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Signal Quantification of Intravenous Contrast Media Enhancement From Biphase Liver CT Scan Procedures

Rawa' Khaled Abed Almajeed Alqam

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Prepared By: Rawa’ Khaled Alqam

B.Sc. of Medical Imaging, Palestine Ahliya University, Palestine

Supervisor: Dr. Hjouj Mohammad

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Prepared by: Rawa' Khaled Alqam
Registration Number: 21911987
Supervisor: Dr. Mohammad Hjouj

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The name and signatures of the examining committee members are as Follows:

1- Head of the committee:	Dr. Mohammad Hjouj	Signature:
2- Internal Examiner:	Dr. Hussien ALMasri	Signature: Hussein ALMasri
3- External Examiner:	Dr. Muntaser S. Ahmad	Signature:

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Dedication

I arise today
Inspired by the land of beauty, Palestine
With its flowers blooming in small children's smiles
With sun shining from its people heart
With its soil delighting, the deepest roots of the surviving olive trees
Today I arise and pray, for the wind of change.
My heartfelt gratefulness to my Parents, Family, and friends.

Rawa' Khaled Alqam

Declaration

I certify that this thesis submitted for the degree of master, is the result of my own research, except where otherwise acknowledged, and that thesis has not been submitted for a higher degree to any other university or institution.

Signed: 

Rawa' Khaled Alqam

Date: 22/7/2023

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Rawa' Khaled Alqam

Abstract

Computed Tomography (CT) is a diagnostic imaging technique that produces comprehensive images of skeletons, arteries, veins, tissues of the body, and organs inside the body. This imaging program MSc thesis concentrated on contrast agent (CA) assessed to the region of interest (ROI) in CT image. It was compared with automated bolus monitoring with a fixed time delay technique of contrast enhancement in multi-detector computed tomography (MDCT) during abdominal and pelvic CT treatments using an intravenous (IV) CA. During this investigation, all variables impacting contrast enhancement were collected, including patient characteristics such as body weight, cardiac output, and contrast injection settings. The sample for this study was split into two groups: 100 retrospective and 43 prospective patients. Hounsfield Unit was measured before administering the CA, and it was also measured 30 seconds and 70 seconds after administering the CA in the first group. This group contained 50 patients from a government hospital and another 50 patients from an Non-Governmental hospital. The second group collected patient information, which included the patient's age, weight, heart rate, systolic and diastolic blood pressure, and Creatinine level. HU values were measured before and after the CA was administered at a time estimated by the radiographic technologist based on the HU values reaching 120. The HU values in both groups were analyzed to determine the differences between both HU measurements and to develop an equation for predicting imaging time when employing the automated bolus monitoring technique. The study's findings revealed that there is no difference in age between males and females in all sample patients, and the predictors of the Bolus Time Equation dealt with patient weight, heart rate, Creatinine level, and systolic blood pressure, where the percentage of dependence on these variables was up to 34.9%, and the effect of each variable in the equation had a value of up to 59.1%. The ANOVA test demonstrated that this equation can be relied upon, as the result was $p = 0.002$. When the equation was used, the findings revealed no discrepancies between the Bolus Time value gathered in the study and the Bolus Time utilizing the equation, with a p-value of ($0.992 > 0.05$). The HU rate differed significantly between the first group and the second group, where the p-value was 0.00. The research indicated that using bolus monitoring resulted in a wide range of enhancements compared to when fixed-time was used, and the bolus tracking produced better improvement results than fixed-time.

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Abbreviations

CT	Computed Tomography
HU	Hounsfield Unit
IV	Intravenous
CM	Contrast Media
MRI	Magnetic Resonance Imaging
MDCT	Multi-Detector Computed Tomography.
EAP	Early Arterial Phase
LAP	Late Arterial Phase
LPP	Late Portal Phase
NgP	Nephrogenic Phase
DP	Delayed Phase
SVC	Superior Vena Cava
ROI	Region of Interest
FOV	Field of View
ST	Slice Thickness
SNR	Signal-To-Noise Ratio
CNR	Contrast-To-Noise Ratio
NECT	Non-Enhanced Computed Tomography.
kVp	Kilovoltage Peak
SPSS	Statistical Package for The Social Sciences
PACS	Picture Archiving And Communication System
NGO	Non-Governmental Organization
WT	Patient Weight
HT	Patient Height
HR	Heart Rate
SBP	Systolic Blood Pressure
DBP	Diastolic Blood Pressure

Definitions

X-Ray: is a form of radiation is released when electrons in an atom move to a less energetic state.

CT: CT stands for computed tomography. CT is an X-ray system that uses X-rays in conjunction with computerized algorithms to produce images of the internal organs of the body and structures.

Contrast Media (CM): is a substance with a high atomic number and density that is used to augment the HU disparities between human body structures.

Intravenous (IV): is one method that describes how material from outside the body interacts with the person. The procedure for injecting fluids into a vein.

Bolus Tracking Monitoring: is monitors the attenuation within a vessel or target organ on repeated axial sections.

Fixed Timing technique: is a fixed delayed period for a post-contrast injection.

Hounsfield unit (HU) : is a relative quantitative measurement of radio density used by radiologists in the interpretation of computed tomography (CT) images.
Arterial phase helical CT: is an acquisition obtained during peak arterial contrast opacification.

Portal Venous Phase of CT : is a liver imaging typically occurs at 60 to 90 seconds after the start of IV contrast injection and is characterized by full enhancement of the portal veins and hepatic arteries, forward enhancement of the hepatic veins, and bright liver parenchymal enhancement.

Delayed Phase: is obtained at 3 to 5 minutes after contrast injection. During this phase, contrast has equilibrated between the intravascular and interstitial water of the liver.

Chapter 1

Introduction

1.1 Background of The Study

Computed Tomography (CT) is a diagnostic imaging technique that produces comprehensive images of skeletons, arteries, veins, tissues of the body, and organs inside the body. Clinicians can use CT to find and diagnose trauma injuries, identify the location and size of a lesion, identify tumor stages, evaluate diseases, identify the location of blood coagulates, detect pulmonary and heart diseases, and recognize ambiguous stomach disorders.

CT is a common modality that comes in a variety of sizes, devices, and slice numbers (number of channels). Philips, Siemens, Toshiba, and GE are the leading CT scan manufacturers. Each CT scanning brand offers a variety of CT scan machines. All brands use computer technologies to calculate the Hounsfield Unit (HU), utilizing a compilation algorithm to build axial or horizontal images (slices) of the human body. CT scan cross-sectional images can be reconstructed in several planes to provide three-dimensional views. CT scanning is frequently the most effective diagnostic technique for various illnesses. Because it is rapid, painless, noninvasive, and extremely accurate, it aids clinicians in recognizing numerous diseases, saving valuable time for patients. It can identify injuries inside that are bleeding sufficiently rapidly in an emergency situation to help preserve human lives (Jensen et al., 2019).

There are numerous CT protocols. One of the most popular is liver and abdominal protocol. In this protocol, CT imaging uses intravenous (IV) contrast Media to visualize the intricate structure of the liver and other abdominal organs in order to improve both diagnosis and therapy. For all patients, the CT protocols employed in the imaging department are the same. To acquire optimal image quality at the ideal time to take an image with perfect organ enhancement, it must perform different protocols depending on the patient. CM reaches organs at various times in different people. CT has presented researchers with ongoing possibilities to improve image quality and clinical practice (CHOI et al., 2015).

CT scans can be performed with or without the use of injectable CM. The contrast media is a chemical material that is taken orally and/or injected into an IV line to make the organ or tissue under study more visible (enhanced). CAs are a class of chemical compounds that have been produced to aid in pathological characterization by enhancing the contrast resolution of an imaging modality. Different contrast media have been designed for each structural imaging technique and administration strategy. There are numerous CM, each with its own unique image modalities; barium sulfate contrast media have been employed in the gastrointestinal tract. Radiographic, fluoroscopic, angiographic, and CT imaging all use iodinated contrast fluids, while magnetic resonance imaging (MRI) uses gadolinium contrast agents.

All CT contrast media in CT are extracellular fluid indicators that are distributed in intravascular and interstitial space and excreted by the kidney; CM operates by utilizing compounds that interact with how medical imaging technology acquires images. The contrast used in CT scans is a chemical that absorbs radiation in specific areas of the body.

This concept alters the appearance of the tissues containing the medical imaging contrast on the images.

There are many factors that radiologic technologists should consider when using CM, such as the duration of injection, which is the most important injection-related factor influencing CT scan timing, and the amount of CM, which corresponds to the essential patient-specific variables influencing the amount of vascular and parenchymal contrast enhancement, the latter of which is represented by body weight (Eisa et al., 2012).

Numerous interacting factors influence the enhancement of contrast in CT. These elements can be classified into three types: patient, contrast media, and CT scanning. Individual differences in body weight, blood flow, circulatory time, and cardiac abnormalities can all affect the time window of the contrast material as well as the required rate and volume. As a result, they may present difficulties in attaining optimal contrast enhancement (Adibi & Shahbazi, 2014). According to CM, the viscosity, osmolarity, ioniscity, and other chemical properties affect the enhancement of CM in the organs, while CT scanning types, particularly the number of channels employed, also affect the CM enchantment.

Timing tracking and automatic bolus tracking are the two basic strategies used in CT scan assessment with CM. Automatic bolus tracking is a technique for optimizing imaging time. It is a bolus contrast synchronizing tomographic modality that is frequently used in human medicine, mostly for assessing the cardio circulatory system and permeability index of neoplasms, most of which are found in the liver. By selecting a location of interest, usually located in a vessel's lumen, the bolus tracking approach enables real-time monitoring of the contrast bolus.

1.2 Problem Statement

With the latest advances in helical computed tomography (CT) technology, multi-detector CT (MDCT) scanning of the whole liver in less than 20 seconds with two or more separate phases is now achievable. With this fast scanning, it is critical to reduce the time delay between the contrast agent injection and the diagnostic scan beginning, particularly for the arterial phase. Individual differences in body weight, heart rate, and cardiac blood pressure might affect the time frame and the required rate and amount of the contrast agent, making it challenging to achieve optimal contrast enhancement.

Tracking the bolus technique of the contrast agent could assist with individualizing the time delay, but it is a time-consuming procedure. To address these constraints, an automated bolus monitoring system that automatically launches diagnostic scans prompted by contrast enhancement has been recently developed. Using low-dose scans (approximately 50 mA), this method enables scans to begin, either manually or automatically, when the contrast enhancement in a region of interest (ROI) reaches a predetermined threshold.

Some investigations found that automated bolus tracking might increase the degree of contrast enhancement and lesion-to-parenchyma conspicuity by better individualizing the time delay for the beginning of diagnostic scans of the liver and pancreas. However, this area still has considerable debate, and past research has yielded conflicting findings. Some studies propose bolus monitoring only if the patient is over 70 years old, has

cardiovascular diseases, or has no appropriate antecubital vein for a contrast agent injection to decrease the excess radiation dosage(Itoh et al., 2004). Furthermore, some studies have shown that using the bolus monitoring approach, 35% of patients may not attain a threshold of 50 HU above baseline within 60 seconds following injection beginning, necessitating a programmed delay(Paulson et al., 1998). and some studies have shown compared between the fixed time and bolus tracking technique, individualized fixed time could achieve reliable scan timing, optimize vessel opacification and obtain better image quality for head and neck CT angiography. (Yuan, 2023)

Many medical imaging departments employ hepatic, abdominal, and pelvic CT procedures on a regular basis. The procedure is often carried out by injecting an iodine-containing contrast agent. However, for various individuals, contrast media enters the ROI at different times and with varying degrees of enhancement due to various parameters such as the patient's blood pressure, weight, injection rate, contrast agent amount, and other factors.

1.3 Justification

Fixed time delay, timed bolus, and automated bolus tracking are the most commonly used CT protocols. The fixed-time approach initiates CT scanning by administering CM. This delay will be computed based on past data and the operator's comprehension. Variations were often overlooked. Although this procedure promised a positive outcome, especially in people with no underlying cardiovascular disease, scan delays should be customized to each person.
In the timed bolus approach, CM is given in a small amount (15 to 20 ml), and then repeated low-dose CT scans are performed. The graph of the enhancement-time connection is drawn to calculate the time to peak enhancement and, hence, the scan delay. The timing bolus approach still has a flaw in that, despite using a lot of contrast, there is no discernible increase in contrast enhancement degree. The bolus tracking approach employs a series of low-dose scans that are initiated when a full bolus of CM has been injected and vascular enhancement at the anatomic region of interest (ROI) exceeds a predetermined threshold. This approach saves CM and is successful. However, the scan may fail if the ROI is wrong, the patient moves, or there is a venous inflow issue.

In CT, accurate timing optimization is required to obtain optimal contrast enhancement; hence, superior image quality is important for monitoring human anatomical structures and diagnosing disorders.

1.4 Study Objectives

This dissertation has different aims:

1. To assess the effectiveness of automated bolus monitoring vs. fixed time delay in liver procedure contrast enhancement of the liver undergoing MDCT.

2. Creating an equation to determine the best time to produce an image in a bolus monitoring approach.

1.5 Study Hypothesis

Hypothesis 1: public hospital do not use standard criteria for injecting iodine-based contrast material in terms of injection rate, volume, and most importantly, timing.

Hypothesis 2: using an automated bolus tracking approach to determine the suitable injecting timing in performing dual-phase liver CT improve contrast enhancement in the abdominal organ over a fixed delay time.

Chapter 2

Literature Review

2.1 Introduction

Developments in computed tomography (CT) enable multi-detector CT (MDCT) to scan every part of the liver through various perfusion phases in a mere twenty seconds(Itoh et al., 2004). This rapid scanning is critical for minimizing the time between the contrast agent injection and the diagnosis process. Individual variability in cardiac limitations, body weight, circulatory time, and heart rate may impact the time as well as the needed volume and rate of the contrast agent, making attaining optimal enhancement of contrast more difficult(Adibi & Shahbazi, 2014).

The computerized bolus tracking system was automatically built to overcome these constraints. Automatic bolus tracking is the best pancreatic and liver disease, enhancing (CA)(Fukukura et al., 2010)(Kulkarni et al., 2018). However, there remains some debate in this area, and earlier studies yielded various outcomes. Some research studies propose bolus tracking only if the patient is age over 70, has cardiovascular illness, and there is inadequate antecubital vein to inject CA to limit the excess radiation dose. Furthermore, certain studies have shown that when using the bolus tracking approach, 35% of patients might fail to reach a threshold of 50 HU over baseline by 60 seconds following injection beginning, necessitating the use of a programmed delay. (paulson et al., 1998) Furthermore, a study found that while contrast enhancement of the spleen and aorta rose, it did not affect liver enhancement. Bolus tracking technique, on the other hand, is associated with lower variation in liver enhancement among patients(Choi et al., 2016).

2.2 Contrast Media(CM)

To differentiate between adjacent tissues on a CT scan, these tissues need to have distinct attenuation. varied attenuation coefficients occur as a result of the varied densities, different atomic numbers, and different tissues thickness, and different energy used leading to an image that effectively reveals the distinct tissues.

To create an attenuation difference between the patient's organs, a contrast agent (CA) is usually administered orally or intravenously. The goal is to assign diverse attenuation coefficients to various tissues that would otherwise have equal attenuation coefficients; these strategies increase the visibility of the organs in the CT image. Although intravenous injection is the most widespread, it can also be delivered by gastrointestinal (oral, rectal), cystourethral, vaginal, intraosseous, and other pathways.

2.3 Phases of Intravenous (Iv) Contrast Enhancement

In CT scans, CA is used for identifying pathology by enhancing the contrast between a lesion and adjacent normal structures. In some cases, a lesion will be hypovascular compared to normal tissue. Conversely, a lesion will be hypervascular compared to

adjacent tissue throughout the enhancing process in certain circumstances(Jensen et al., 2019).

The enhancement in CT can be seen in several stages(Yap et al., 2021); Without contrast agent (CT), which is useful in detecting diseases such as calcium deposits, adrenocortical adenomas, appendicitis, diverticulitis, and omental infarction; Early arterial phase (EAP): 15-20 seconds following contrast administration or bolus tracking. The contrast is limited to the vasculature except in hepatic artery and has not benefited the body's organs or soft tissues; Late arterial phase (LAP): 35-40 seconds following contrast administration. In this stage, a portal vein and the organs that accept the blood are evident and are going to be enhanced; Late portal phase (LPP): 70-80 seconds following contrast administration. The portal vein supplies blood to the liver during the late portal phase; Nephrogenic phase (NgP): 100 seconds following contrast administration. This phase happens as the medulla and the remainder of the parenchyma of the kidney improve. Only during this stage can small renal cell carcinomas be detected; The delayed phase (DP) occurs 6-10 minutes after the contrast administration. Except for fibrous tissue, which exhibits poor late washout and will grow fairly dense compared to adjacent normal tissue, all abdominal organs have been washed out of contrast.

2.4 Factors Determining Contrast Enhancement and Timing

The patient, contrast injections, and CT scans are the key components determining CM enhancement in CT imaging. The CT scan (image acquisition) variables, on the other hand, are critical for viewing the contrast enhancement effectively. Although all of these aspects and parameters that determine contrast enhancement are intimately connected, various parameters affect the degree and timing of contrast enhancement (Ye, 2022).

2.4.1 Patients Factors:

The body weight is cardinal output have significant impact on CT enhancement. Light contrast enhancement is affected by the patient's weight, gender, age, kidney function, numerous clinical states, and venous access (Eisa et al., 2012). One of the patient characteristics influencing the CM in CT images is patient weight. The blood volume is higher when a patient is overweight than when the patient is underweight. Furthermore, the CM in the blood is diluted more in overweight patients than in underweight ones. As a result, the extent of enhancement and the patient has an inverse interaction (Hubbard et al., 2019).

Also, one of the most important patient factors determining contrast enhancement timing is the heart's output. When cardiac output falls, the contrast bolus arrives, delaying peak arterial and parenchymal enhancement and slowing contrast medium circulation. The period between the arrival of the contrast bolus and the greatest enhancement in the aorta and liver is directly related to and proportionate to the decrease in cardiac output that occurs. When cardiac output is reduced, the contrast bolus is eliminated more slowly once it reaches the central blood compartment, resulting in a higher, more prolonged enhancement(Apitzsch et al., 2016).

2.4.2 Contrast Injection Factors:

Injection time, injection rates, contrast medium volume (= injections duration x rate), concentration, and use of saline flushing are all parameters that influence contrast injections(Onishi et al., 2011).

2.4.2.1 Injection Duration:

The injection duration is determined by the contrast volume and the rate at which it is delivered. Injection duration substantially influences the magnitude and timing of contrast enhancement. If a greater iodine mass is deposited with an extended injection duration, the amount of vascular and parenchymal enhancement rises. Scan time influences the length of CM injection(Yamaguchi et al., 2011).

2.4.2.2 Injection Rate:

When the rate of injection is increased at a particular volume of CM, the magnitude of enhancement grows and occurs earlier, and the duration of high-magnitude enhancement is reduced. However, for a given increase in injection rate, the rate of rise in the amplitude of aorta contrast enhancement is significantly higher than that of the liver. Consequently, a wider timing window of desired contrast enhancement increases the amplitude of the vascular and parenchymal enhancement peaks(Murakami et al., 2006).

2.4.2.3 Concentration:

A greater amount of iodine concentration in the CM instantly results in a larger overall iodine dosage. As a result, the amplitude of the peak contrast enhancement is enhanced, and the time window for a given quantity of enhancement is extended. The time to peak enhancement remains constant since the injection duration and rate stay constant(Bae & Heiken, 2005).

2.4.2.4 Saline Flush:

A saline flush pushes the remaining portion of the injected contrast bolus into the central blood volume, which is otherwise unusable and stays in the injection tube and peripheral veins and is thus employed for imaging. As a consequence, a saline flush can aid in CM efficiency as well as contrast augmentation. A saline flush improves bolus geometry by reducing intravascular CM dispersion and reducing streak artifacts from thick CM in the brachiocephalic vein and superior vena cava (SVC) on thoracic CT scans(Kidoh et al., 2013).

2.5 Methods of Contrast Media Delivery

The investigation type and clinical indications determine the process of injecting iodinated CA. Several ways of delivering CM are employed in various medical institutes(Solbak et al., 2020).

2.5.1 Fixed Delayed Time Method:

Many contrast-enhanced CT still uses a fixed delayed period for a post-contrast injection. Careful CM management is required because of the increased scan speeds of multi-detector computed tomography (MDCT) scanners. The hazards of a fixed-delay technique are caused by the fact that in certain patients, the time for circulation differs significantly from the protocol used. One of the risks associated with the fixed-delay strategy is the circulation time. The scan succeeds when the circulation time is less than the set delay. When the circulation time exceeds the set delay, the scan fails because the attenuation inside the arteries is insufficient (Noda, Kawai, et al., 2021). And the fixed scan delay is calculated based on experience. It is a preprogrammed delay between CM injection and the start of the image acquisition without monitoring the desired ROI. The fixed scan delay method is unable to adjust for cardiovascular circulation time variation between individuals. Short acquisition times provided by the faster CT scanners could lead to early or late vascular opacification if the bolus delivery is not predetermined accurately

2.5.2 Test-Bolus Method:

The test-bolus procedure involves administering a modest amount of CM (10-20 mL) before doing diagnostic CT with a whole bolus of CM. Numerous low-dose sequential pictures are collected at a set scan level after CA injection. The enhancement within a region of interest (ROI) over a target organ (aorta or heart chamber) is measured to produce a time-enhancement curve. Time-to-peak test-bolus contrast enhancement is calculated from time-to-peak enhancement and is used to predict scan delays for full-bolus diagnostic CT (Matsumoto, Higaki, et al., 2019). also estimate the contrast time needed to reach the aorta as in the curve. The time difference between the pulmonary and aorta is calculated.

2.5.3 Bolus-Tracking Method:

The bolus tracking technique is dependent on ROI, which must be analyzed, and the threshold that is selected prior to beginning CT data gathering. During the administration of CM, a single-level static scan is done at regular intervals. When the CM reaches the ROI level, an attenuation change is detected, and a CT scan is initiated after the specified

threshold is reached (Matsumoto, Higaki, et al., 2019).When the Bolus tracking method is utilized, the timing is improved, and the amount of CM reduces as the injection rate increases.

2.6 Similar Studies

Awai et al., 2004 investigated the effects of contrast material timing, aortic enhancement and peak, and the patient's weight on the amount of CA administered. The study included 199 patients, 84 females and 115 males with weights ranging from 30 to 92 pounds (and 35-83), respectively. Based on the contrast agent injection methodology, these patients' samples were randomly assigned to one of three groups: A, B, or C. The scan has a flow rate of 4 ml/s and an injection duration of 25 seconds across all samples, group B has an injection time of 35 seconds for all samples, and group C has an injection rate of 4 ml/sec for all samples. In along with the power injector, they used a cannula caliber 20 injected into an antecubital vein.

The scanning began at the third vertebra in the lumbar spine to determine the aorta's baseline attenuation value. From 2 seconds to 10-60 seconds following the CA injection, single-level serial shots were acquired at the same level. Then, 70 seconds after the CA arrived, a routine abdominal CT scan in the portal and venous phases was done. The aforementioned variables were used: 50 cm field of view (FOV), 7 mm slice thickness (ST), 5 mm detector row width, 3.0 helical pitch, 0.8-sec rotation time, 220-280 mAs, 120 kVp. There was no correlation between aorta peak time and patient weight or aortic peak time and injection rate in groups B and A, whose average aortic peak times were 29.2 seconds 2.0 and 21.4 seconds 2.3, respectively. Group C demonstrated a connection between aortic peak time and patient weight, with a mean aortic peak time of 19.7 seconds 4.4 respectively. By employing a set injection time, the research outcomes regarding aortic peak enhancement values and aortic peak times can be lowered. As a result, incorporating these results in the arterial phase CT liver tumor scanner and angiography would be diagnostically useful. However, given the acquisition time dependent on the anatomy collected and the acquisition procedures utilized, it is critical to ensure that the injection time is sufficient for appropriate improvement.

Yu et al., 2022 conducted a study in bolus tracking abdominal multiphase CT, researchers investigated the image quality and diagnosis differences between a specific post-trigger delay and a typically fixed one. There were 104 patients in the trial. These 104 patients were randomly assigned to one of two treatment groups, A or B, based on bolus tracking methodologies. A is a customized post-trigger delay of 11 seconds, while B is a fixed post-trigger delay of 11 seconds. All CT scan parameters and contrast medium protocol parameters were the same in both groups. Quantitative (enhancement of organs and blood vessels, image noise, signal-to-noise ratio (SNR), and contrast-to-noise ratio (CNR)) and qualitative (total image quality and diagnostic trust) visual metrics were evaluated. Images from group A had more significant attenuation in the arterial phase ($P \leq 0.001$). Although SNRs of the liver, pancreas, and aorta were comparable in group A and B, CNRs of the liver, pancreatic, and portal vein in group A were considerably greater (all $P \leq 0.002$). The two groups had comparable overall objective image quality and diagnostic confidence ($P = 0.809$; $P = 0.768$). As a result, using a customized post-trigger delay can improve objective

picture quality in the arterial phase while maintaining diagnostic quality in abdominal multiphase CT.

(H.-P. Dinkel et al, , 1998) conducted a study optimal liver enhancement during portal venous-phase helical CT is crucial in the detection of parenchymal liver lesions. researchers investigated the effects of a real-time bolus-tracking system on mean and maximal liver enhancement. In 79 patients referred to us for abdominal CT we injected 120 ml of non-ionic contrast (300 mg I/ml) at a rate of 3 ml/s. After a non-intravenous contrast upper abdominal scan a portal venous phase was performed. In 39 patients (mean weight 72.6 ± 18.7 kg, range 48–139 kg) real-time bolus tracking was performed using the CARE Bolus software (Siemens, Erlangen, Germany). The software performs repetitive low-dose test scans in a preselected region of interest and measures the Hounsfield attenuation and liver enhancement in real-time. After a critical threshold (we selected 31 HU) is surpassed, the software starts diagnostic spiral scanning. Our control consisted of 40 patients weighing 51–100 kg (mean 73.2 ± 11.1 kg) who were scanned with a fixed, preselected start delay of 80 s. Mean hepatic enhancement was 54.0 ± 9.9 HU (range 33.3–74 HU) in 37 automatically triggered patients, mean peak hepatic enhancement 64.6 ± 12.6 HU (range 42.0–91.8 HU). In 2 patients of the study group scanning had to be started manually. In the control group with fixed delay mean enhancement was 48.3 ± 9.2 HU (range 33.8–71.6 HU) and peak enhancement 55.5 ± 9.7 HU (range 39.7–81.0 HU). Differences were significant ($p < 0.05$, Student's t-test). Real-time bolus tracking significantly increased mean hepatic enhancement and may improve portal venous hepatic CT scanning.

(Joern J. Sandstede et al, , 2001) conducted a study was to optimize bolus tracking for timing of the arterial phase of biphasic helical liver CT and to compare optimized bolus tracking to a standard delay. 150 patients were examined with six protocols: 5- or 10-s delay after triggering at a threshold of 50 or 75 or 100 HU enhancement in the aorta at the origin of the celiac arteries after injection of 120 ml contrast material at 3 ml/s. Optimal arterial enhancement was defined as 20–30% of hepatic enhancement in portal venous phase. Another 50 patients were examined with the optimized protocol and compared to 50 gender- and age-matched patients who underwent a 25-s standard delay. A 10-s delay after the 75-HU threshold resulted in the most patients with an optimal arterial phase ($p<0.01$). Thirty-one of 75 patients examined with this protocol showed optimal early liver enhancement. Bolus tracking compared with standard delay revealed only a trend for a difference ($p=0.07$). The outcome of automatic bolus tracking differs depending on the protocol used; however, optimal arterial phase imaging was seen in only 41% of patients, indicating only a trend for superior timing compared with a standard delay.

(Aoife Murphy et al.,, 2023) conducted a study to compare test bolus and bolus track contrast enhancement protocols in terms of enhancement of the pulmonary vessels and aorta, radiation dose and suboptimal scan rate to determine the optimal technique for CTPA. A total of 200 CTPA examinations (100 using each protocol) performed between January and February 2021 were assessed retrospectively. All scans were performed on a 2x128 Dual Source Siemens Drive Scanner. CT attenuation was measured in Hounsfield Units (HU), with measurements taken from the main pulmonary trunk, right pulmonary artery and left pulmonary artery, ascending and descending aorta. The mean effective dose was calculated from the dose-length product (DLP). The suboptimal scan rate was calculated as the percentage of examinations below 210HU. The average HU of the pulmonary arteries was 358 HU SD 129.2 in the test bolus group and increased to 394 HU SD 133.9 in the bolus track group with a P value of ≤0.05. The average HU of the aorta

was 235 HU SD 82.8 in the test bolus group and increased to 319 HU SD 91.8 in the bolus track group with a P value of 0.05). Fewer suboptimal scans were performed with the bolus track protocol (5 scans).

(Tan Seu Kean et al., 2023) conducted a study was to compare the test bolus and the bolus tracking protocols for CTPA among pregnant women by analysing the mean contrast enhancement of the pulmonary artery, diagnostic quality and radiation dosage, as well as the outcome of repeated CTPA among pregnant women due to initial non-diagnostic CTPA. This retrospective study from two tertiary centers included pregnant women who underwent CTPA using test bolus and bolus tracking protocols. CTPA quality, mean pulmonary artery enhancement and dose length product (DLP) were collected and compared between both protocols. The frequency and outcome of CTPA repetition due to suboptimal quality were analysed. Test bolus protocol yields a slightly higher number of diagnostic qualities CTPA than bolus tracking protocol; however not statistically significant. The bolus tracking protocol had significantly better acceptable CTPA quality than the test bolus protocol. Test bolus protocol had significantly lower mean DLP, 220 mGy.cm ± 69, than bolus tracking protocol, 323 mGy.cm ± 34, p-value <0.001. Half of the repeated CTPA did not show significantly better CTPA quality on repetition. No significant difference between test bolus and bolus tracking protocol in CTPA among pregnant women, but the bolus tracking protocol had better overall CTPA quality with higher radiation dose. Repetition of CTPA studies for poor CTPA quality may not always benefit. Hence, we advise weighing the risk and benefits of study repetition.

(Escher et al. , 2023) conducted a study was to optimize our preprocedural CT protocol comparing bolus tracking (BT) and test bolus (TB) techniques. 151 patients referred for full-cycle MDCT evaluation for transcatheter tricuspid valve repair comparing BT with TB (BT n=75 TB n=75). Contrast-to-noise ratios (CNR) were obtained. Demographic data, laboratory, electrocardiographic, and transthoracic echocardiography/transoesophageal echocardiography parameters were collected from electronic health records. Also, the volume of contrast agent and saline chaser and radiation dose length product and milliampere seconds were collected. BT and TB resulted in comparable CNR (BT: 0.47 [0.34 to 0.98]; TB: 0.51 [0.41 to 1.40]; P=0.1). BT was associated with a shorter scan duration (BT: 8.3 min [4.1 to 24.4]; TB: 13.9 min [6.2 to 41.4]; P<0.001), less radiation in terms of dose length product (BT: 1186±585; TB: 1383±679, P=0.04), and lower total volume administration (BT: 101 mL [63 to 16]; TB: 114 mL [71 to 154]; P<0.001). In patients with severely impaired ejection fraction (left ventricular ejection fraction [LVEF] ≤35%; n=65 [TB n=31; BT n=34]) using the TB technique yielded significantly better image quality in terms of CNR (TB=0.57 [0.41 to 1.07); BT=0.41 [0.34 to 0.65]; P=0.02). BT showed advantages in terms of shorter duration, less radiation, and lower contrast agent volume.

Chapter 3

Research Design

3.1 Methodology and Research Design

The research protocol, which involves collecting samples from patients undergoing abdominal and pelvic CT scans with an intravenous (IV) contrast media, is covered in this chapter. At several health hospitals, samples were collected, and comparisons were performed between them. The health facilities public, NGO and private. Where these reviews are regularly and often conducted, were provided samples. CT was used to image the patients. Patients got IV injections from the injector. The CT examination employs an automatic bolus tracking system. Each patient had their own unique timeline for reaching the threshold. The data and measurements were gathered and contrasted with results from different groups that took the identical exam using a fixed time-delay approach. SPSS version 20 and Microsoft Excel 2010 were used to gather and evaluate data and parameters.

3.2 Study Design

The current investigation compared two patient groups using both retrospective and prospective approaches. All patients who have previously completed the abdominal and pelvic protocols for liver CT scan procedures are included in the first group. The data was obtained after the CT scan had occurred. The second group of patients had an automated bolus-tracking CT scan of the pelvis and abdomen. With the help of the timing approach, data were collected prospectively. The prospective data collection period was from 15 October 2022 to 10 November 2022, whereas the retrospective data collection period was from 1 April 2022 to 31 October 2022.

3.3 Study Locations

The health hospitals where abdominal and pelvic protocols for liver CT examinations are routinely and regularly conducted, including public and commercial health facilities, provided the data for this study. Initially, these medical hospitals were chosen: Bethlehem's Beit Jala governmental hospital; Al-yamamah Hospital in Bethlehem; and Al-Ahli Hospital in Hebron. The medical hospitals were contacted, and permission to gather data was granted.

3.4 Study Sample

The participants are divided into three groups; the first two groups obtained the data retrospectively and included all patients who underwent abdomen and pelvis protocols for liver CT scan with CM in Beit Jala government hospital and Al-yamamah hospital between 1 April 2022 and 31 October 2022. All needed data for this group were carefully obtained from the selected hospitals and compared with data from the second group, which was collected prospectively and included patients who requested an abdominal and pelvic CT. The patients in the second group underwent abdominal and pelvic CT in accordance with the study's criteria, which include a precise protocol for CM injection using an automated bolus tracking system.

3.5 Inclusion Criteria

All participants included in this study were either male or female and had an abdominal and pelvic procedure for a liver CT examination with an IV contrast media. The type of contrast media used Iodine .

3.6 Exclusion Criteria

All patients obtained abdominal and pelvic CT scans of the liver without IV contrast media similar to stone protocol CT. Also, for the recalcitrant patients, all motion artifact assessments were performed, as were all patients with high levels of Creatinine.

3.7 Study Instrumentations

All CT examinations were done by the CT system found in the medical hospitals chosen in this study, and those hospitals were given permission to access the CT device in their radiology department, and use the PACS system to read pixel values for all included subjects in the retrospective. 50 retrospective patients were chosen who had already been referred for biphasic liver study CT.

3.8 Data Collection and Interpretation Procedure

The researcher created two tables of parameters that were utilized in the diagnostic procedures of the patients. This information-collection form includes all of the criteria required for group comparison. Each patient in either group had their own parameters gathered. The data were coded and put into the software, and the statistical analysts analyzed the data using the SPSS software. The outcomes of both groups were then compared.

3.8.1 Ct Scanners:

To assess the CT scanning parameters related to contrast enhancement and scan time, three CT scanners were used: one in a public hospital, one in an NGO, and one in a private practice. Table (3.1) displays the parameters of three CT scanners in the regions of Hebron and Bethlehem.

Table 3.1: CT scanner parameters at Bethlehem and Hebron hospitals.

Medical Institution	**Sector**	**Manufacturer/ Year of installation**	**Scanner Model**
Beit Jala Governmental Hospital	Governmental	Philips Brilliance	16 Slices
Al-Ahli Hospital	NGO	Perspective / 2020	256 Slices
Al-yamamah	Private	Philips Ingenuity Elite/2017	64 Slices

3.8.2 The Techniques Used:

The patient was in a supine posture with the feet first protocol or head-first procedure according all of the hospitals that were considered. The arms are lifted over the patient's head, and the gantry is centered on the abdomen region. First, a single breath-hold non-enhanced CT (NECT) scan was performed from the diaphragm to the symphysis pubis. Power injectors administered the water-soluble, non-ionic IV contrast media at various volumes and flow rates. Postcontrast arterial, venous, and delay measurements were recorded via bolus tracking or fixed time delay at various timing intervals. The following parameter used with prospective patient in Al-ahly hospital: Kilovoltage peak (kVp) parameters were manually adjusted and set to 120 to 140 kVp, with a fixed mAs of 313 to 438 based on patient size, a rotating time of 0.75, and a 0.938 pitch. The volume of CM varies from 90 to 120 ml depending on patient size, with flow rates ranging from 3 to 3.3 ml/s..

3.9 Quantitative Assessment

Three radiologists (O.F., I.Z., and I.M., with 5-, 10-, and 10-years' expertise in reading body CT images, respectively) measured the HU in the middle portal vein of the liver for patients. The retrospective patients' images were placed on a commercially available DICOM by establishing a circular region of interest (ROI) with an area of about 2 mm^2. The HU for prospective patients' images was directly measured from a CT computer by creating a circular ROI with an area of roughly 2 mm^2.

3.10 Statistical Analysis

The obtained data was encoded and utilized as entries in SPSS 20. For each variable, descriptive statistics were generated. as well as Bolus period predictions. the mean and standard deviation were calculated. As well as a sheet of Excel for the percentages, and The ANOVA P-value to determine the degree of correlation between each variable and the value of Bolus time.

3.11 Ethical Considerations

Ethical approval was obtained by the Research Ethics Subcommittee Chair and the Health Professions Committee and Dr. Hussein Al-Masri according to Ref.No.: RESC/2022-20

Chapter 4

Result

4.1 Demographic Information of The Patients

The study comprised 143 patients who had liver CT scan procedures at three hospitals: Beit Jala Government Hospital 50 (34.9%), Al-yamamah Hospital 50 (34.9%), and Al-Ahli Hospital 43 (30.09%). The participants average ages were 47.64, 36.42, and 34.44 years, respectively (Table 4.1). Table 4.2 reveals that 89 (62.2%) of the participants were males and 54 (37.8%) were females, with ages of 38.87 and 41.20 years, respectively.

Table 4.1: Demographic data distribution in the sample under study.

Hospital name	N (%)	Age (Years)
Beit Jala Government	50 (34.965035)	47.64
Al-yamamah	50 (34.965035)	36.42
Al-Ahli	43 (30.0699301)	34.44

Table 4.2: Gender and age distribution through participants.

Gender	N	Mean Age	Std. Deviation
Male	89 (62.2%)	38.87	15.241
Female	54 (37.8%)	41.20	15.422

Table (4.3) and Figure (4.1) demonstrate how the contrast media (CM) behaved when compared in the region of interest (ROI), since the variance across the three hospitals was insignificant, with Beit Jala Government Hospital having the slightest variation. It can be shown that the protocol utilized at Al-Ahli Hospital achieves its maximum value of HU, similar to the maximum value of HU (130.62) in Beit Jala Government Hospital, in less than half the time needed by other hospitals.

Table 4.3: The Hounsfield Unit in different hospitals before and after contrast media administration.

Hospital name	HU before contrast		HU after contrast (arterial)	
	Time (s)	Mean	Time (s)	Mean
Beit Jala Government	0	40.38	30	105.92
Al-yamamah	0	39.70	30	110.56
Al-Ahli	0	33.16	31.33	130.63

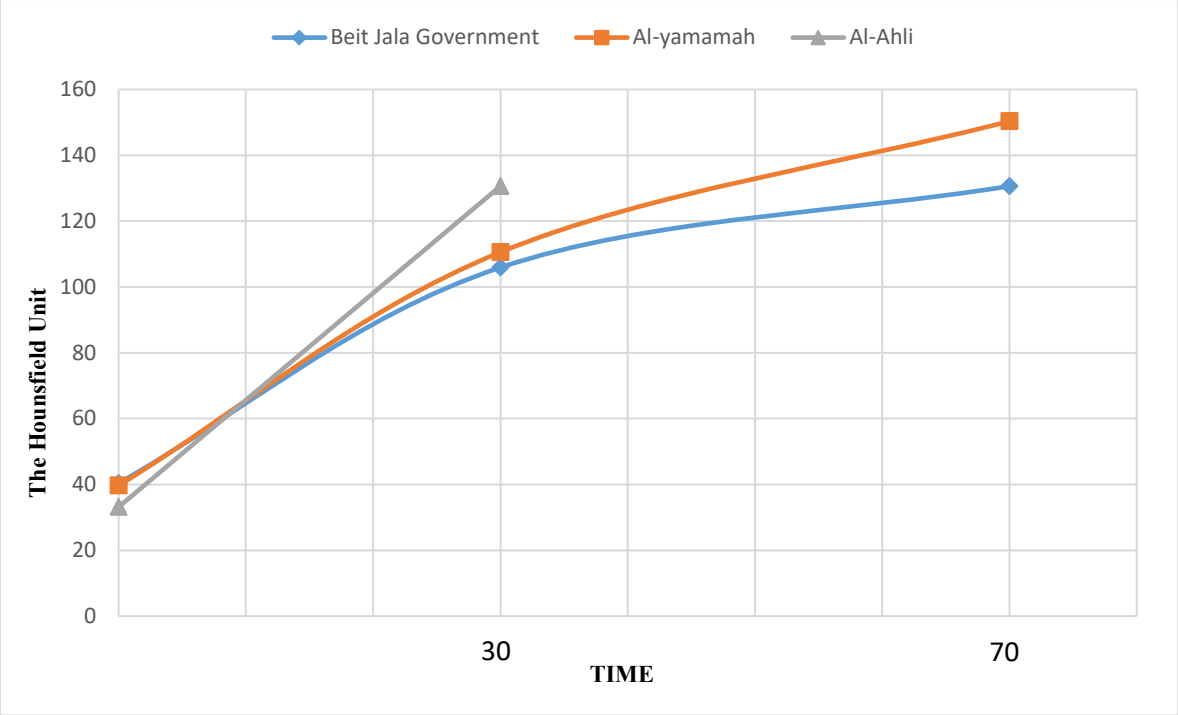

Figure 4.1: Histogram curve for contrast media with different time.

4.2 Descriptive Statistics For Prospective Participants

Descriptive statistics, which are information coefficients, may be used to summarize datasets. Variability was measured using the standard deviation, mean, minimum, and maximum. Table (4.4) lists all of the variables that were used to create an equation for the predictors of the bolus time.

Table 4.4: Variable using the Bolus-tracking method for all prospective patients.

Variable	Age	wt.	Ht.	HR	systolic Blood pressure	diastolic Blood pressure	Creatinine	CM amount	HU on ROI before CM	HU on ROI after CM
Mean	34.44	82.37	163.76	77.11	122.9	80.49	0.77	100	33.16	130.62
Std. Deviation	9.97	17.20	20.03	9.12	8.50	4.46	0.15	10.63	7.48	7.14
Minimum	19	49	59	65	98	68	0.50	90	22	115
Maximum	60	125	175	98	144	88	1.20	120	52	150

wt:weight; Ht :Height; HR: Heart Rate; CM: Contrast media; HU: Hounsfield Unit; ROI: Region of interest

4.3 Predictors of The Bolus Time

To forecast the value of Bolus time, the degree to which each variable was included in the research was associated with this factor. since the study included the following variables: age, patient weight, patient height, heat rate, Creatinine level, CM amount, flow rate, systolic blood pressure, and diastolic blood pressure.

The ANOVA P-value was used to determine the degree of correlation between each variable and the value of Bolus time. It was discovered that patient weight, heat rate, Creatinine level, and systolic blood pressure had values less than 0.05. This suggests that each of these factors has an influence on the value of Bolus time.

The values of R and R Square were determined to figure out the relationship between the four variables(patient weight, heart rate, ,and systolic blood pressure) and bolus time, and the results for the variable patient weight were 0.386 and 0.149, respectively; the heat rate variable was 0.372 and 0.139, respectively, and the Creatinine level variable was 0.330 and 0.109, respectively. Similarly, the variable systolic blood pressure is between 0.389 and 0.151. All of these data suggest that the value of dependency for each variable and its influence on the bolus time were modest by measured the value of R square in which was less than 0.2 for all variables. As a result, the researcher will develop the bolus time equation by determining a coefficient factor for each of the four variables then find the relationship between the four variables and the bolus time.

Table 4.5: Summary of the variables affecting bolus time.

	Variables	Relationship	Anova P-value
Bolus Time	Age	No	0.588
	Patient Weight	Yes	0.014
	Patient Height	No	0.643
	Heart Rate	Yes	0.014
	Creatinine Level	Yes	0.031
	CM amount	No	0.316
	Flow Rate	No	0.331
	Systolic Blood pressure	Yes	0.027
	Diastolic Blood pressure	No	0.123

4.3.1 Weight Coeffeicient:

The relationship may be used to compute the coefficient of the patient's weight which effects on bolus time are one of the following relationships: linear; logarithmic; inverse; quadratic; cubic; compound; power; growth; exponential; or logistic. To find which is the most suitable relationship from aforementioned relationship, R and R-squared were measured. R-squared shows how much of a data set's variability (patients' weight) can be attributed to a single independent variable (bolus time), in contrast to correlation's (R) focus on the strength of a link between two variables (patient weight and bolus time). The value of R square might be any percentage between 0 and 1, while the value of R between -1 to +1. R square is expressed as a percentage, between 0% and 100%.

When the percentage approaches 100%, it means that the independent variable used to establish the dependent variable is optimal. A high R-squared value in investing, between 85% and 100%, implies that the stock or fund's performance follows the index with little deviation. If a fund's R-squared is 70 percent or less, it does not closely track the performance of the index. A more helpful beta value is indicated by a larger R-squared value. By taking into account the impact of all independent variables (patient weight) on the regression function, adjusted R-squared gives a more precise correlation between the variables. This makes it straightforward to identify the specific causes of the observed link. Knowing which factors are more crucial than others is also helpful.

Table 4.6 shows the strongest relationship between patient weight and bolus time.

Relationship	R	R Square	Adjusted R Square	Std. Error of the Estimate
Linear	.373	.139	.118	7.516
Logarithmic	.359	.129	.108	7.561
Inverse	.333	.111	.089	7.639
Quadratic	.376	.141	.098	7.601
Cubic	.459	.211	.150	7.381
Compound	.386	.149	.129	.236
Power	.371	.137	.116	.238
Growth	.386	.149	.129	.236
Exponential	.386	.149	.129	.236
Logistic	.386	.149	.129	.236

A cubic relationship may be used to compute the coefficient of the patient weight, which is the most significant variable in the value of bolus time. Figure 4.2 shows the equation between bolus time and patient weight. This equation, which can be expressed as follows:

$$\omega = 183 - (5.84 * weight) + (0.07 * weight^2) - (0.000265 * weight^3) \text{.....(1)}$$

Where ω is the weight coefficient, this symbol was selected in role of first letter of weight – just for easy memorized-.R-square 21.1% which indicates the highest percentage among all relationships which means that patient weight attributes 21.1% on the bolus time, the value R equals to 45.9% which indicates the strength of a link between patient weight and bolus time. Adjusted R-square have the height value in cubic relationship comparing with other relationships. The value was 15% which means the patient weight can gives additional contributes on the bolus time by 15%.

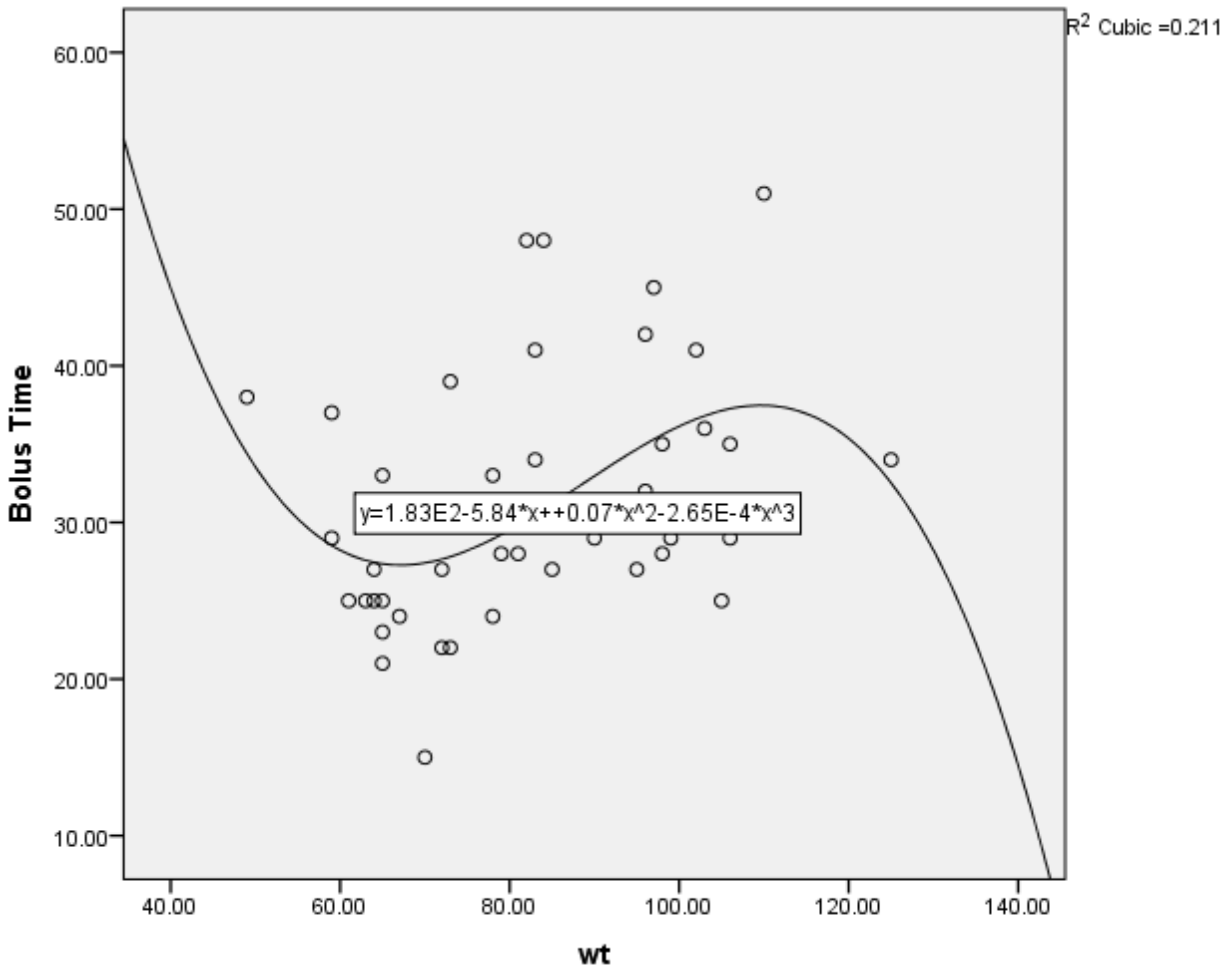

Figure 4.2: mathematical relationship between bolus time and patient weight.

4.3.2 Heart Rate Coefficient:

R, R square, and Adjusted R square in Table 4.7 which calculate to find which suitable relationship can be used to find the equation between heart rate and bolus time.

Table 4.7 : shows the strongest relationship between patient heart rate and bolus time.

Relationship	R	R Square	Adjusted R Square	Std. Error of the Estimate
Linear	.372	.139	.118	7.520
logarithmic	0.377	0.142	0.121	7.504
Inverse	.380	.145	.124	7.494
quadratic	.386	.149	.107	7.566
Cubic	.387	.155	.107	7.563
Compound	.360	.129	.108	.239
Power	.365	.133	.112	.239
Growth	.360	.129	.108	.239
Exponential	.360	.129	.108	.239
Logistic	.360	.129	.108	.239

Another cubic relationship may be used to compute the coefficient of the heart rate, which is the second most significant variable in the value of bolus time. Figure 4.3 shows the equation between bolus time and patient heart rate. This equation, which can be expressed as follows:

$$\partial = 411 - (15.79 * HR) + (0.21 * HR^2) - (0.000914 * HR^3) \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where ∂ is the heart rate coefficientR-square 15.5 % which indicates the highest percentage among all relationships which means that patient heart rate attributes 15.5 % on the bolus time, the value R equals to 38.7 % which indicates the strength of a link between patient heart rate and bolus time. Adjusted R-square have the height value in cubic relationship comparing with other relationships. The value was 10.7 % which means the patient heart rate can gives additional contributes on the bolus time by 10.7 %.

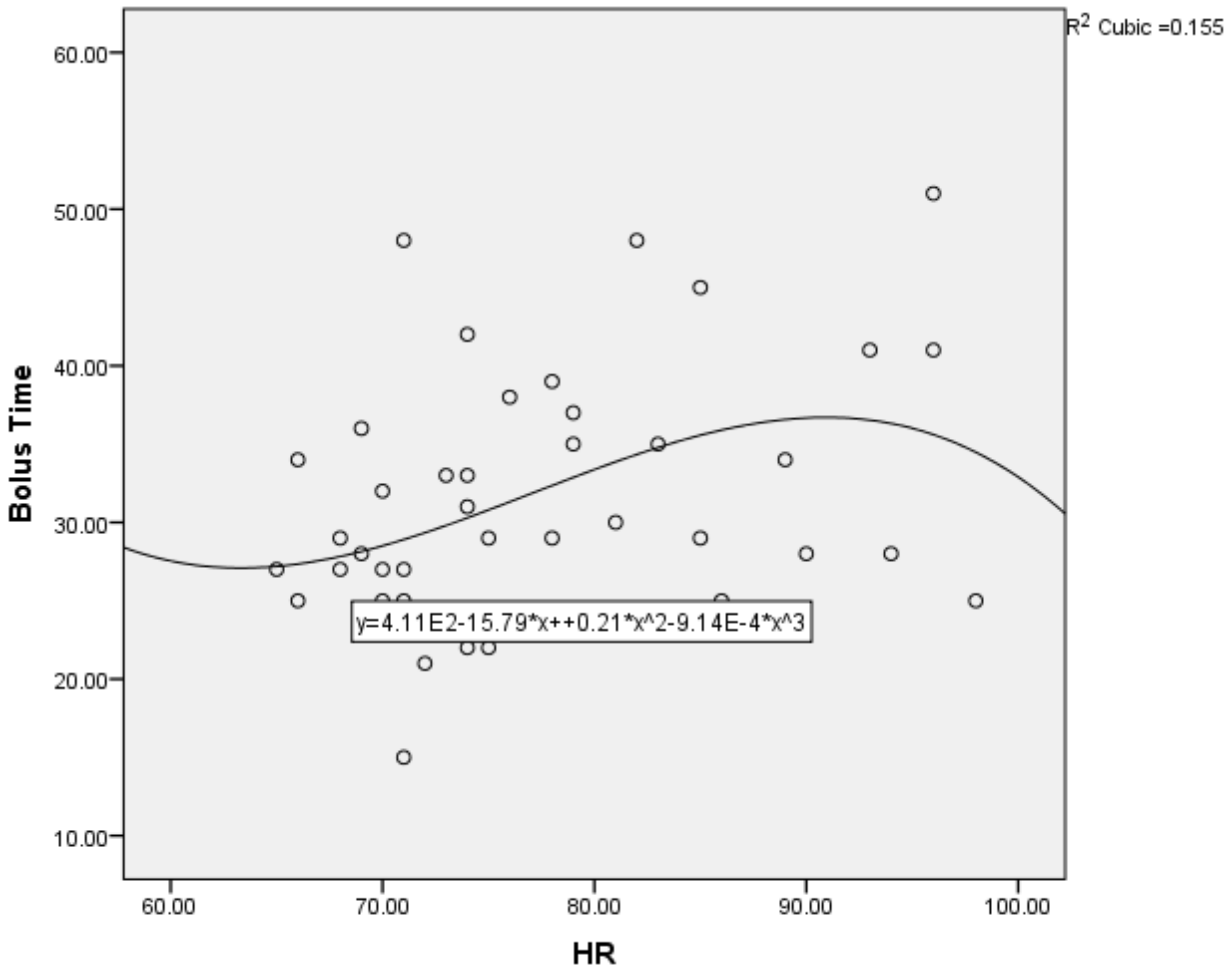

Figure 4.3: Mathematical relationship between bolus time and patient heart rate (HR).

4.3.3 Creatinine Coefficient:

R, R square, and Adjusted R square in Table 4.8 which calculate to find which suitable relationship can be used to find the equation between Creatinine level and bolus time.

Table 4.8: shows the strongest relationship between patient creatinine and bolus time.

Relationship	R	R Square	Adjusted R Square	Std. Error of the Estimate
Linear	.330	.109	.087	7.649
Logarithmic	.323	.104	.082	7.669
Inverse	.312	.098	.076	7.697
Quadratic	.334	.111	.067	7.732
Cubic	.360	.129	.062	7.751
Compound	.348	.121	.100	.240
Power	.343	.118	.096	.241
Growth	.348	.121	.100	.240
Exponential	.348	.121	.100	.240
Logistic	.348	.121	.100	.240

Another cubic relationship may be used to compute the coefficient of Creatinine. Figure (4.8) shows the equation between bolus time and patient Creatinine level. This equation, which can be expressed as follows:

$$C = -59.16 + (325 * creatinine) - (396 * creatinine^2) + (163 * creatinine^3) \quad \ldots\ldots(3)$$

Where C is the creatinine level coefficient, this symbol was selected in role of first letter of Creatinine – just for easy memorized-. R-square 12.9 % which indicates the highest percentage among all relationships which means that Creatinine attributes 12.9 % on the bolus time, the value R equals to 36 % which indicates the strength of a link between Creatinine and bolus time. Adjusted R-square have the height value in cubic relationship comparing with other relationships. The value was 6.2 % which means the Creatinine level can gives additional contributes on the bolus time by 6.2 %. Note that the equation states

with value -59.16 and that is shown in the figure by stating with minus level

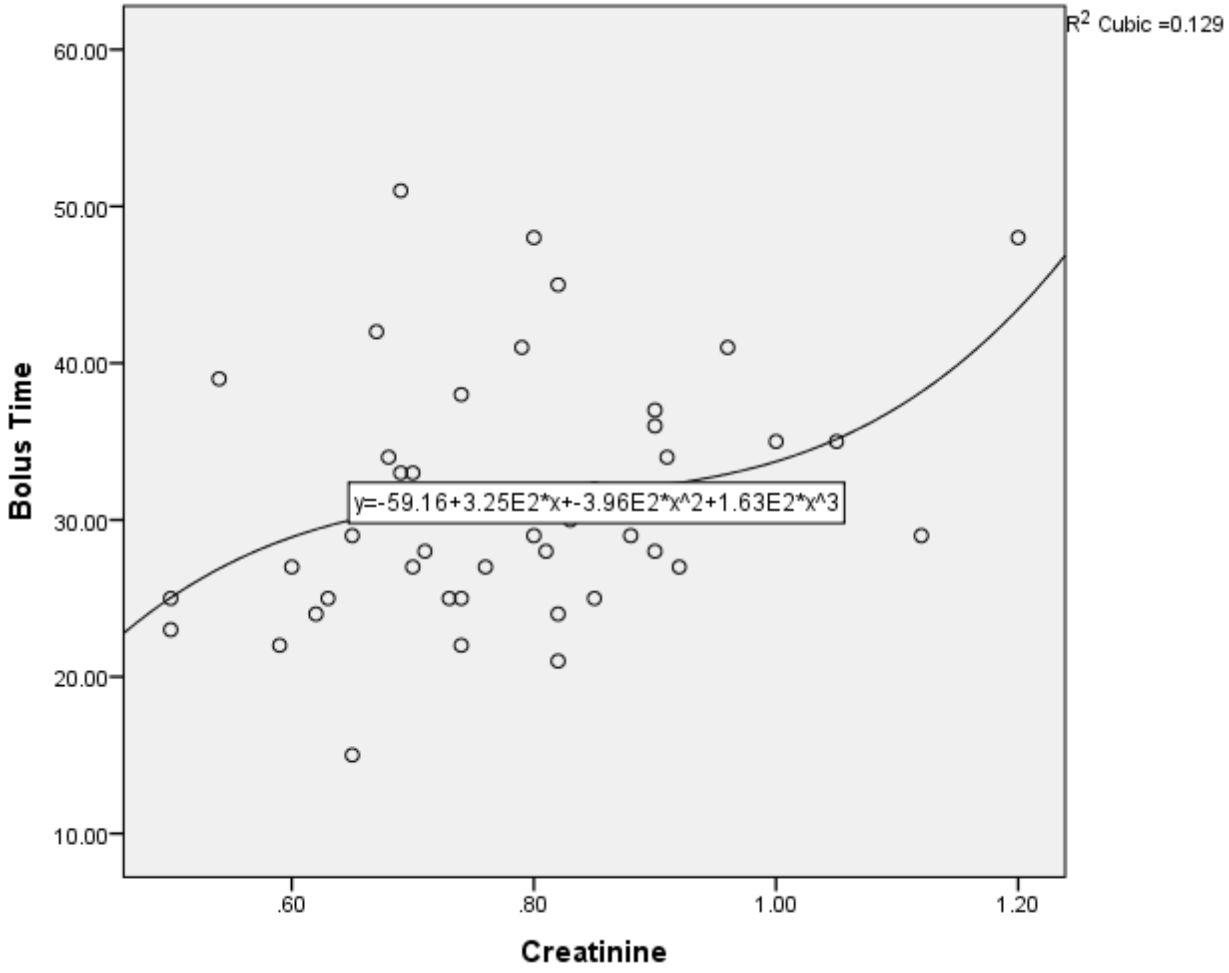

Figure 4.4: Mathematical relationship between bolus time and patient Creatinine level.

4.3.4 Systolic Blood Pressure (Sbp) Coefficient:

R, R square, and Adjusted R square in Table (4.9) which calculate to find which suitable relationship can be used to find the equation between systolic blood pressure and bolus time.

Table 4.9: shows the strongest relationship between patient systolic blood pressure and bolus time.

Relationship	R	R Square	Adjusted R Square	Std. Error of the Estimate
Linear	.337	.114	.092	7.628
Logarithmic	.347	.121	.099	7.598
Inverse	.356	.126	.105	7.573
Quadratic	.385	.149	.106	7.569
Cubic	.389	.179	.109	7.558
Compound	.351	.123	.102	.240
Power	.363	.132	.110	.239
Growth	.351	.123	.102	.240
Exponential	.351	.123	.102	.240
Logistic	.351	.123	.102	.240

Another cubic relationship was used to compute the coefficient of the systolic blood pressure. Figure (4.9) shows the equation between bolus time and Systolic Blood Pressure. This equation, which can be expressed as follows:

$$\tau = 1250 - (32.96 * SBP) + (0.29 * SBP^2) + (0.000828 * SBP^3) \ldots\ldots\ldots (4)$$

Where τ is the systolic blood pressure coefficient.R-square 17.9 % which indicates the highest percentage among all relationships which means that SBP attributes 17.9 % on the bolus time, the value R equals to 38.9 % which indicates the strength of a link between SBP and bolus time. Adjusted R-square have the height value in cubic relationship comparing with other relationships. The value was 10.9 % which means the patient SBP can gives additional contributes on the bolus time by 10.9 %.

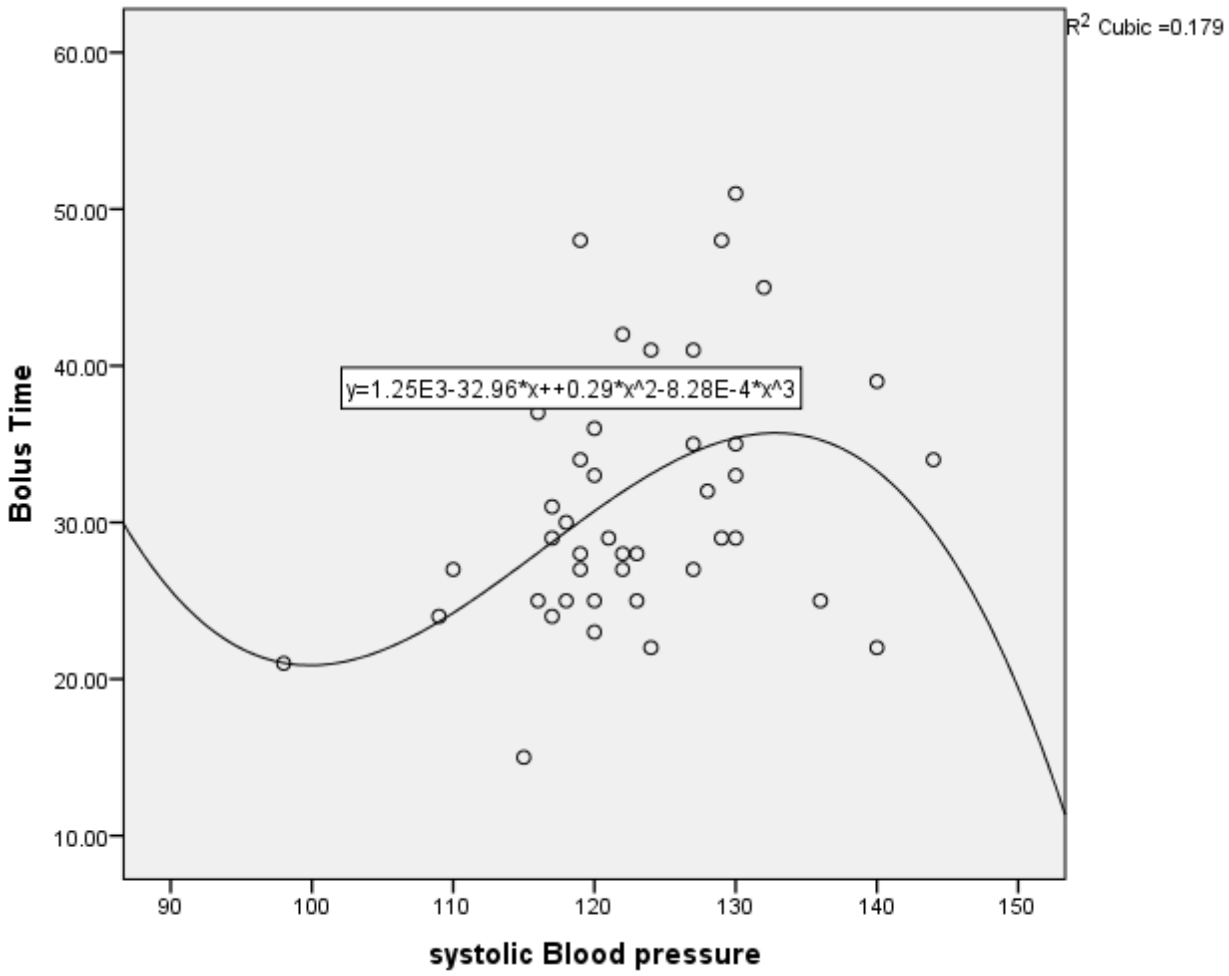

Figure 4.5: Mathematical relationship between bolus time and Systolic Blood Pressure.

The coefficient of determination, or R-Square, indicates how much of the variability in the dependent variable (bolus time) can be accounted for by changes in the independent variables (weight, heart rate, Creatinine level, and systolic blood pressure). Table (4.10) implies that the factors weight, heart rate, Creatinine level, and systolic blood pressure may predict 34.9% of the variation in bolus time. This is a global measure of the strength of association and does not indicate the strength of the link between any two independent variables. R-Square is a popular measure of statistical significance. The strength link between four variables and bolus time was 59.1%.

As more predictors are added to the model, part of the variation in the dependent variable (bolus time) will be explained by chance alone, and the R-square statistic will need to be adjusted accordingly. As more predictors are included, the model's ability to describe the dependent variable improves; however, some of this improvement in R-square is attributable to random variation in the sample. The purpose of the adjusted R-square is to provide a more accurate assessment of the population's R-squared. Adjusted R-square was 28%, whereas R-square was 34.9% in total.

Table 4.10: R and R Square between Bolus time and independent variables.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.591[a]	0.349	0.28	6.79057
a. Dependent Variable: Bolus Time				
b. Predictors: constant, systolic blood pressure coefficient, heart rate coefficient, Creatinine coefficient, patient weight coefficient				

Table (4.11) displays the results of the ANOVA analysis and whether there is a statistically significant difference between regression and residual. The F-value is calculated by dividing the Mean Square Regression (234.798) divided by the Mean Square Residual (46.112), which gives us F=5.092. The related p-value for this F-value is very low (0.002). When answering the question "Do the independent variables reliably predict the dependent variable?" these values are consulted. Your alpha level (usually 0.05) is compared to the p-value. The dependent variable (bolus time) may be accurately predicted using independent factors (body weight, heart rate, Creatinine, and systolic blood pressure). The capacity of individual independent variables to predict the dependent variable is not an issue here; rather, the test analyzes whether the collection of independent variables can consistently predict the dependent variable when used collectively.

Table 4.11: ANOVA test between regression independent variables and bolus time.

ANOVA[a]						
Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	939.190	4	234.798	5.092	.002[b]
	Residual	1752.251	38	46.112		
	Total	2691.442	42			
a. Dependent Variable: Bolus Time						
b. Predictors: constant, systolic blood pressure coefficient, heart rate coefficient, Creatinine coefficient, patient weight coefficient						

The table(4.12)below lists each independent variable and discusses the capacity of each variable to predict the dependent variable. Using these estimations, the various factors affect the outcome of interest can be assessed. A one-unit increase in the predictor is assumed to increase in bolus time of approximately these values. In analyzing the coefficients, keep in mind that for the insignificant independent variables, there is no statistically significant difference between them and 0.(For information on whether or not the coefficients are statistically significant, refer to the rows labeled "t-value" and "p-

value"). Patient Weight Coefficient (ω)– The coefficient (parameter estimate) is .634. So, for every unit (i.e., point, since this is the metric in which the tests are measured) increase in math, a .389 unit increase in science is predicted, holding all other variables constant. (It does not matter at what value you hold the other variables constant, because it is a linear model.) Or, for every increase of one point on the ω, the bolus time is predicted to be higher by .634 points. This is significantly different from 0. Heart Rate Coefficient (∂)– For every unit increase in ∂, there is a 1.178 unit increase in the predicted bolus time, holding all other variables constant. The variable ∂ is technically not statistically significantly different from 0, because the p-value is greater than 0.05 which was 0.144. Creatinine Coefficient (C)– The coefficient for C is .615. This means that for a 1-unit increase in the C, we expect an approximately 0.615-point increase in the bolus time. This is not statistically significant with p-value 0.144; in other words, .615 is not different from 0. Systolic Blood Pressure Coefficient (τ)– The coefficient for τ is .362. Hence, for every unit increase in τ we expect a 0.362-point increase in the bolus time. This is not statistically significant with p-value 0.116.

Table 4.12: Equation coefficient between independent variables and bolus time.

Coefficients						
Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	-47.711	20.434		-2.335	.025
	Patient Weight Coefficient(ω)	.634	.373	.254	1.700	.097
	Heart Rate Coefficient (∂)	1.178	.789	.202	1.493	.144
	Creatinine Coefficient (C)	.615	.412	.208	1.490	.144
	Systolic Blood Pressure Coefficient (τ)	.362	.225	.230	1.607	.116
a. Dependent Variable: Bolus Time						

Standard Deviation (Std. Error): These are the coefficients' standard deviations. By dividing the parameter estimate by the standard error, a t-value can be calculated (see the column with t-values and p-values) that may be used to evaluate whether or not the parameter is substantially different from 0. The final two columns of this table provide a confidence interval calculated from the standard errors and applied to the parameter. The outcomes of the predictors' use of coefficients with Std. Error 1 are estimates that are close to the true values.

Standardized coefficients are denoted by the symbol "beta." After normalizing the dependent (bolus time) and all of the independent variables (ω, ∂, C, and τ), these are the coefficients that would be obtained by running the regression. Before conducting the regression, standardizing the variables ensures that they are all on the same scale, allowing you to compare the coefficients' magnitudes to determine which variable is more

influential. Also, bigger t-values (1.7) are correlated with larger betas (0.254). However, because all coefficients are scaled to the same value, standardized coefficients cannot be included into the equation. Unstandardized Coefficients illustrates the range of coefficient magnitudes.

Sig. (p-value) and t- value. The t-value and two-tailed p-value for testing the 0-significance level of the coefficient or parameter in these columns. With a 2-tailed test, you would check each p-value against the significance level you've established (0.05). P-values for coefficients that are smaller than alpha indicate statistical significance. With a 2-tailed test and alpha of 0.05, you should not reject the null hypothesis that the coefficient for (ω, ∂, C, and τ) is equal to 0, because p-value = 0.097, 0.144, 0.144, and 0.116 > 0.05, respectively. All coefficient p-values are larger than 0.05, indicating that there is no statistical significance at the 0.05 level. All of the coefficients' impacts on the bolus time are represented by the same indicators throughout a rather narrow range. Because of this, the researcher adjusted the coefficients for each patient's weight, heart rate, Creatinine level, and systolic blood pressure. While the coefficient had no effect on the bolus time, the early findings without coefficients (patient's weight, heart rate, Creatinine level, and systolic blood pressure) did.

Table (4.11) also shows that the P-value approaches 0.002, which indicates that all coefficients in the generalized equation effect on the bolus time and that the equation may be used to calculate the bolus time. Bolus timing was not affected by any of the individual coefficient. The finalized bolus time equation can be calculated by using the following equation:

$$\boldsymbol{BolusTime = -47.711 + (0.634 * \omega) + (1.178 * \partial) + (0.615 * C) + (0.362 * \tau)} \quad \textbf{.....(5)}$$

4.4 Differences of Bolus Time Between Tracker Controlled in Real Measurement and Equation Measurement

Table (4.13)and Table (4.1)4 display the mean and standard deviation of the research samples when applying the Bolus Time equation and the actual values obtained from the patients. The values for real bolus time (31.32± 8) as well as the values derived using the equation (31.33±4.7). There is no difference between the two measurements since the Sig. (2-tailed) value of-value (0.992> 0.05), indicating that Bolus Time may be approximated using the equation.

Table 4.13: Paired Sample Statistics Between Real Bolus Time and Equation Measurement.

Paired Samples Statistics					
		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Bolus Time	31.3256	43	8.00512	1.22077
	Bolus time using equation	31.3361	43	4.72976	.72128

Table 4.14: P-value between real bolus time and measuring time using the equation.

Paired Samples Test									
		Paired Differences					T	Df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Bolus Time - Bolus time using equation	-.01048	6.45912	.98501	-1.99830	1.97734	-.011	42	.992

4.5 Difference of HU Between Fixed (30 Seconds) and Tracker Bolus Tracking

Table (4.15) and Figure (4.6) show that the independent samples test offers context for group comparisons, including sample size (n), mean, standard deviation, and standard error mean per group. The tracker controlled 43 patients and fixed 30 seconds for 100 patient groups, which are included in the table. The mean for the tracker-controlled group is 130.6, whereas the mean for the fixed 30-second group is 108.2.

Table 4.15: Differences between Hounsfield Units using Bolus Time and Fixed Time.

Signal intensity post-CM injection		N	Mean	Std. Deviation	Std. Error Mean	P-value
HU on RoI after CM	Tracker Controlled	43	**130.6**	7.1	1.1	0.00
	Fixed 30 Seconds	100	**108.2**	27.2	2.7	

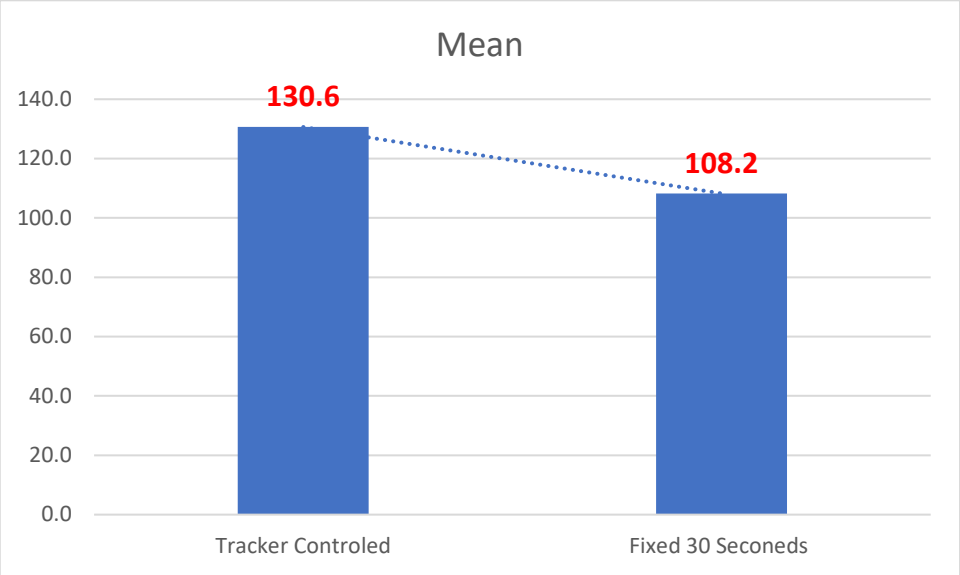

Figure 4.6: Depicts the difference between the tracker controlled mean and the fixed 30 seconds.

Table (4.11) displays the P-value resulting from the application of Levene's Test for Equality of Variances, which is equal to 0.00, less than 0.05, indicating the existence of a difference in the values of HU on RoI after applying CM, as the bolus-tracking method gives a variation in HU compared with the fixed delayed time method.

Chapter 5

Discussion

The technology behind CT and other modalities advancements has contributed to enhancing the quality of images, clinical practice, and the discovery of novel imaging applications. Patient Age, weight, height, heart rhythm, systolic blood pressure, diastolic blood pressure, and Creatinine levels have all been assessed. The HU on ROI before CM, and HU on ROI after CM for potential Al-Ahli Hospital patients. In addition, for retrospective patients at Beit Jala government and Al-Yamamah hospitals that were tested for age, HU on ROI before and after CM Al-Yamamah Hospital and Beit Jala Hospital procedures are modified to every patient without regard to particular factors. Researcher propose that bolus tracking be used to offer superior diagnostic information, replacing CT acquisition correction methods with IV contrast. While some institutions solely employ the Fix procedure, others utilize CT bolus tracking scans with CM as a regular assessment for many abdominal purposes. The essential injection factors that determine the timing of distinct phases are injection time and flow rate because they directly affect the maximal improvement time in organs and arteries(Bae, 2010). Because of the extremely variable injection duration, this resulted in varying amounts of CM improvement that differed substantially across these institutions. The difference in enhancement was caused by ignoring essential criteria such as age, weight, height, heart rate, systolic blood pressure, diastolic blood pressure, Creatinine, and the quantity of CM which was evident in the institutions.

5.1 Patient Preparation

Hospitals follow a specific strategy for patient preparations in order to minimize any adverse reactions to CM as much as possible. Referring doctors and radiologists should think about the risk-to-benefit profile of CM IV-enhanced exams as well as other options that might offer the same or even better diagnostic information, as well as verify a compelling clinical indication for the use of IV CM-enhanced CT exams(Matsumoto, Masuda, et al., 2019). It is recommended that radiologists and referring doctors investigate renewal options that would provide higher-level diagnostic data, potentially lowering the risk-to-benefit ratio. While some institutions employ fixed time contrast solely, others use bolus monitoring with CM as a common evaluation for a variety of abdominal reasons. Because it has a direct impact on peak enhancement in organs and arteries throughout time, injection duration is one of the most important injection-related parameters regulating phase timing(Bae, 2010).

The research found that various criteria resulted in varying amounts of augmentation at three hospitals. Neglecting important factors seen across all hospitals, such as injection time, CM volume, flow rate, patient weight, height, heart rate, blood pressure, and CM concentration, led to the difference in enhancement. Data from hospitals were submitted and compared using the SPSS application. A regression equation is used for predicting the values of a dependent variable, including, patient age, weight, height, heart rate, creatinine level, contrast media amount, flow rate, and systolic and diastolic blood pressure, as a function of the values of one or more independent variables. Based on the data, the

patient's weight, heart rate, Creatinine level, and systolic blood pressure are predictors that impact bolus time; in table 4.6 (R = 0.591), the R-value reflects the correlation between the observed and anticipated values. R square = 0.349, which reflects the proportion of the variance in the dependent variable that the independent variable can explain. R-Square represents in-sample predictive power, whereas Std. The estimation error (= 6.79057) takes into account all other variables that affect the variation of the dependent variable. T-test compares regression to residual regression; T-test compares if there are distinctions between regression and residual regression for two separate groups. The regression represents the patient's weight, heart rate, Creatinine level, and systolic blood pressure, and the residual regression reflects the other variables, with the sum of squares for the regression (=939.190) vs. the sum of squares for the residual regression (=1752.251). The significance value is (=0.02) less than 0.05, indicating that the biggest differences exist across groups. The beta coefficient is represented in Table 4.8. The coefficient test finds the summary Coefficient of (Weight, Creatinine, Heart Rate, and SBP) of The Bolus Time finding :

$$BolusTime = -47.711 + (0.634 * \omega) + (1.178 * \partial) + (0.615 * \mathrm{C}) + (0.362 * \tau)..(6)$$

An independent sample ANOVA test as carried out to assess the impact of the HU on ROI after CM for Tracking Controlled and Fixed 30 Seconds. Tracker-controlled (M = 130.6, SD = 7.1) and fixed 30 seconds (M =108.2, SD = 27.2) had significant differences. The size of the mean differences (mean difference = 22.4) was relatively substantial as shown in Table 4.11.

To make certain that the produced equation is applied to the variables in the stated equation. The findings were outstanding, with a mean for the estimated bolus time using the equation of 31.3361 and a standard deviation of 4.72976. At the same time, the true measurements had an arithmetic mean of 31.3256 and a standard deviation of 8.0051 To confirm the equation's applicability. the Paired Samples Test was performed to determine the differences between the two readings, which estimated the value of the p-value by 0.992, giving the appearance that the two equations are quite close Table 4.13.

To evaluate the HU on ROI after CM for equal variances expected and equal variances not assumed, an independent-samples t-test was used. The value of the mean differences (P-value =0.00) Table (4.11) As a result, we can demonstrate the disparity between bolus tracking and fixing time in Figure (4.5) where the difference between the equal average of 22.4 is bigger; this indicates that we must employ the bolus time in our approach because it was improve the enhancement in CT images more than fix time technique.

According to the findings of this research, the patient's weight, heart rate, Creatinine level, and systolic blood pressure are the factors influencing the CM's arrival time at the ROI. The findings contrast with the previous research(Bae, 2010), which found no significant association between the patient's weight and the bolus tracking technique, which is superior to the fix time technique for improving the quality of abdomen CT with IV; this result is inconsistent with the study (Zeng et al., 2023), in which the total subjective quality of the image and diagnostic confidence were comparable (P = 0.809; P = 0.768).

In patient weight coefficient R-square 21.1% which indicates the highest percentage among all relationships which means that patient weight attributes 21.1% on the bolus time, the value R equals to 45.9% which indicates the strength of a link between patient weight and bolus time. Adjusted R-square have the height value in cubic relationship comparing with other relationships. The value was 15% which means the patient weight can gives additional contributes on the bolus time by 15% table (4.6). and Where ∂ is the heart rate coefficientR-square 15.5 % which indicates the highest percentage among all

relationships which means that heart rate attributes 15.5 % on the bolus time, the value R equals to 38.7 % which indicates the strength of a link between heart rate and bolus time. Adjusted R-square have the height value in cubic relationship comparing with other relationships. The value was 10.7 % which means the patient heart rate can gives additional contributes on the bolus time by 10.7 % table(4.7). R-square 12.9 % which indicates the highest percentage among all relationships which means that Creatinine attributes 12.9 % on the bolus time, the value R equals to 36 % which indicates the strength of a link between Creatinine and bolus time. Adjusted R-square have the height value in cubic relationship comparing with other relationships. The value was 6.2 % which means the Creatinine level can gives additional contributes on the bolus time by 6.2 % table (4.8). R-square 17.9 % which indicates the highest percentage among all relationships which means that SBP attributes 17.9 % on the bolus time, the value R equals to 38.9 % which indicates the strength of a link between SBP and bolus time. Adjusted R-square have the height value in cubic relationship comparing with other relationships. The value was 10.9 % which means the patient SBP can gives additional contributes on the bolus time by 10.9 % table(4.9). The bolus track protocol demonstrated increased opacification of the pulmonary arteries and aorta, an increased number of diagnostic CTPA scans according to (Aoife Murphy et al., , 2023)This justifies the use of bolus track protocol at this site when performing CTPA's with similar parameters, also at similar sites with comparable patient population and subset of scanner models.

Chapter 6

Conclusions and Recommendations

6.1 Conclusions

Certain conditions need computed tomography (CT) with intravenous contrast media to be detected. The CT scan with an IV contrast media should not be generalized or considered routine. The employment of the described CM technique will provide superior results; on one hand, the timing may be readily modified based on well-known and defined parameters; on the other hand, a considerably higher improvement in the diagnostic value will be obtained. The bolus tracking technique was generate superior enhancement outcomes than fix delay time.

6.2 Recommendations

1. A strict CM safety policy should be developed in order to deliver safer and higher-quality patient care.
2. CM procedures should be created and specified based on the nature of the CT test.
3. More investigations should be conducted utilizing established CM methods, and CT images should be evaluated qualitatively.

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Appendices

Appendices A :Research Ethics Subcommittee of Faculty of Health Professions Letter of Approval

Al Quds University
Faculty of Health Professions
Jerusalem –Abu Dis

جامعة القدس
كلية المهن الصحية
القدس – أبو ديس

Research Ethics Subcommittee of Faculty of Health Professions
Letter of approval

Nov. 8, 2022
Ref. No.: RESC/2022-20

Dear Applicants, (**Dr. Mohammad Hjouj, Ms. Rawa' Alqam**)
Program: **MSc Medical Imaging Program**

The Research Ethics subcommittee of Faculty of Health Professions has recently reviewed your proposal entitled (**Signal Quantification of Intravenous Contrast Agents Enhancement from Biphase Liver CT Scan Procedures**) submitted by (**Dr. Mohammad Hjouj**). Your proposal is deemed to meet the requirements of research ethics at Al-Quds University, but further assessment is required by the Central Research Ethics Committee of Al-Quds University. We wish you all best for the conduct of the project.

Hussein ALMasri
Research Ethics Subcommittee Chair
Faculty of Health Professions

Hussein ALMasri

CC: File
CC: Committee members

Research Informed Consent

TITLE of STUDY

Signal Quantification of Intravenous Contrast Media Enhancement From Biphase Liver CT Scan Procedures

PRIMARY RESEARCHER

Name - Rawa Khaled abed Almajeed Alqam

Department - Graduate studies, faculty of health profession, medical imaging technology

Address - Jerusalem Hebron Street, Bethlehem, Palestine.

Phone - 0569750124

Email - rawaalqam37@gmail.com

PURPOSE of STUDY

This dissertation has different aims:

3. To assess the effectiveness of automated bolus monitoring vs. fixed time delay in liver procedure contrast enhancement of the liver undergoing MDCT.

4. Creating an equation to determine the best time to produce an image in a bolus monitoring approach.

PROCEDURES

The patient should be in a supine posture with the feet first protocol or head-first procedure according all of the hospitals that were considered. The arms are lifted over the patient's head, and the gantry is centered on the abdomen region. First, a single breath-hold non-enhanced CT (NECT) scan was performed from the diaphragm to the symphysis pubis. Power injectors administer the water-soluble, non-ionic IV contrast agent at various volumes and flow rates. Postcontrast arterial, venous, and delay measurements were recorded via bolus tracking or fixed time delay at various timing intervals.

RISKS

There is no risk to the patient's life

BENEFITS

accurate timing optimization to obtain optimal contrast enhancement; hence, superior image quality is important for monitoring human anatomical structures and diagnosing disorders.

CONFIDENTIALITY

Please do not write any identifying information.

Every effort will be made by the researcher to preserve your confidentiality including the following:

- Assigning code names/numbers for participants that will be used on all research notes and documents
- Keeping notes, interview transcriptions, and any other identifying participant information in a locked file cabinet in the personal possession of the researcher.

Participant data will be kept confidential except in cases where the researcher is legally obligated to report specific incidents. These incidents include, but may not be limited to, incidents of abuse and suicide risk.

COMPENSATION

Patients will be compensated if their personal information is used

CONTACT INFORMATION

If you have questions at any time about this study, or you experience adverse effects as the result of participating in this study, you may contact the researcher whose contact information is provided on the first page. If you have questions regarding your rights as a research participant, or if problems arise which you do not feel you can discuss with the Primary Researcher directly by telephone at 0569750124 or at the following email address rawaalqam37@gmail.com .

VOLUNTARY PARTICIPATION

Your participation in this study is voluntary. It is up to you to decide whether or not to take part in this study. If you decide to take part in this study, you will be asked to sign a consent form. After you sign the consent form, you are still free to withdraw at any time and without giving a reason. Withdrawing from this study will not affect the relationship you have, if any, with the researcher. If you withdraw from the study before data collection is completed, your data will be returned to you or destroyed.

Note: Please delineate the "Consent" section of the Informed Consent Form by drawing a line across the page (like this - ~~Example~~). This delineation is important because the consent form grammar shifts from second person to first person, as shown in the example.

CONSENT

I have read and I understand the provided information and have had the opportunity to ask questions. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason and without cost. I understand that I will be given a copy of this consent form. I voluntarily agree to take part in this study.

Participant's Signature _____ Date _____

Researcher's Signature _____ Date _____

القياس الكمي للإشارة لتعزيز وسائط التباين الوريدي من إجراءات المسح المقطعي المحوسب للكبد ثنائي الطور

إعداد: رواء خالد علقم

إشراف: د. محمد الحجوج

الملخص

التصوير المقطعي المحوسب (CT) هو تقنية تصوير تشخيصية تنتج صورًا شاملة للهياكل العظمية والشرايين والأوردة وأنسجة الجسم والأعضاء داخل الجسم. ركزت أطروحة الماجستير في برنامج التصوير الطبي على عامل التباين الذي تم تقييمه للمنطقة المحددة في الصورة المقطعية. تمت مقارنتها مع مراقبة البلعة الآلية مع تقنية تأخير زمني ثابت لتعزيز التباين في التصوير المقطعي المحوسب متعدد الكاشف أثناء التصوير المقطعي المحوسب للبطن والحوض باستخدام المادة المونة عن طريق حقنها بالوريد .خلال هذا الدراسة تم جمع جميع المتغيرات التي تؤثر على تعزيز التباين، بما في ذلك خصائص المريض مثل وزن الجسم، والنتاج القلبي، وإعدادات حقن التباين. تم تقسيم عينة هذه الدراسة إلى مجموعتين: 100 مريض بأثر رجعي و 43 مريضا محتملا. تم قياس الكثافة الاشعاعية قبل حقن المادة الملونة بجسم المريض للمنطقة المحددة ، وتم قياسها أيضًا بعد 30 ثانية و 70 ثانية من حقن المادة الملونة في المجموعة الأولى. ضمت هذه المجموعة 50 مريضاً من مستشفى حكومي و50 مريضاً آخرين من مستشفى غير حكومي. قامت المجموعة الثانية بجمع معلومات المريض والتي شملت عمر المريض، وزنه، معدل ضربات القلب، ضغط الدم الانقباضي والانبساطي، ومستوى الكرياتينين. تم قياس قيم وحدة الكثافة الاشعاعية قبل وبعد حقن المادة الملونة في وقت يقدره فني التصوير الشعاعي بناءً على قيم وحدة الكثافة الاشعاعية التي تصل إلى 120. وتم تحليل قيم وحدة الكثافة الاشعاعية في كلا المجموعتين لتحديد الاختلافات بين قياسات وحدة الكثافة الاشعاعية ولتطوير معادلة للتنبؤ وقت التصوير عند استخدام تقنية مراقبة البلعة الآلية. كشفت نتائج الدراسة أنه لا يوجد فرق في العمر بين الذكور والإناث في جميع مرضى العينة، وتناولت المتنبئات بمعادلة وقت البلعة وزن المريض، ومعدل ضربات القلب، ومستوى الكرياتينين، وضغط الدم الانقباضي، حيث بلغت نسبة الاعتماد على وكانت هذه المتغيرات تصل إلى 34.9%، وكان تأثير كل متغير في المعادلة بقيمة تصل إلى 59.1%. وأثبت اختبار ANOVAإمكانية الاعتماد على هذه المعادلة، حيث كانت النتيجة .p = 0.002 عند استخدام المعادلة، أظهرت النتائج عدم وجود اختلافات بين قيمة وقت البلعة التي تم جمعها في الدراسة ووقت البلعة باستخدام المعادلة، مع قيمة p تبلغ (0.992 > 0.05). اختلف معدل الكثافة الاشعاعية بشكل كبير بين المجموعة الأولى والمجموعة الثانية، حيث كانت القيمة .p 0.00 أشار البحث إلى أن استخدام مراقبة الجرعة أدى إلى مجموعة واسعة من التحسينات مقارنة بوقت استخدام الوقت المحدد، وأدى تتبع الجرعة إلى نتائج تحسين أفضل من الوقت المحدد.