Institute of Technology Management and Entrepreneurship

A TELECOBALT^{60}-COMPUTED RADIOGRAPHY VERIFICATION MODEL TO IMPROVE THE CERTAINTY OF THE IRRADIATION

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A thesis submitted
in fulfillment of the requirements for the degree
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DECLARATION

I declare that this thesis entitled "A Telecobalt^{60}-Computed Radiography Verification Model to Improve the Certainty of the Irradiation" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ………………………………….

Name : Hendrik

Date : 1 August 2023.

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.

Signature : ....

Supervisor Name : Prof. Dr. Massila binti Kamalrudin

Date : 1 August 2023

DEDICATION

I would like to dedicate my highest acknowledgment to my beloved family for always being with me through all the hardship during my study years by giving consistent support and encouragement.

ABSTRACT

Radiotherapy remains the main treatment of cancer to date. To achieve the certainty of the irradiation, the radiotherapy must be delivered using teletherapy, which is equipped with a verification portal imaging device. However, the telecobalt^{60} is not equipped with the verification portal imaging device. Therefore, in the telecobalt^{60} utilization, the wrong site being treated errors in radiotherapy delivery are rarely verified. To solve this issue, this study aimed to determine the factors that could influence the telecobalt^{60}-computed radiography verification model to improve the certainty of the irradiation, to develop the telecobalt^{60}-computed radiography verification model, to formulate the standard of procedures (SOP) of the telecobalt^{60}-computed radiography verification model, and to improve the certainty of the irradiation by existing and performing the SOP of the telecobalt^{60}-computed radiography verification model and compare with the previous SOP of the irradiation. The research design was a mix of qualitative and quantitative methods. A qualitative study was used to determine the factors that could influence the telecobalt^{60}-computed radiography verification model, to develop the telecobalt^{60}-computed radiography verification model, and to formulate the SOP of the telecobalt^{60}-computed radiography verification model. Meanwhile, a quantitative study was used to improve the certainty of the irradiation by performing the SOP of the telecobalt^{60}-computed radiography verification model. Based on the results, the factors that could influence the telecobalt^{60}-computed radiography verification model are the equality of the irradiation field (the scheme of simulator image, body size of the patient, and the patient positioning) and accuracy of the irradiation target factors (the set-up of the patient and teletherapy device, calibration of the teletherapy, quality of conducting the human resource, mechanical malfunctioning of the teletherapy). In developing the telecobalt^{60}-CR verification model, formulating the SOP of the telecobalt^{60}-CR verification model, and evaluating the improvement by the SOP of the verification model, there was significant ($p<0.05$) improvement of the certainty of the irradiation by existing and performing the SOP of the telecobalt^{60}-computed radiography verification model as compared to the previous SOP of the irradiation. The conclusion was the equality of the irradiation field and accuracy of the irradiation target factors significantly ($p<0.05$) influenced the telecobalt^{60}-computed radiography verification model to improve the certainty of the irradiation. The certainty of the irradiation obtained by the verification model performed by the SOP of the telecobalt^{60}-computed radiography verification model was improved as compared to the previous SOP irradiation. The telecobalt^{60}-CR verification model developed in this study is useful for the radiotherapy servicer and researchers to improve and sustain the survival and quality of life of cervical cancer patients.

MODEL VERIFIKASI RADIOGRAFI TERKOMPUTASI - TELECOBALT^{60} UNTUK MENINGKATKAN KEPASTIAN PENYINARAN

ABSTRAK

Radioterapi kekal sebagai rawatan utama kanser sehingga kini. Untuk mencapai kepastian penyinaran, radioterapi mesti dihantar menggunakan teleterapi, yang dilengkapi dengan peranti pengimejan portal pengesahan. Walau bagaimanapun, telekobalt60 tidak dilengkapi dengan peranti pengimejan portal pengesahan. Oleh itu, dalam penggunaan telekobalt60, tapak yang salah dirawat ralat dalam penghantaran radioterapi jarang disahkan. Untuk menyelesaikan isu ini, kajian ini bertujuan untuk menentukan faktor-faktor yang boleh mempengaruhi model pengesahan radiografi yang dikira telekobalt60 untuk meningkatkan kepastian penyinaran, untuk membangunkan model pengesahan radiografi yang dikira telekobalt60, untuk merumuskan standard prosedur (SOP) bagi model pengesahan radiografi yang dikira telekobalt60, dan untuk meningkatkan kepastian penyinaran dengan sedia ada dan melaksanakan SOP model pengesahan radiografi yang dikira telekobalt60 dan bandingkan dengan SOP penyinaran sebelumnya. Reka bentuk kajian adalah gabungan kaedah kualitatif dan kuantitatif. Kajian kualitatif digunakan untuk menentukan faktor-faktor yang boleh mempengaruhi model pengesahan radiografi yang dikira telekobalt60, untuk membangunkan model pengesahan radiografi yang dikira telekobalt60, dan untuk merumuskan SOP model pengesahan radiografi yang dikira telekobalt60. Sementara itu, kajian kuantitatif telah digunakan untuk meningkatkan kepastian penyinaran dengan melaksanakan SOP model pengesahan radiografi yang dikira telekobalt60. Berdasarkan keputusan, faktor yang boleh mempengaruhi model pengesahan radiografi yang dikira telekobalt60 ialah kesamaan medan penyinaran (skim imej simulator, saiz badan pesakit, dan kedudukan pesakit) dan ketepatan faktor sasaran penyinaran (penetapan pesakit dan peranti teleterapi, penentukuran teleterapi, kualiti pengendalian sumber manusia, kerosakan mekanikal teleterapi). Dalam membangunkan model pengesahan telecobalt60-CR, merumuskan SOP model pengesahan telecobalt60-CR, dan menilai penambahbaikan oleh SOP model pengesahan, terdapat peningkatan yang ketara ($p<0.05$) kepastian penyinaran oleh sedia ada dan melaksanakan SOP model pengesahan radiografi yang dikira telekobalt60 berbanding dengan SOP penyinaran sebelumnya. Kesimpulannya ialah kesamaan medan penyinaran dan ketepatan faktor sasaran penyinaran secara signifikan ($p<0.05$) mempengaruhi model pengesahan radiografi yang dikira telekobalt60 untuk meningkatkan kepastian penyinaran. Kepastian penyinaran yang diperolehi oleh model pengesahan yang dilakukan oleh SOP model pengesahan radiografi yang dikira telekobalt60 telah dipertingkatkan berbanding dengan penyinaran SOP sebelumnya. Model pengesahan telekobalt60-CR yang dibangunkan dalam kajian ini berguna untuk perkhidmatan radioterapi dan penyelidik untuk memperbaiki dan mengekalkan kemandirian dan kualiti hidup pesakit kanser serviks.

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AAPM	-	American Association of Physicists in Medicine
ACS	-	American Society of Cancer
ART	-	Adaptive radiation therapy
BZ	-	Body size of patient
BAPETEN	-	Badan Pengawas Tenaga Nuklir (Nuclear Energy Control Board-NECB)
C	-	Calibration of Tele-therapy device
ca	-	Cancer
CCTV	-	Closed circuit television
CNR	-	Contrast to noise ratio
CR	-	Computed radiography
CRT	-	Conformal radiation therapy
CT - scan	-	Computerized tomography – scan
CTV	-	Clinical target volume
Cx	-	Cervix (of the uterus)
D	-	Dimensional (e.g.,= 2D, 3D, 4D)
DRR	-	Digitally reconstructed radiography
EBRT	-	External beam radiation therapy
e.g.	-	exempli gratia

EPID	-	Electronic portal imaging device
FGD	-	Forum group discussion
FIGO	-	Federation International of Gynaecologist and Obstetrician
GTV	-	Gross tumor volume
HDR	-	High dose rate
HIC	-	High income countries
I	-	Influenced
IAEA	-	International Atomic Energy Agency
IARC	-	International Agency for Research on Cancer
ICRU	-	International Commission on Radiation Units (and Measurements)
i.e.	-	id est
IGRT	-	Image-guided radiation therapy
IMRT	-	Intensity-modulated radiation therapy
IP	-	Imaging plate
IPR	-	Imaging plate reader
IROS	-	Indonesian Radiation Oncologist Society (i.e.,= PORI)
ISCRO	-	Inter-Society Council for Radiation Therapy
IV	-	Irradiation volume
LDR	-	Low dose rate
Linac	-	Linear accelerator
LMIC	-	Low-middle income countries
MDR	-	Middle dose rate
MF	-	Medical physicist
MLC	-	Multi-leaf collimator

MT	-	Malfunctioning of Tele-therapy device
N	-	Number (i.e.,= true sample size)
NPIC	-	National Power Institute Company
OAR	-	Organ at risk
ODI	-	Optical distant indicator
PC	-	Personal computer
PORI	-	Perhimpunan Dokter Spesialis Onkologi Radiasi Indonesia (IROS)
PP	-	Patient positioning
PTV	-	Planning target volume
QHR	-	Quality of conducting human resources
QART	-	Quality assurance of radiation therapy
RO	-	Radiation oncologist
RSCM	-	Rumah Sakit Dr.Cipto Mangunkusumo (national general hospital)
RSUD	-	Rumah Sakit Umum Daerah (regional general hospital)
RTT	-	Radiation therapist (radiotherapist)
RV	-	Record and verify
S	-	Scheme (of simulator image)
SBRT	-	Stereotactic body radiation therapy
SFR	-	Screen film radiography
SNR	-	Signal to noise ratio
SOP	-	Standard of procedures
SP	-	Set-up (of the patient)
SRS	-	Stereotactic radio surgery
SRT	-	Stereotactic radiation therapy

SSD	-	Source to skin distance
STD	-	Set-up of Tele-therapy device
TPS	-	Treatment planning system
UMIC	-	Upper-middle income countries
USA	-	United States of America
VMAT	-	Volumetric-modulated arc therapy
VPI	-	Verification portal image
Web	-	Word electric browser
X-ray	-	X beamed ray

LIST OF APPENDICES

LIST OF PUBLICATIONS

1. Hendrik, Kamalrudin, M, Razali, M., 2019. Radiotherapy error and its verification approach. *International Journal of Recent Technology and Engineering (IJRTE)*, 8(1S5), pp. 191–196.

2. Hendrik, Kamalrudin, M, Razali, M, Purnamawati, S, Widikusumo, A., 2022. Control factors for site errors management of radiotherapy delivery. *Wiadomosci Lekarskie*, 75(9-1), pp. 2060-2064.

3. Hendrik, Kamalrudin, M, Razali, M, Purnamawati, S, Widikusumo, A., 2022. Computed radiography utilization for telecobalt^{60} to achieve the radiation certainty. *Wiadomosci Lekarskie*, 75(12), pp. 3080-3086.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Data from the American Society of Cancer (ACS) presents that cancer disease has caused death to millions of people in the world (Thun and DeLancey, 2009; Baskar and Lee, 2012; Organization, 2018, 2020; Krzyszczyk and Acevedo, 2019; Radiologists, 2021). Meanwhile, radiotherapy is the cure for more than 60% of the new cancer cases in low or middle-income countries (LMIC) (Kumar and Bhasker, 2015; Zubizarreta and Fidarova, 2015).

To achieve the certainty of irradiation and better outcome of radiotherapy quality, the radiotherapy must be delivered using a teletherapy machine which is equipped with a verification portal imaging (VPI) device (Thwaites and Centre, 2003; Ravindran, 2007; Fox and Romeijn, 2008; Acharya and Lamichhane, 2017; van der Merwe and Van Dyk, 2017; Beyzadeoglu and Ozyigit, 2018; Gürsel, 2018; Halperin and Perez, 2018; Scaringi C, Agolli L, 2018; Fiorino and Guckenberger, 2020; Huh and Kim, 2020; Tepper and Foote, 2021; Bielajew and Tedgren, 2022). Telecobalt^{60} is one of the teletherapy machines that is still relevant until now, however, it is not equipped with the VPI device (Bansal, 2006; Fox and Romeijn, 2008; Ravichandran, 2009; Ravichandran and Ravikumar, 2015). When using the telecobalt^{60}, the wrong sites being treated errors in radiotherapy delivery are rarely verified. The errors come from either the errors when determining the equality of the irradiation field or the accuracy of the irradiation target. Afterward, it will make some radiotherapy servicers are not able to handle the uncertainty of the irradiation and neglect it due to tedious process, as well as lack of experience and essential tool to assist the verification of these errors (Bansal, 2006; Fox and Romeijn, 2008; Ravichandran, 2009; Ravichandran and Ravikumar, 2015).

This chapter presents the introduction of the research objectives to develop a telecobalt^{60}-computed radiography (CR) verification model by improving the certainty of the irradiation in the telecobalt^{60} machine usage. It focused on determining the factors that could influence the telecobalt^{60}-CR verification model, developing the telecobalt^{60}-CR verification model, formulating the standard of procedures (SOP) of the telecobalt^{60}-CR verification model, and improving the certainty of the irradiation by performing the SOP of the verification model and comparing with the previous SOP of the irradiation.

1.2 Research background

In 2007, about 7.6 million death in the world were caused by cancer as reported by the American Cancer Society report (Thun and DeLancey, 2009; Baskar and Lee, 2012; Krzyszczyk and Acevedo, 2019). The cases increased to 9.6 million in 2018 according to the International Agency for Research on Cancer-World Health Organization (WHO) (Organization, 2018, 2020; Radiologists, 2021). It is predicted in 2030 there will be about 26 million new cancer cases and 17 million people died by cancer per year, in which more than a half of the incidences will happen in the LMIC (Thun and DeLancey, 2009; Baskar and Lee, 2012; Dad and Shah, 2014; Datta and Samiei, 2014; Fisher and Daugherty, 2014; Jaffray and Gospodarowicz, 2014; Grover and Xu, 2015).

Radiotherapy remains the gold treatment of cancer which is used to treat at least 60% of the total number of new cancer cases in the LMIC (Baskar and Lee, 2012; Kumar and Bhasker, 2015; Zubizarreta and Fidarova, 2015). This is due to limited infrastructures available in LMIC to prevent, diagnose, and cure cancer (Grover and Xu, 2015; Efstathiou and Heunis, 2016; Abdel-Wahab and Zubizarreta, 2017; Gondhowiardjo and Handoko, 2020; Abdel-wahab and Gondhowiardjo, 2021).

The telecobalt^{60} is one of the tele-radiotherapy machine (tele-therapy) for treatment of cancer (Fox and Romeijn, 2008; Beyzadeoglu and Ozyigit, 2010, 2018; Gunderson LL, 2012; Dyk, Battista and Bauman, 2013; Acharya and Lamichhane, 2017; Scaringi C and Agolli L, 2018; Gürsel, 2018; Halperin and Perez, 2018; Huh and Kim, 2020; Fiorino and Guckenberger, 2020; Tepper and Foote, 2021; Bielajew and Tedgren, 2022). About 31% of telecobalt^{60} machines were distributed in the LMIC and upper- and middle-income countries (UMIC), such as in Latin America, Africa, East Europe, Asia, and Pacific, compared to 7% in the high-income countries (HIC). Each telecobalt^{60} can serve 1.4 million cancer patients in the LMIC and UMIC, compared to 0.4 million cancer patients in the HIC (Zubizarreta and Fidarova, 2015; Abdel-Wahab and Zubizarreta, 2017; Gondhowiardjo and Handoko, 2020; Abdel-wahab and Gondhowiardjo, 2021).

In the advance global crisis involving the management of cancer care, telecobalt^{60} machine remains relevant in developing countries, especially in the LMIC and UMIC (Kumar and Bhasker, 2015; Abdel-Wahab and Zubizarreta, 2017; Gondhowiardjo and Handoko, 2020; Abdel-wahab and Gondhowiardjo, 2021). Telecobalt^{60} has an edge over the other teletherapy machine (linac) because of less maintenance costs, less infrastructure requirements, low power demands, and simply quality assurance of the beam parameters (Kumar and Bhasker, 2015). In contrast, new teletherapy linac is expensive, sophisticated, and difficult to operate, hence this novel technology is less utilized than radiotherapy in resource-constrained developing countries (Kumar and Bhasker, 2015; Gondhowiardjo and Handoko, 2020).

Nevertheless, the telecobalt^{60} utilization is still far from the expecting to achieve the better and more quality outcome of the cancer treatment and remains risky to the errors in