EVALUATION OF PATIENT DOSE DURING MULTI-CATHETER INSERTION IN CT-GUIDED INTERSTITIAL LIVER BRACHYTHERAPY

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by

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LIST OF SYMBOLS

cm	centimeter
mm	milimeter
kV	kilovoltage
kVp	Peak Kilo Volt
mA	milliampere
mAs	milliampere second
Gy	Gray
mGy	miliGray
mGy.cm	miligray centimeter
cm^3	centimeter cube
<	less than
p	Significance value
r	Correlation coefficient

LIST OF ABBREAVIATIONS

CT	Computed Tomography
CTDIvol	Volume Computed Tomography Dose Index
DLP	Dose Length Product
DVH	Dose-volume histogram
HDR	High-dose rate
HCC	Hepatocellular Carcinoma
HCT	Helical Computed Tomography
Ir-192	Iridium-192
I-125	Iodine 125
LDR	low-dose-rate
PTV	Planning target volume
3D	Three Dimensional
6F	6 -French
RTP	Radiation Treatment Planning
PACS	Picture Archiving and Communication System

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PENILAIAN DOS PESAKIT SEMASA PENYISIPAN KATETER BERPANDU-CT DALAM BRAKITERAPI HATI INTERSTISIAL

ABSTRAK

Pengenalan: Brakiterapi merupakan sejenis rawatan kanser yang melibatkan bahan radioaktif berkapsul yang diletakkan berhampiran ataulangsung ke dalam tumor. Brakiterapi hati telah dipraktikkan di pelbagai institusi di mana beberapa kateter dimasukkan ke dalam hati dipanduoleh pengimejan tomografi berkomputer (CT). Pelbagai kajian sebelum ini telah mengesahkan dos yang diterima semasa rawatan brakiterapi, namun, dos yang diterima pesakit semasa prosedur penyisipan kateter dipandu CT tidak dibincangkan. Oleh itu, pelbagai aspek prosedur dikaji untuk pengoptimuman seluruh prosedur. **Objektif:** Kajian ini bertujuan untuk menilai dos pesakit diperolehi daripada penyisipan kateter semasa brakiterapi hati interstisial, untuk menentukan hubungan antara bilangan kateter dengan nilai dos CT ($CTDI_{vol}$ dan jumlah DLP), di samping untuk penilaian dos organ yang diterima oleh pesakit yang menjalani prosedur tersebut menggunakan aplikasi IndoseCT. **Kaedah:** Kajian ini melibatkan tinjauan retrospektif terhadap 18 orang sampel dengan purata umur 56.4 tahun yang telah menjalani imbasan CT untuk penyisipan kateter sebelum brakiterapi hati untuk menilai dos pesakit. Maklumat demografi pesakit (umur dan jantina), data CT (jumlah kateter, bilangan fasa CT, parameter imbasan seperti kVp. mAs, pitch dan panjang imbasan (cm)), data dos CT ($CTDI_{vol}$ dan jumlah DLP), isipadu dan diameter pertumbuhan dikumpulkan untuk analisis lanjut. Di samping itu, imej aksial pesakit diperolehi daripada sistem PACS dan seterusnya dimuatnaik ke dalam aplikasi IndoseCT untuk pengiraan dos organ. **Keputusan:** Bilangan kateter menunjukkan hubungan yang lemah dengan data dos CT ($CTDI_{vol}$ dan jumlah DLP) dan bilangan fasa CT, manakala bilangan kateter menunjukkan hubungan yang kuat dengan isipadu dan diameter ketumbuhan atau tumor. Selain itu, pesakit yang menjalani protokol RTP Abdomen HCT 3 mm, organ yang merekodkan dos tertinggi adalah jantung iaitu sebanyak 755.79 mGy, sementara itu, buah pinggang merekodkan dos tertinggi bagi pesakit yang menjalani RTP Abdo/Pelvis HCT 3 mm protocol iaitu sebanyak 964.79 mGy. **Kesimpulan:** Penyelidikan hubungan antara pembolehubah yang digunakan dalam prosedur adalah sangat penting untuk pengoptimuman prosedur tersebut dengan lebih lanjut serta dapat memberikan pemahaman lanjut dalam membuat keputusan yang tepat dalam penentuan parameter prosedur untuk kemajuan masa depan.

Kata Kunci: tomografi berkomputer, kateter, CTDIvol, DLP, dos organ

EVALUATION OF PATIENT DOSE DURING MULTI-CATHETER INSERTION IN CT-GUIDED INTERSTITIAL LIVER BRACHYTHERAPY

ABSTRACT

Introduction: Brachytherapy is a type of cancer treatment that involves placing an encapsulated radioactive source either near or directly into the tumour. Liver brachytherapy has been practiced in institutions where multiple catheters are inserted into the liver under CT-guidance. Numerous studies have acknowledged the dose received during brachytherapy, however, the dose received during CT-guided multi-catheter insertion lacks in discussion, hence, the optimisation of the procedure is presented by investigating various aspects of the procedure. **Objectives:** This study aims to evaluate the patient dose received from multi-catheter insertion during interstitial liver brachytherapy, to determine the association between number of catheters with the CT dose values ($CTDI_{vol}$ and total DLP) and to evaluate the organ dose for the patients undergoing multi-catheter insertion in CT-guided interstitial liver brachytherapy using IndoseCT software as well. **Methods:** This study involved a retrospective survey on 18 patients who undergone CT-guided multi-catheter insertion for liver brachytherapy for evaluation of the patient dose received from the procedure. Patients' demographic information (age and gender), CT data (number of catheters, number of CT phases, exposure settings – kVp, mAs, pitch and scan length (in cm)), patient dose data ($CTDI_{vol}$(in mGy) and total DLP (in mGy.cm)), volume of lesion (in cm^3) and diameter of lesion (in cm) were retrieved from CT workstation and recorded for further analysis. Besides that, the axial CT images of patients were obtained and retrieved from the Picture Archiving and Communication System (PACS) for further analysis. The collected CT images were uploaded in the IndoseCT software (Version

20b) to estimate the organ dose (developed by Anam et al., 2021). **Result:** Number of catheters showed weak correlation with CT dose indices ($CTDI_{vol}$ and total DLP) and number of CT phases while number of catheters had strong correlation with volume and diameter of lesion. Furthermore, the organ that received the highest dose for patient undergone RTP Abdomen HCT 3 mm protocol was heart with 755.79 mGy, while kidneys received the highest dose (964.79 mGy) for patients underwent RTP Abdo/Pelvis HCT 3 mm protocol. **Conclusion:** The examination of association between variables used in the procedures is extremely important to further optimise the procedure as well as provide insight on accurate decision making for future advancements.

Keywords: computed tomography, catheter, CTDIvol, DLP, organ dose

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Brachytherapy refers to a short distance treatment of cancer with the involvement of radiation from encapsulated radionuclide sources. Brachytherapy is also known as internal radiation therapy where seeds, or capsules which contains radioactive sources are inserted into the body and placed near the tumour or directly in to the tumour (National Cancer Institute, 2019). One of the brachytherapy treatment techniques is interstitial brachytherapy. High-dose rate (HDR) brachytherapy is a technique where the radioactive source is implanted into the patient's body and is removed after the radiation is delivered to the tumour. HDR treatment delivers a high dose of radiation to the tumour by sparing the surrounding organ at risk (Mendez and Morton, 2018). Interstitial brachytherapy is the mode of treatment where the radioactive sources are directly implanted into the tissue which causes a sharp dose fall off outside the target region. After-loading technique is used in brachytherapy where the radiation sources are inserted into the patient after the accurate position of device (catheters, needles or applicators) is confirmed. Computed tomography (CT)-guided interstitial brachytherapy refers to an after-loading technique which uses Ir-192 source as it is temporarily inserted through catheters placed under CT-guidance into the target volume (Wieners et al., 2015).

The commonly used imaging in this procedure is CT imaging which depicts for postimplantation assessment of catheter positioning as well as dosimetry for low-dose-rate (LDR) brachytherapy. In this procedure, the dose-volume histograms (DVHs) can be resulted for the planning target volume (PTV) and intended organ at risk (OAR) due to the involvement of CT imaging that provides CT-based treatment planning (Lee, Damato and Viswanathan, 2013).

Multiple-catheters insertion technique is applied for liver brachytherapy for the radioactive sources to pass through the catheter from the remote after-loader into the tissue being treated. CT-guided interstitial brachytherapy enables the accurate positioning of the after-loading catheter and exact 3D dosimetry based on CT data sets (Gebauer, 2013). Real-time CT imaging is used to guide accurate placement of the brachytherapy catheters to ensure precise positioning of the radioactive sources in relation to the tumour and surrounding healthy tissues.

After the catheter is positioned in the intended location, a treatment planning is developed to determine the appropriate radiation dose targeted to the tumour while minimising exposure to adjacent normal tissues.

The dose received by patient during radiotherapy treatment should be accurate to ensure that the treatments involving radioactive sources are safe to be executed without deteriorating patient's health while delivering an effective treatment to the patient. Besides, the dose received from CT imaging during the brachytherapy catheter insertion should also be evaluated to optimise the dose delivered to patient. Thus, this study aims to evaluate patient dose received during multi-catheters insertion in CT-guided interstitial liver brachytherapy.

1.2 Problem Statement

Interstitial brachytherapy is a safe and effective option for liver cancer treatment. Since radioactive sources was inserted through the multi-catheter during treatment procedure, patient will receive higher dose throughout the brachytherapy treatment. Apart from dose received during brachytherapy treatment, patient will also receive dose from CT imaging during CT-guided imaging for catheter insertion. The patient may receive higher cumulative dose from CT-guided imaging and brachytherapy procedure. Hence, the evaluation of potential radiation risks should be conducted through the estimation CT dose and organs doses.

The associated factors that contribute to the total CT dose received by the patient during the CT-guided interstitial brachytherapy procedure for liver cancer should be carefully analysed. Since catheters are the essential instrument used in interstitial liver brachytherapy procedure, catheters should be considered as one of the primary contributors that could influence the dose received by the patient during multi-catheter insertion under CT-guided imaging.

The association between the number of inserted catheters with the dose received by the patient during multi-catheter insertion in CT-guided require further investigation. This evaluation is important to ensure the correlation between the number of catheters with the number of CT phases and other exposure parameters.

However, the contribution of CT radiation dose to the patient during CT-guided multi-catheter insertion in interstitial liver brachytherapy remains insufficiently documented and poorly understood. Further research and detailed reporting are needed to fully assess and quantify the potential risks and impacts associated with the radiation exposure during this procedure. Therefore, this study intended to evaluate the CT dose received by patient during multi-catheter insertion in CT-guided interstitial liver brachytherapy. The dose evaluation is crucial in order to optimise the imaging procedure and minimise the dose received.

1.3 Objective of Study

1.3.1 General Objective

This study aims to evaluate patient dose received during multi-catheter insertion in CT-guided interstitial liver brachytherapy.

1.3.2 Specific Objective

1. To evaluate the patient dose received from multi-catheter insertion during interstitial liver brachytherapy.
2. To determine the association between number of catheters with the CT dose values ($CTDI_{vol}$ and total DLP).
3. To evaluate the organ dose for the patients undergoing multi-catheter insertion in CT-guided interstitial liver brachytherapy using IndoseCT software.

1.4 Significance of Study

The evaluation of CT dose received by patient during CT-guided multi-catheter insertion in interstitial liver brachytherapy is still inadequately presented. In most studies related to brachytherapy procedures, the radiation dose from the radioactive source far exceeds the dose received from the CT scans used during catheter insertion. Consequently, the contribution of CT radiation to the overall patient dose is often underreported and not thoroughly investigated. In this study, the relationship between the associated factors such as the catheter insertion with the CT dose will be thoroughly investigated. These findings will significantly contribute to new data and deepen the understanding on the total CT dose received during CT-guided procedure. These findings will also provide guidance optimising the procedure through the careful evaluation of patient dose.

CHAPTER 2

LITERATURE REVIEW

2.1 Liver Anatomy and Physiology

Liver is known to be the second largest organ in the human body right after skin. The liver is located inferior to the diaphragm and it consists of four lobes which are the right lobe, left lobe, caudate lobe and quadrate lobe. The inferior aspect of the liver is close to the gallbladder and right kidney. Furthermore, the lobule is known as the liver’s functional unit. Hepatocyte clusters in the form of liver lobules are hexagon-shaped, with central vein at their center (Vernon, Wehrle and Kasi, 2020).

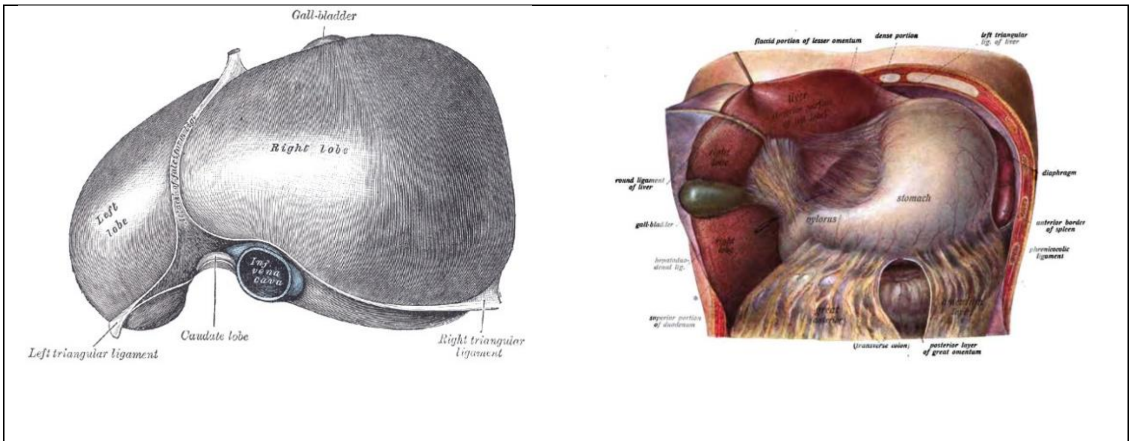


Figure 2. 1. Superior surface of the liver (left), Liver anatomy (right) (Vernon, Wehrle and Kasi, 2020)

The falciform ligament divides the liver into bigger right lobe and smaller left lobe, attaching the liver on its diaphragmatic surface. As for the quadrate and caudate lobes, they are visible on the visceral surface of the liver. With the exception of the gallbladder fossa, where the gallbladder elevates the peritoneum off the hepatic surface, the whole visceral surface of the liver is covered in visceral peritoneum.

Therefore, the peritoneal cavity divides the liver's visceral surface from all other viscera to which it is linked (Bazira, 2023).

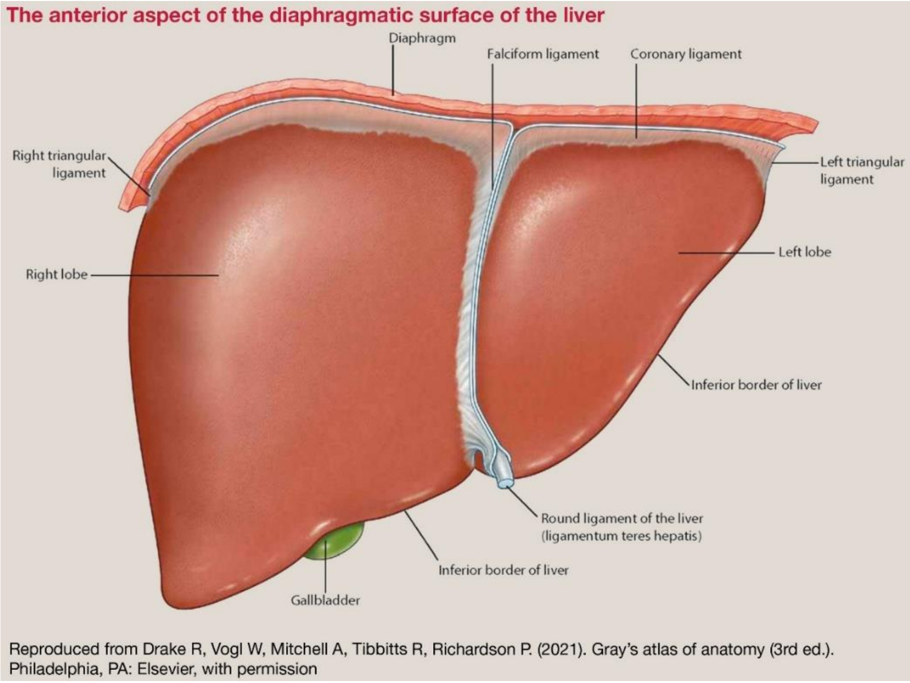


Figure 2. 2. Anterior aspect of the diaphragmatic surface of the liver (Bazira, 2023)

Hepatic artery and portal vein depicts the arterial and venous blood supply to the liver respectively. Both hepatic artery and portal vein splits into the right and left to contribute for right and left hemilivers. Furthermore, all the vein commonly drains into the portal vein which carries blood that supplies oxygen to the hepatocytes (Mahadevan, 2020).

The liver plays crucial role in the human body by interacting with almost every organ system. Firstly, liver functions in bile production as bile is an essential fluid in excreting the substances that the kidneys are not able to eliminate, and consequently contributes in absorption and digestion. Furthermore, liver aids in maintaining the cholesterol homeostasis and stores fat-soluble vitamins. Other functions of the liver include metabolism and detoxification of xenobiotics, synthesizing the body's plasma protein and clotting factors, heme breakdown where the heme is converted to biliverdin, which is then degraded to produce unconjugated bilirubin (Kalra et al., 2023).

2.2 Liver Malignancies

Liver is known as the organ that is commonly exposed to various type of malignancies. It is also said to be usual target for metastases from other cancers such as the colorectal and gastrointestinal cancers (Wust et al., 2021). Even though liver is prone to metastases, there are also primary liver cancers such as hepatocellular carcinoma and cholangiocarcinoma (bile duct cancer). Liver cancer was found to be the sixth most commonly diagnosed cancer and also ranked third as root cause of cancer-related mortality. This statement is evident as liver cancer caused about 830,000 deceased with 90% of the cases were found to be diagnosed with hepatocellular carcinoma (HCC) (Heinze et al., 2023).

Furthermore, hepatocellular carcinoma (HCC) is identified as the primary malignancy affecting the liver, evolving into a significant complication among Asian populations (Mohnike, Ricke and Corradini, 2021). Hepatocellular carcinoma (HCC) being the common form of primary liver cancer has strong relationship with chronic hepatitis B and C virus infections. Apart from HBV and HCV, patients with diabetes are also direct targets of liver cancer as the liver functions in glucose metabolism. As a result of diabetes melitus, consequences such as cirrhosis, fatty liver, liver failure and chronic hepatitis are posed. Furthermore, gender is also included as one of the causes for the development of HCC. As men are more likely to smoke cigarettes, drink and have higher body index. Additionally, the high testosterones level are associated to HCC in hepatitis B carriers (Balogh et al., 2016).

In Malaysia, liver cancer ranks fifth as the most common cause of cancer among males whereas ranks eighth for both genders combined. Globally, the yearly mortality rate due to liver cancer is 11.4% from 100,000 people; Southeast Asia reported 12.1%. In 2013, Malaysia recorded 6.1%, indicating a rise of 42.8% from 1990. The investigation concluded that Hepatitis B virus (HBV) was most frequent cause of HCC, garnering 51.3% of the total of 115 patients (Mohamed et al., 2018). The common indication and symptoms of liver cancer are jaundice, nausea, vomiting, loss of appetite, unusual weight loss, swollen abdomen and fever (National Cancer Institute, 2022).

Detecting the presence of liver cancer at an early stage to provide proper treatment is extremely important. The diagnosis of liver cancer can be done by imaging examinations comprising Ultrasonography, Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Digital Subtraction Angiography (DSA), Nuclear Medicine Imaging and Biopsy (Zhou et al., 2018).

For individuals with primary or secondary liver cancer, surgery remains as the most effective option, however, due to age factor and concomitant medical conditions, health status, severity of hepatic decompensation, undesirable location of the lesion and the extent of metastases makes a large proportion of the patients as poor surgical candidates. Thus, minimally invasive treatment such as high-dose-rate brachytherapy serves as an effective alternative for factors such as tumour size and location does not limit the application of this procedure (Karagiannis et al., 2022).

CT-guided brachytherapy for liver tumour is often used when conventional external beam radiation therapy may not be suitable or when a more targeted and localised approach is desired. It serves as an effective treatment option for certain cases of HCC and other liver malignancies. CT-guided brachytherapy for the liver involves

CT imaging to guide the placement of brachytherapy applicators or catheters directly into or near the liver tumour. The irradiation of the tumour is performed using after-loading technique after the insertion of catheters are done under CT-guided percutaneous implantation (Denecke and Lopez Hänninen, 2008).

2.3 CT-guided interstitial brachytherapy

In a usual brachytherapy practice, the insertion of interstitial catheters can be done under the guidance of various imaging techniques such as fluoroscopy, CT, magnetic resonance imaging (MRI), and ultrasound. CT-guided interstitial brachytherapy for the liver is a medical procedure that involves CT imaging to guide the placement of brachytherapy catheters directly into or near the liver cancer following treatment planning. In a study conducted by Xu et al. (2021), compared intrahepatic progress of 114 patients with hepatocellular carcinoma and 50 patients with colorectal liver metastases following CT-guided HDR brachytherapy (CT-HDRBT). A 6F angiographic sheath was introduced into the lesion under CT-fluoroscopic-guidance. Following the sheath insertion, a close-ended 6F brachytherapy catheter was introduced through it. The positioning of catheters relative to the tumour was visualised using a contrast-enhanced CT scan.

In another study done by Collettini et al. (2013), the technical feasibility and clinical outcome of CT-HDRBT ablation of metastases adjacent to the liver hilum was presented. In this research, a total of 271 patients with unresectable liver metastases were treated using HDR brachytherapy. The catheter placement was done under CT fluoroscopy-guided by utilising 17-G needle and 6F catheter sheath punctured into the target liver lesion. Another study done by Xu et al. (2021), performed using the similar procedure followed by a breath hold contrast-enhanced helical CT scan acquisition of the liver. The purpose of this CT-guided scan is to confirm an accurate position of each catheter within the tumour as it is the foundation for treatment planning and dosimetry.

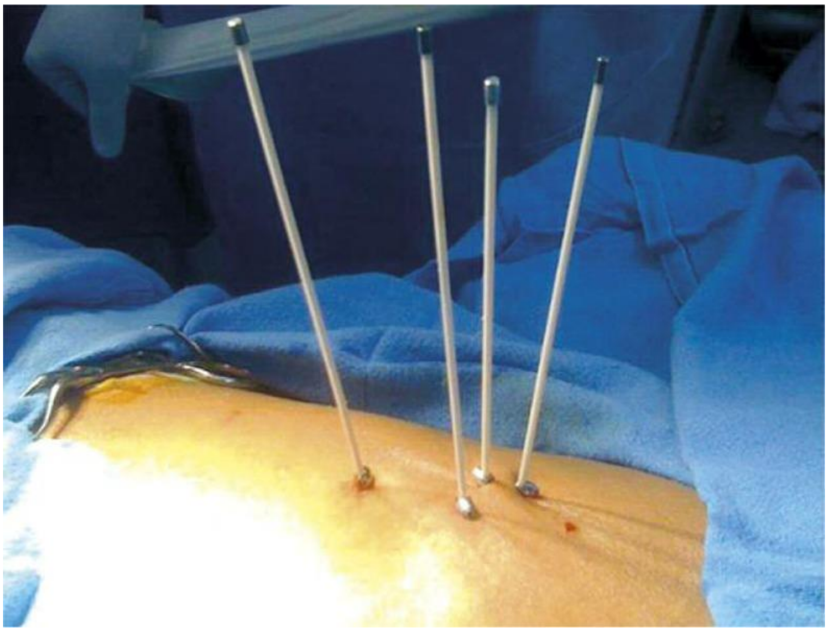


Figure 2. 3. Needle placement with screw in CT-guided interstitial liver brachytherapy (Sharma et al., 2013)

Verifying accurate placement of the catheters are crucial to ensure optimal dose is achieved (Tanderup et al., 2017). The acquired CT images from CT simulation is then transferred to the treatment planning system. There are various software systems in the treatment planning that are used in radiotherapy such as MONACO, Eclipse, Oncentra, Pinnacle and Plato. Sharma et al. (2013) conducted the treatment planning on PLATO planning system where the intended volumes such as clinical target volume (CTV), organ at risk and liver volume were contoured. The planning was then proceeded by marking the implanted needles to reconstruct the needle length. Brachytherapy treatment was then carried out on the patient using Ir-192 source in the Microselectron HDR brachytherapy unit. Upon the completion of treatment delivery, the needles were removed in breath hold position and the puncture site was sealed.

2.4 Advantage of CT-guidance in brachytherapy

In an I-125 brachytherapy treatment, CT guidance allows for clear visualization of the essential blood vessels and organs surrounding the tumour. This enables clinicians to accurately control the direction and depth of the needle implantation. Other than that, carrying out the procedure under CT-guidance helps to reduce the risk of damaging the intestines, vital blood vessels and the bile duct (Xu et al., 2021).

Another study conducted by Kusada et al. (2017), studied the oncologic outcomes and complications of cervical cancer patients from the CT-based image guided brachytherapy (IGBT) technique. They stated that CT is the most preferable imaging technique used as a guidance technique in clinical practices as compared to magnetic resonance imaging (MRI). This is because MRI has few limitations such as limited accessibility and longer operating time for MRI procedure. CT also offers additional benefit of more consistent contouring of larger high-risk clinical target volumes (HR-CTVs) when compared to MRI, as demonstrated in the study by Viswanathan et al. (2014). Besides that, CT scans are superior in terms of spatial resolution where structures such as bone can be clearly seen.

Furthermore, CT scans require less time compared to MRI which is surely helpful in dealing with patients who are in pain (DeMarco, 2023). Moreover, the MRI is usually not located within the department in plenty of the radiation oncology department, hence, the patient needs to be brought back to the procedure suite if any needles are required to be inserted, removed or retracted, and then they must return to acquire the post-implant scan. This results in more patient exposure to general anesthesia, increased use of clinic and hospital resources as well as cause higher costs. (Elledge et al., 2020)

2.5 Factors that affect number of catheters being inserted under CT-guidance

Catheters are narrow tubes that are introduced through angiographic introducer sheath into the tumor under CT guidance. Multiple-catheter insertion technique is applied for liver brachytherapy for the radioactive sources to pass though the catheter from the remote after-loader into the tissue being treated. The number and trajectory of simulated brachytherapy catheters are usually determined cooperatively between interventional radiologists and radiation oncologists who are well versed in brachytherapy. (Hass et al., 2019)

In a study conducted by Wieners et al. (2015), it stated that the arrangement and number of catheters are determined based on the shape, size of the lesion and the local anatomy of the tumour. A study by Kieszko et al. (2018) indicated that during interstitial liver brachytherapy, the number of catheters inserted is determined by the size of the tumour to ensure comprehensive coverage of the entire tumour volume. The positioning of these catheters is guided by CT imaging. The positioning of the catheters was performed with the guidance of CT imaging with simultaneous administration of a single-dose intravenous iodinated non-ionizing intravenous contrast agent.

In the study by Omari et al. (2018), visceral metastases including those in the liver, lymph nodes, and adrenal glands, as well as additional lung metastases, were treated. They reported that an average of 2.3 catheters per lesion were used to fully cover the target lesions for 21 metastases, which had a median diameter of 2.2 cm. Table 2.1 presented the number of lesions, and its maximum diameter associated with the number of catheters used per lesion for liver metastases.

Table 2.1. Summary of the number of catheters used per lesion for liver metastases (Omari et al., 2018)

Number of lesions	Maximum diameter (cm) of lesions	Number of catheters used per lesion
1	4.1	3
1	6.3	5
1	6.8	7
5	3.4 / 1.9 / 2.7 / 1.2 / 0.9	2 / 2 / 1 / 1 / 1

2.6 CT Dosimetry

Parameters such as CT dose index ($CTDI_{vol}$), scan length and dose-length product (DLP) are essential in determining the radiation dose related to CT-guided interventional procedure to ensure patient protection and efficiency of the procedure.

Inoue (2023) reported that volume CT dose index ($CTDI_{vol}$) indicates the intensity of radiation exposure during imaging procedure and the $CTDI_{vol}$ value is obtained directly from the CT scanner and it is based on the measurement done on a dosimetry phantom of 16cm or 32cm. Therefore, $CTDI_{vol}$ does not depict nor estimate patient dose.

Furthermore, $CTDI_{vol}$ is the parameter used to compare machine performance including the radiation output between the CT scanners. Particularly, there are a number of aspects that influence the value of $CTDI_{vol}$ namely the scan conditions including the tube voltage, tube current, collimator size, gantry rotation time, pitch factor and the use of bowtie filter. Moreover, the dose delivered to the patients undergoing brachytherapy differs depending on imaging modalities that are used, imaging protocols implemented in different institutes and the image quality produced (Okamoto et al., 2020).

In a study done by Yang et al. (2018), the CT scans were executed at 120 kV with pitch values of either 0.563, 0.938 or 1.375 and under tube current modulation or fixed mAs. The radiation dose varies based on a few aspects such as the size of the patient, target site and the complicatedness of the interventional task. Since there are numerous values of $CTDI_{vol}$ per examination, $CTDI_{vol}$ value is acquired by summing individual $CTDI_{vol}$ from each series. Furthermore, the DLP value is also described as the summation of DLP values from individual scan series.

Inoue et al. (2015) investigated the dose-length product in computed tomography of the chest considering sex and body weight where eight-hundred CT examinations of the chest were done using four different CT scanners. Dose length product (DLP) are usually used as the indicator of the radiation dose in CT along with $CTDI_{vol}$. DLP is described as the total dose delivered for the complete scan range and it emerged as a helpful key in determining and monitoring the radiation dose in CT. The equation in determining the DLP as described in this study is as follows:

$$Dose\ length\ product\ (DLP) = CTDI_{vol} \times scan\ length$$

In this paper, DLP is said to be dependent on patient size. For example, when larger size patients are treated, the scan range is increased to include the required region in the scan thus further increasing the DLP given the same scanner and imaging protocol is used. Other than that, DLP also highly varies according to the scanner being used as derived from this study and it is also described to be relying on the imaging protocol and the gender of the patient under that procedure.

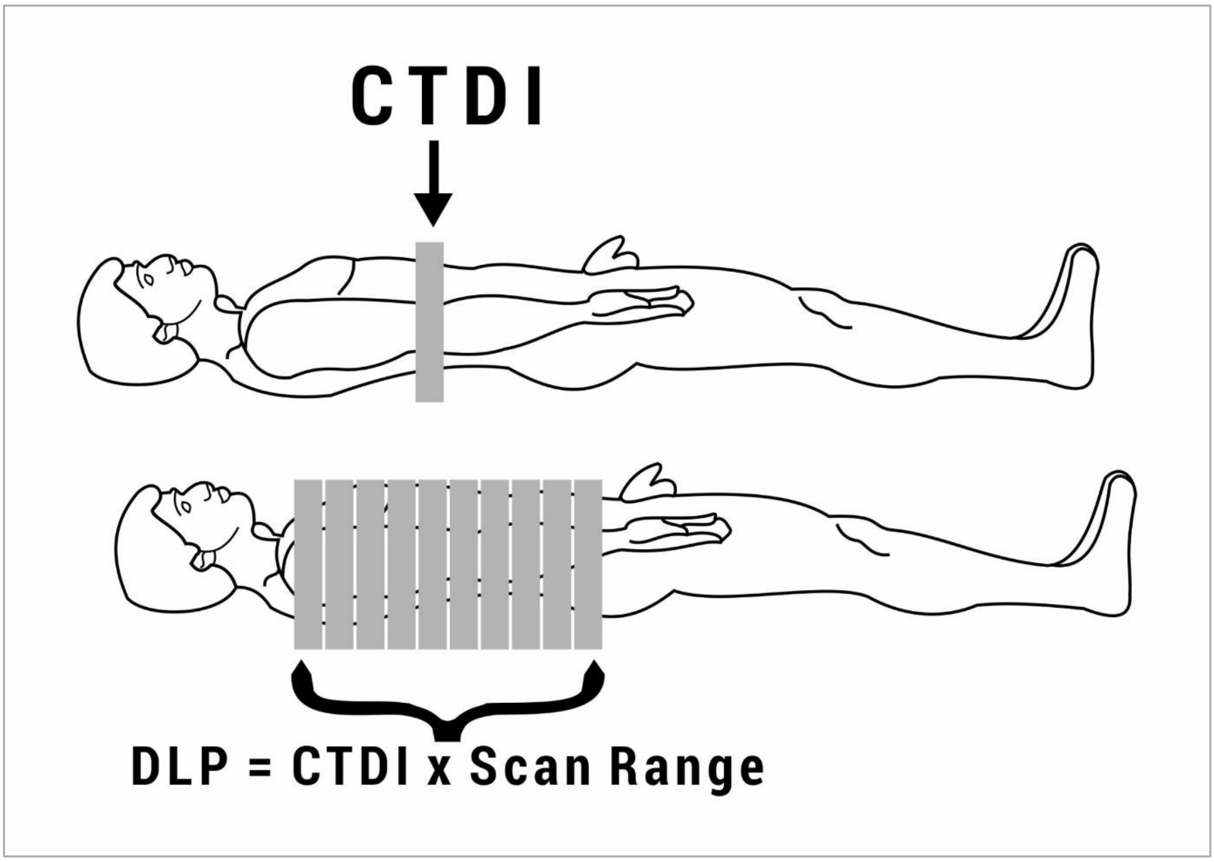


Figure 2. 4. Illustration on CTDI, DLP and scan range (Essam, 2019)

2.7 CT dose reduction method

There are few parameters that can be altered to reduce CT radiation dose during CT-guided interventional procedures (Lamba, 2014). This is because this procedure will contribute particularly higher dose within the treated regions (abdomen and pelvis). Tube current was known as one of the factors in which reducing the tube current-time product (mAs) will reduce the overall dose delivered. Besides that, analysing prior CT images can aid in determining the range of scanning to avoid taking repeated scans which in turn might reduce the radiation dose from CT.

Furthermore, improving the target contrast serves as one of the methods that can reduce the CT dose. This is because, as a consequence of low target-to-background contrast of lesion, the CT-guided procedure especially in the liver is resulted in technical difficulty.

Raman et al. (2013) investigated about CT scan parameters and radiation dose as a guide for the radiologists and reported that altering the CT parameters such detector configuration, tube current, tube potential (kVp), reconstruction algorithm, patient positioning, scan range slice thickness and pitch will reduce CT dose contributed to the patient as the radiation dose received by the patient during CT imaging is highly concerning.

Patient positioning should be done properly as misplacement or rotation of the patient will affect the patient surface dose as well as obstructing the image quality. This is evident as they found that incorrect centering of phantoms in the scanner gantry resulted an increase of 23% in surface dose and an increase of 7% in image noise. Moreover, the scan range is also said to have a great influence on CT dose. The scan range should be minimised to an extent that only the intended organ and region should be included due to the fact that increasing the scanning range will cause unnecessary exposure to the patient.

In the same year, another paper by Raman, Johnson, et al. (2013) described about the CT dose reduction applications and reported that the radiation dose can be decreased by reducing the tube voltage (kVp). However, study by Inoue (2023) reported that reducing the CT radiation dose will increase the image noise causing it to be grainy which indicates that there will be drawbacks in other aspects in attempting to reduce the radiation dose to almost none.

2.8 Organ dose

Organ dose refers to the absorbed dose to a specific organ in the body, it is often calculated as the ratio of the energy deposited in the organ by ionizing radiation to the mass of the organ. The accurate approach in predicting organ dose involves simulating CT scans and computing organ dose using computational anthropomorphic phantoms with realistic anatomical features, utilizing Monte Carlo (MC) algorithms (Gao et al., 2017).

Since $CTDI_{vol}$ and DLP are initially determined by the manufacturer using standardized phantoms, which are typically shown on the console when doing CT scans, these values do not reflect the absorbed dose of actual patients. This is because, the tissue composition of human bodies varies widely, therefore, it is critical to determine the organ dose to each organ when evaluating the radiation exposure from CT scans (Yamashita et al., 2021).

Organ dose depends on the patient's anatomy, scan region and scanner's output. Several studies confirmed that dose estimation is very difficult for organs at the borders of the scan regions (Mattia et al., 2020). The association of patient age >18 years and male sex with higher radiation dose is likely related to overall increased bodyweight and differences in the body-habitus. Prior studies have demonstrated higher radiation dose in males. Males are, however, less radiosensitive and have lower cancer risk when exposed to similar (or even higher) radiation doses (Nagpal et al., 2020).

CT imaging has been widely used for various diagnostic and interventional procedures that the level of radiation dose became a concern that has been discussed in many studies. This is because the lower energy photons are absorbed in the body's superficial tissues, where they simply raise the received doses, particularly in delicate organs such as thyroid, eyes, gonads, and breast, however they do not contribute in image construction (Hakimabad, Motavalli and Akhlaghi, 2014).

The hematopoietic system, gastrointestinal system, skin, reproductive system and brain are the most vulnerable organs to radiation. While high-dose whole-body irradiation which is greater or equals to 8 Gy in humans causes acute GI syndrome in addition to hematopoietic complications, a dose range of 1-7 Gy in humans poses a risk of damage to the hematopoietic system, resulting in decrease in blood cells and platelet counts and increases in susceptibility to infection and hemorrhage (Kiang and Olabisi, 2019).

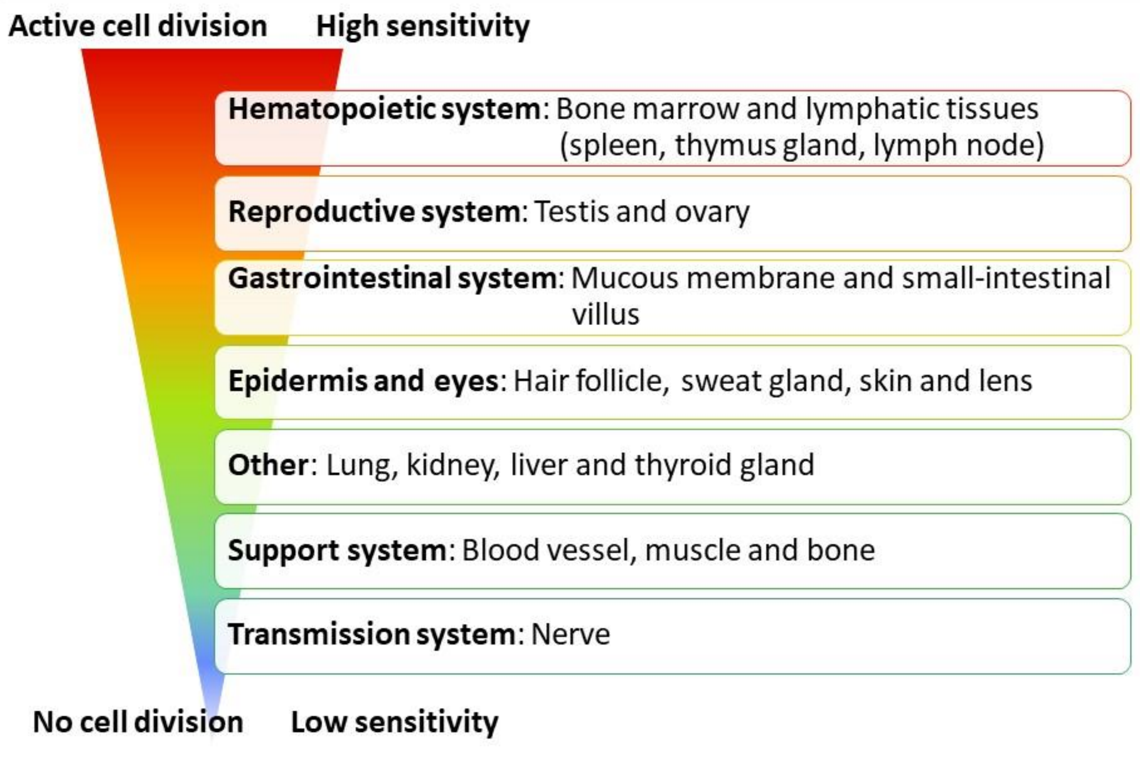


Figure 2. 5. Radiosensitivity of organs and tissues (Ministry of Environment Government of Japan, 2013)

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Research Tools

3.1.1 CT Simulator

This study included CT data acquired using the CT simulator stationed at the Oncology and Radiotherapy Unit in Advanced Medical and Dental Institute (AMDI), Universiti Sains Malaysia, Bertam, Kepala Batas, Penang. The CT simulator used is the Toshiba Aquilion LB (Cannon Medical System Malaysia Sdn Bhd), presented in Appendix B.

The CT simulator is different from a diagnostic CT which is evident from the physical appearance of the CT simulator as it has bigger bore, laser marking system and a flat table. Each of these dissimilarities has its purpose, for instance, the bore of the CT simulator is larger to accommodate various patient positioning during CT simulation. The CT simulator consists of the CT scanner and CT simulation control panel in which the technical parameters are selected during the procedure. The scan images are displayed on the monitor along with the CT parameters for each patient.

Figure 3. 1. CT Simulator Aquilion LB

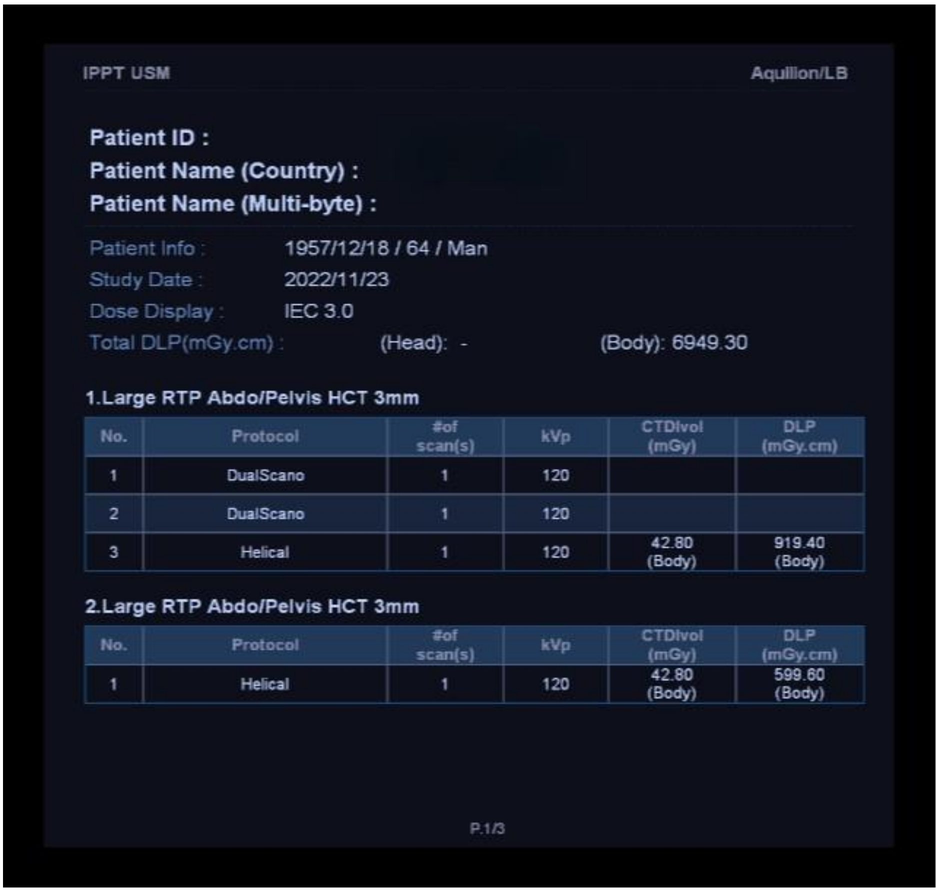
3.1.2 Pictures Archiving and Communication System

Pictures Archiving and Communication System (PACS) is the digital system used in the medical field to store patient information and images. Data such as CT scan model, number of CT phases, CT protocol, exposure settings (kVp, mAs, pitch) and CT dose indices ($CTDI_{vol}$ and DLP) were collected from PACS (ZFP version 6.0, GE Healthcare).

The images and data that are routinely stored in the department's PACS permits other departments in both PPUSMB and HUSM to access the intended details. The implication of PACS in this study has eased up the process of retrieving and reviewing the images and required data of each patient. Apart from that, retrieval of data from this system was time-saving. The data collected from PACS was used to calculate the organ dose from selected image slices while the CT parameters recorded was used to determine the relationship between variables.

In addition, PACS provided the CT dose report for patients which aided in gathering the CT dose indices ($CTDI_{vol}$ and DLP). The value of individual $CTDI_{vol}$

and DLP was used to calculate the total $CTDI_{vol}$ and total DLP so as to satisfy the study objectives. An example of the collected dose report is presented.



IPPT USM Aquilion/LB

Patient ID :
Patient Name (Country) :
Patient Name (Multi-byte) :

Patient Info : 1957/12/18 / 64 / Man
Study Date : 2022/11/23
Dose Display : IEC 3.0
Total DLP(mGy.cm) : (Head): - (Body): 6949.30

1.Large RTP Abdo/Pelvis HCT 3mm

No.	Protocol	#of scan(s)	kVp	CTDIvol (mGy)	DLP (mGy.cm)
1	DualScano	1	120		
2	DualScano	1	120		
3	Helical	1	120	42.80 (Body)	919.40 (Body)

2.Large RTP Abdo/Pelvis HCT 3mm

No.	Protocol	#of scan(s)	kVp	CTDIvol (mGy)	DLP (mGy.cm)
1	Helical	1	120	42.80 (Body)	599.60 (Body)

P.1/3

Figure 3. 2. Layout of Dose Report

While department staff and students may have permission to access PACS, the system still mandates the use of authorized identification and passwords to protect patient confidentiality.

3.1.3 IndoseCT software

Indose-CT (Version 20.b) software developed by Anam et al. back in 2015, is used to calculate the radiation dose of patients' that underwent CT examination. This software has been recognised and recorded in the Letter of Registration of Creation, Ministry of Law and Human Rights and Republic of Indonesia.

IndoseCT software was installed and used to calculate organ dose for each patient included in this study. The axial CT image obtained from PACS was uploaded in the IndoseCT software to estimate organ dose. Once the image is uploaded, the patient data is displayed making it easier for patient verification. The organ dose is also shown in graphs which quickens the process of deriving 10 organs receiving the highest dose for each patient, the example of organ dose graph generated by the software is provided in Appendix B. Apart from organ dose estimation, IndoseCT thoroughly provides tools to store patient dosimetry data in the database.

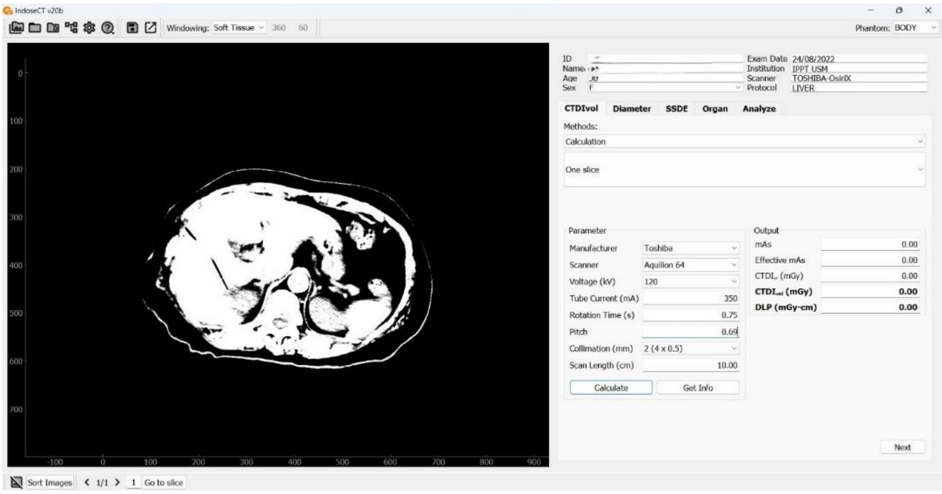


Figure 3. 3. Screenshot of IndoseCT software layout

3.1.4 Microsoft Excel

Microsoft excel was used to manage and clean the data. The spreadsheet aids in clearly visualizing the raw data to be used for further analysis. The excel sheet accommodated all the data such as patient ID, gender, age, exam date and CT scan model were collected and easily tabulated in the spreadsheet.

Furthermore, the corresponding data of technical parameters (kVp, mAs, pitch factor), number of catheters for each patient, number of CT phases, CT protocol, dose indices ($CTDI_{vol}$, DLP and total DLP), volume of lesion and diameter of lesion were added manually in the spreadsheet which was then organised to be viewed without difficulty. The spreadsheet of raw data is presented in Figure 6.5 (Appendix B).

3.1.5 IBM SPSS Statistics Version 27.0

International Business Machine (IBM) Statistical Package for the Social Sciences (SPSS) Statistic (Version 27.0) was incorporated in this study to run descriptive and statistical analysis. The software calculated all the selected data for evaluation of patient dose where the SPSS spreadsheet is presented in Figure 6.6 (Appendix B). Descriptive analysis was done for CT dose parameters such as scan length, CT dose ($CTDI_{vol}$ and DLP) and organ dose. On the contrary, statistical analysis was done to determine the correlation between number of catheters with the CT dose ($CTDI_{vol}$ and DLP), number of phases, volume of lesion and diameter of lesion.

3.2 RESEARCH METHODOLOGY

3.2.1 Study Design

This study involved a retrospective survey on evaluation of patient dose in CT-guided multi-catheter insertion for interstitial liver brachytherapy where patients' demographic information (age and gender), CT data (number of catheters, number of CT phases, exposure settings – kVp, mAs, pitch and scan length (in cm)), patient dose data ($CTDI_{vol}$(in mGy) and total DLP (in mGy.cm)), volume of lesion (in cm^3) and diameter of lesion (in cm) were retrieved from CT workstation and recorded for further analysis. Besides that, the axial CT images of patients were be obtained and retrieved from the Picture Archiving and Communication System (PACS) for further analysis.