similar to our domain of contain. At the third process, we accessed and evaluated the studies by checking the content of the studies and we had excluded most of the paper due to irrelevant topic found in the studies. Irrelevant studies will be rejected at this stage and on the hand the relevant studies will be examined further. Out of 5770 papers, there are 12 papers found similar to our content of reviewing. Next, the following data ware extracted from 12 papers: i) the objectives, ii) methodology of the studies, and iii) the result presented. The extracted data were carefully studied to filter and distil possible overlap. The synthesized data resulted in field the type of radiotherapy errors and its related work on verification approaches.

2. TYPE OF RADIOTHERAPY ERRORS AND RELATED VERIFICATION APPROACHES

3.1. Type of Errors

Error in radiotherapy is a performance of radiotherapy delivery uncertainty in statistical form which indicates the spread of values from repeatedly particular measurement, and also a discrepancy between its measured value and theoretically expected value in the context of the safety of radiotherapy patient.[24]

The most common errors in radiotherapy which were ever happened and reported are the wrong receiving delivery dose of radiation to the patient, the wrong site being treated, and the wrong patient being treated, besides the other errors whose number of the incidences were a little, such as error in calibration of the radiation source, error in commissioning of treatment planning system, error in accelerator software, and wrong repair followed by human error.[8], [24], [26], [27] The table 1. below illustrates the type of radiotherapy errors:

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Table 1: Type of radiotherapy errors

Author, year	Type of errors		
	Wrong receiving dose (error in:)	Wrong site being treated (error in:)	Wrong patient being treated (error in:)
Novotny, 1995.[28]	Irradiation exposed time/dose (23%) Irradiation patient dose chart (14%) Enter data or using computer software or TPS (2%)	Determine of patient irradiation anatomy (12%) Set-up patient or teletherapy device (3%) Calibration/malfunctioning teletherapy device (5%)	Patient identity (6%) Patient prescription (5%) Treatment of patient medical record (2%)
Thwaites DI, et al, 2003[26]	Irradiation exposed time/dose (26%) Irradiation patient dose chart (15%) Enter data or using computer software or TPS (2%)	Determine of patient irradiation anatomy (14%) Set-up patient or teletherapy device (4%) Calibration/malfunctioning teletherapy device (3%)	Patient identity (6%) Patient prescription (5%)
PAPSA, 2009[8]	Irradiation exposed time/dose (40%) Irradiation patient dose chart (4%)	Determine of patient irradiation anatomy (24%) Set-up patient or teletherapy device (6%) Calibration/malfunctioning teletherapy device (4%)	Patient identity (16%)
IAEA, 2016[24]	Irradiation exposed time/dose (26%) Irradiation patient dose chart (15%) Enter data or using computer software or TPS (2%)	Determine of patient irradiation anatomy (14%) Set-up patient or teletherapy device (4%) Calibration/malfunctioning teletherapy device (3%)	Patient identity (7%) Patient prescription (6%)
Briggs G, 2008[27]	Irradiation exposed time/dose (17%) Irradiation patient dose chart (3%)	Determine of patient irradiation anatomy (24%) Set-up patient or teletherapy device (7%) Calibration/malfunctioning teletherapy device (8%)	-
Total mean percentage	38%	27%	11%

This illustration from the table above showed us the type of radiotherapy errors which is found that the type of the most common errors in radiotherapy delivery are the wrong receiving delivery dose of radiation to the patient, the wrong site being treated, and the wrong patient being treated.

The wrong receiving delivery dose of radiation to the patient which takes portion 38% from all the cause of the errors in radiotherapy comes from errors in determining of treatment planning (such as errors in irradiation data/chart, models, irradiation dose planning, and the computer software or hardware) [8], [23], [24], [26], [29].

The wrong site being treated which takes portion 27% from all the cause of the errors in radiotherapy comes from errors in determining of patient anatomy (such as errors in obtaining the scheme of radiation field and patient positioning), irradiation target volume (such as errors in defining the gross/clinical target volume - GTV, CTV, PTV, and organ at risk - OAR, ensuring the shape and location of the tumour, estimating in homogeneities of the radiation isodose curve, accounting movements of tumour and organ), and radiotherapy delivery (such as errors in patient set-up, and tele therapy device calibration and setting) [8], [23], [24], [26], [29]. The geometric uncertainties during the radiotherapy delivery, such as body organ, tumour, or patient movements, tumour shape or target volume changes after some weeks of the radiotherapy delivery, or inter- or intra-fraction patient (position) set-up of the radiotherapy delivery often underlie the incidence of such errors [21], [23], [24], [29].

The wrong patient being treated which takes portion 11% from all the cause of the errors in radiotherapy comes from errors in the data of patient (such as errors in identification, diagnosis, prescription, and records of treatment) [8], [23], [24], [26], [29].

The PAPSA data showed that there were 25 reports of the errors in radiotherapy events occured from 2004 until 2009. It consisted of 24 errors in the external beam radiation therapy delivery and 1 errors in brachytherapy delivery. Six events of them were serious events and 19 events were mild events. This data also showed that the most common errors in radiotherapy delivery came from wrong receiving delivery dose of radiation (40%), wrong site or location being treated (24%), and wrong patient being treated (16%) [8].

A published case study data in Glasgow-Scotland reported one error in radiotherapy delivery in 2005 regarding to the wrong receiving delivery dose of radiation. The other data from Cleveland Clinic in 1995 showed that the crude radiotherapy delivery error rate was 0,18% [8]. Some factors which contribute to the errors in radiotherapy are lack of practice, capability, or experience, exhausted and stress, poor outlines and documentations of procedures, over-confidence on automatic device system, poor communication and inadequate of team work, gap between junior and senior staff structure, inadequate staffing and competency level, poor design of working environment, and changes in radiotherapy technology and its delivery process.[27]

However, from the data above showed that the incidences of errors in radiotherapy delivery relatively are rare or low. The reason why for the rare incidences is due to there are the strict regulatory and quality control standard environment surrounding the radiotherapy delivery, safety measurements continuously, and using computerized technology. However the real danger can occur if there is an error in radiotherapy delivery procedure goes undetected.[8]

3.2. Related Work on Verification Approaches

Control factor and verification

Radiotherapy is a high risk treatment procedure due to there are many processes and staffs, besides modern and sophisticated radiotherapy technology and its technique unfortunately is very complex and complicated, thus potentially increasing the risk for occuring the errors in radiotherapy [8], [9], [22]–[25]. The data also revealed that the most common errors in radiotherapy are the wrong

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receiving delivery dose of radiation to the patient, the wrong site being treated, and the wrong patient being treated [8], [24], [26], [27].The control factor strategy to reduce risk of the wrong receiving delivery dose of radiation is by checking and re-checking to the standard of procedures (SOP) or guidelines of radiotherapy delivery before the radiotherapy is delivered. Meanwhile the device to verify and measure the control factor for this errors is by using the standard checklist of radiotherapy delivery planning with the computerized record and verify (RV) system.[8], [23]–[27], [29]–[31]

The control factor strategy to reduce the risk of the wrong site being treated is by verifying the things which relate to the determining of patient anatomy and positioning, irradiation target volume, and treatment delivery. Meanwhile the device to verify and measure the control factor for this errors is by using a portal imaging (such as film □-graphy, electronic portal imaging device/EPID, computerized tomography/CT, or cone beam) or advanced radiotherapy delivery technique (such as IGRT/ART) from modern technology, which is also included in the computerized RV system [8], [23]–[27], [29]–[31]

The control factor strategy to reduce the risk of the wrong patient being treated is by checking and re-checking identification of the patient before the radiotherapy is delivered. Meanwhile the device to verify and measure the control factor for this errors is by using a standard checklist and medical record of the patient data, which is also included in the computerized RV system [8], [23]–[27], [29]–[31]

Radiotherapy delivery approach

Radiotherapy is a high risk treatment procedure due to there are many processes and staffs involved in which the requirement of estimation, achievement, and maintanance of accuracy in its delivery remain the core of its treatment process.[8], [23], [24] Radiotherapy is also a multidisciplinary team work which is every group takes part of the entire radiotherapy process and has a comprehensive approach in the radiotherapy delivery.[23], [24], [27]

A pre-requirement in order to manage and reduce the errors or uncertainties in radiotherapy is must have a guideline of quality assurance in radiotherapy (QART) with explicit documentation, instruction, and communication to ensuring optimal treatment and to stay away from the errors in radiotherapy, in which emphasizes to the education and training continously to the radiotherapy team members.[8], [23], [24], [27], [29], [31]

Some common principles of the guideline of QART are the guideline should clearly define the checking and verification processes, the checking processes usually should be fulfilled following the original method in which to avoid the probability of repeating the same fault, the verification should be active and able to interact with computerized record and verify (RV) system in which to overcome the matter of involuntary automation, the checking and verification processes should fulfill in undisturbed environment, and the effectiveness and frequency of the checking and verification processes have to be audited in which to ensure the value.[8], [23], [24], [27], [30]

Some aspects in which should be checked before the radiotherapy planning transferred to the teletherapy machine are checking and verification of input information, planning process, and output information.[27]

Checking and verification aspects of input information includes identity of the patient, reasonable referral of the patient, history of the illness and treatment, clinical, supporting and imaging examinations, radiotherapy indication, correct site or patient being treated, and radiotherapy delivery planning outlines and its evaluation.[8], [23], [24], [27], [29]

Checking and verification aspects of planning process includes re-checking and verification to the patient data regarding to the consistency of patient identity, results of the received treatments, clinical, supporting and imaging examinations, and ensuring all of radiotherapy delivery planning [32] outlines are appropriate and consistent according to the guidelines of QART including patient positioning, the scheme of radiation field, the shape and location of the tumour, irradiation target volume (such as, GTV, CTV, PTV, OAR, homogeneities of the radiation isodose curve, and movements of tumour).[8], [23]–[27], [29]–[31]

Checking and verification aspects of output information includes re-checking and verification to the acceptable dose distribution receiving of radiotherapy delivery, teletherapy device calibration and setting, patient set-up, and correct site or patient being treated.[8], [23], [24], [26], [27], [29]

In completing the verification process of radiotherapy planning, ensuring correct site being treated and coverage of the target volume is able to be fulfilled either by using simulator or by portal imaging device [33] (such as film □-graphy, EPID, CT, or cone beam), in which its imaging results should be compared to the digitally reconstructed radiography (DRR) planning system following the guideline of QART. Film CR or□□-graphy verification if technically

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possible should be applied when there is no EPID verification available.[8], [23]–[27], [29]–[31]

All the checking and verification processes above are checks of the personal steps of the radiotherapy delivery process. Portal imaging device which is able to fulfill the geometric verification process and identify geometric errors in radiotherapy is the main type of personal check [34]. Portal imaging which is applied at the beginning of a treatment course also gives a chance to reduce and avoid a gross set-up errors in radiotherapy.[23], [24], [27]

The other radiotherapy approach to ensure the QART and prevent to the errors in radiotherapy in the future is audit process. In this process only a restricted number of parameters generally are verified, which is able to be carried out by visitation from an expert team of the independent organization. The results of this audit process furthermore are used to improve the quality of radiotherapy delivery on the daily activity.[23], [24], [27]

3. Result and Discussion

Based on the investigation and analyzation to the preview research articles showed that there were the most common and significant errors in radiotherapy which were ever normally occur, reported and made performance of radiotherapy delivery uncertainty. The table 2.below illustrates the type of radiotherapy errors and its related work on verification approaches:

Table 2: Type of radiotherapy errors and its related work on verification approaches

Type of radiotherapy errors	Related work		
	Control factor	Verification measurement	Approach
Wrong receiving dose of irradiation	Check and re-check the SOP.[8], [23]–[27], [29]–[31]	Standard checklist and RV system. [8], [23]–[27], [29]–[31]	Guidelines of QART.[8], [23], [24], [26], [27], [29]
Wrong site being treated	Determine patient's anatomy, positioning, target treatment volume. [8], [23]–[27], [29]–[31]	Portal imaging, advanced irradiation techniques from modern teletherapy. [8], [23]–[27], [29]–[31]	Guidelines of QART. [8], [23]–[27], [29]–[31]
Wrong patient being treated	Check and re-check the identification of patient. [8], [23]–[27], [29]–[31]	Standard checklist and medical record of the patient's data. [8], [23]–[27], [29]–[31]	Guidelines of QART.[8], [23], [24], [27], [29]
Total	9	9	9

This illustration from the table above showed us the type of radiotherapy errors and its related work on verification approaches. Each of the type of radiotherapy errors had some control factors, verification measurements, and approaches, in which the guidelines of quality assurance in radiotherapy (QART) became the existing approaches in verifying all the type of radiotherapy errors. In additional note, the guidelines of QART had to be equipped with explicit documentation, instruction, and communication to ensuring optimal treatment and to stay away from the errors in radiotherapy, in which emphasizes to the education and training continously to the radiotherapy team members.

For the next research, they would be the directions and justifications to ensure optimal treatment and to manage and reduce the radiotherapy errors or uncertainties, and also useful for the developing radiotherapy delivery improvement and survival to the patients.

Conclusion

The objectives of this paper are, to study the type of errors that normally occur in radiotherapy and analyze the existing approaches in verifying the radiotherapy errors to improve the certainty of radiotherapy delivery. Meanwhile, error in radiotherapy itself is a performance of radiotherapy delivery uncertainty in statistical form which indicates the spread of values from repeatedly particular measurement, and also a discrepancy between its measured value and theoretically expected value in the context of the safety of radiotherapy patient. Therefore, there were the most common and significant errors in radiotherapy which were normally occur, reported and made performance of radiotherapy delivery uncertainty, i.e. the wrong receiving delivery dose of radiation to the patient, the wrong site being treated, and the wrong patient being treated, and the existing approaches in verifying the radiotherapy errors was had to have and conduct the guidelines of quality assurance in radiotherapy (QART) to ensure optimal treatment and to stay away from the errors in radiotherapy delivery.

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