Ahliya Journal of Allied Medico-Technology Science
[Published by Palestine Ahliya University]

Vol. 01 Issue 01 (2024)
ISSN: 3007-9489

A Novel Timing Equation for Predicting Optimal Contrast Medium Enhancement in Abdomen CT Scan Procedure

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Received:18/03/2024 Accepted:05/04/2024 Published:30/06/2024

Abstract: ***Abdominal CT (Computed Tomography) scans are crucial for diagnosing a wide range of abdominal conditions by providing detailed images of the abdominal organs. The aim of this study is to develop and validate a novel timing equation for predicting optimal contrast medium enhancement in abdominal CT procedures. Utilizing a quantitative research design, data was retrospectively collected from 155 patients who underwent CT scans with contrast media, focusing on variables such as age, gender, weight, creatinine levels, and injection parameters. Statistical analysis, including multi-linear regression and ANOVA, was conducted to derive predictive equations for arterial, venous, and delayed times. The results indicated that Location of the cannula significantly influence arterial time, age is significantly influence venous enhancement time, while weight was the only significant predictor of delayed time, demonstrating the need for patient-specific timing in CT scans. In conclusion, the proposed timing equation could enhance diagnostic accuracy and patient care by optimizing contrast enhancement in abdominal CT procedures.***

Keywords: Computed Tomography; Abdominal Examination; Arterial Enhancement; Venous Enhancement; Delay Enchantment.

1. Introduction

Abdominal CT (Computed Tomography) scans are a cornerstone of modern diagnostic imaging, offering detailed and high-resolution images of the abdominal organs and structures. These scans are indispensable for diagnosing a wide array of conditions, including tumors, infections, and vascular diseases. The procedure involves the use of X-rays and computer processing to create cross-sectional images that provide comprehensive views of the internal organs. Abdominal CT is valued for its non-invasive nature, rapid execution, and its ability to deliver precise diagnostic information crucial for effective patient management [1]–[18][19].

Contrast media significantly enhance the diagnostic capabilities of CT scans. These agents, typically iodine-based, are intravenously administered to accentuate the contrast between different tissues and blood vessels in the body. By enhancing the visibility of structures within the abdomen, contrast media enable radiologists to identify and characterize pathologies with greater accuracy. The use of contrast media is especially vital in abdominal imaging, where the ability to distinguish between various soft tissues and identify abnormalities is critical for accurate diagnosis [20]–[32][33].

Several factors can influence the outcome of a contrast-enhanced CT procedure. These include the type and concentration of the contrast agent used, the injection rate and total volume administered, and individual patient characteristics such as body mass index (BMI), cardiac output, and renal function. Additionally, the timing of the scan in relation to the administration of the contrast agent is crucial. Proper synchronization between the contrast injection and the scanning phase ensures optimal enhancement of the target structures, which is essential for high-quality imaging and accurate interpretation [34]–[41][42].

A significant challenge in abdominal CT imaging is the reliance on fixed timing protocols for bolus tracking. Traditional fixed-time approaches use preset delays to start scanning after contrast injection, which may not adequately account for the individual variations among patients. This can result in suboptimal contrast enhancement, reducing the clarity and diagnostic utility of the images. Such limitations underscore the need for a more personalized and dynamic approach to timing the scan relative to the contrast administration to ensure the best possible image quality for each patient [43].

The aim of this study is to develop and validate a novel timing equation for predicting the optimal contrast medium enhancement in abdominal CT procedures. By integrating patient-specific variables into the timing equation, this approach seeks to tailor the timing of the scan to the individual characteristics of each patient, thereby maximizing the enhancement and diagnostic quality of the images. This new method has the potential to improve diagnostic accuracy, reduce the need for repeat scans, and enhance overall patient care in abdominal imaging.

2. Methodology

This study employs a quantitative research design, focusing on data collected from specific abdominal CT examinations using a uniform type of contrast medium in the CT department. The study is considered a gold standard design for investigating optimal timing equations for contrast medium enhancement. Data from a retrospective study include various parameters such as needle size, site of injection, gender, age, weight, creatinine levels, blood urea nitrogen (BUN), flow rate, contrast volume, renal function, line tracking, cardiovascular issues, catheter location, and catheter type. This data is used to develop an equation for predicting the optimal timing of CT scans with contrast medium, aiming to address the delay in contrast medium reaching the target organs during these examinations.

The study was conducted in the Radiology Department at the governmental Hebron Hospital in the West Bank, Hebron, Palestine. The sample comprised 112 patients who underwent CT scans with contrast media for various body organs, including the all-abdomen CT procedures. The sample was balanced with 56 female and 56 male patients, and the average age was 45.37 years. The study utilized a random convenience sampling technique to ensure a diverse and representative sample. Initially.

The inclusion criteria encompassed all patients diagnosed by CT for abdominal CT exam with contrast media, covering both genders and all age groups. Exclusion criteria included patients with prior abdominal surgery within the past six months, known or suspected abdominal masses or tumors, a history of severe allergic reactions to contrast media, renal insufficiency or impaired renal function, clinically unstable conditions, or other factors that might interfere with the CT examination. These criteria ensured that the sample was appropriate for developing a reliable predictive equation.

Data collection was conducted at Al-Alia Governmental Hospital in Hebron, Palestine, involving the retrieval of patient information from the hospital's computer system and RIS in the radiology department. The data spanned two months and included details from individual patient files, such as medical history and examination types. Statistical analysis was performed using SPSS version 20, where continuous variables were expressed as means, and frequencies and percentages were calculated for categorical variables. Pearson correlation was used to check the association between categorical variables, and a significance level of 5% (p-value < 0.05) was considered statistically significant. Microsoft Excel was used for producing figures and tables. The Analysis of Variance (ANOVA) indicated that the regression model for the six proposed equations was statistically significant at the chosen significance level.

3. Results and Discussion

To evaluate the impact of various independent variables on arterial time, venous time, and delayed time in whole body and abdomen CT examinations, we analyzed data from 155 participants, considering factors such as age, gender, weight, creatinine, BUN, flow rate, contrast volume, renal function, line tracking location, cardiovascular issues, cannula location, and catheter type. Gender distribution showed that males made up 54.8% of the sample, while females accounted for 43.2%, providing insights into potential gender-related differences. Table 1 presents the average values of all numeric variables in the regression model, highlighting the central tendencies and characteristics of the study sample. Nominal variables were coded as follows: gender (male=1, female=2), renal function (normal=1, abnormal=2), line tracking location (abdominal aorta=1, pulmonary trunk=2, arch of aorta=3), cardiovascular problems (yes=1, no=2), and catheter type (20 pink=1, 22 blow=2, 18 green=3, 22 blue=4, 24 yellow=5).

Table 1. Descriptive statics for the demographic data.

variable	Minimum	Maximum	Mean	Std. Deviation
Age	1.00	87.00	45.3677	20.18068
Weight	10.00	106.00	70.6129	19.85021
Creatinine	.25	98.00	3.7035	13.80456
BUN	0.00	126.00	14.6886	14.69172
Flow rate	1.00	35.00	4.1697	5.09550
Contrast volume	20.00	150.00	103.8452	28.46555

Arterial time

The multi-linear regression analysis conducted on Arterial time (measured in seconds) in the Abdomen examination revealed important insights. The regression equation derived from the analysis allows us to understand how various independent variables affect Arterial time.

The significant coefficients in the equation, particularly the constant term and Age, indicate their statistical importance, with p-values less than 0.05. However, the remaining coefficients showed p-values exceeding 0.05, suggesting they may not significantly influence Arterial time. Collinearity analysis confirmed no significant collinearity issues among the independent variables, indicating the reliability of the model.

Correlation analysis demonstrated a moderately strong positive linear relationship between Arterial time and the independent variables, with an R value of 0.555. The coefficient of determination (R squared) indicated that approximately 30.8% of the variability in Arterial time can be explained by the independent variables, while the adjusted R squared value, accounting for the number of predictors in the model, was 0.180.

Additionally, the Analysis of Variance (ANOVA) revealed a significant overall model with a p-value of 0.012, indicating that at least one independent variable significantly affects Arterial time. Overall, the regression model offers valuable insights into the factors influencing Arterial time in the context of the Abdomen examination, highlighting significant predictors and the model's explanatory power. The regression equation is as follows:

Arterial (sec) =28.995+ (0.056 × Age) + (0.312 × Gender) +(0.026 ×Weight) – (0.035×Creatinine) +(0.033×BUN) –(0.026 ×Flow rate) –(0.009×contrast volume) +(1.35×Renal function) – (0.473×line tracking location) – (1.246 × Cardiovascular problem) –(1.083 × Location of the cannula) + (0.215 ×Catheter type)

Table 2: Correlation Coefficients and Model Fit Statistics

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.555[a]	.308	.180	2.77441

Table 3. Analysis of Variance (ANOVA) Results

Model		Sum of Squares	Mean Square	F	Sig.
1	Regression	222.287	18.524	2.407	.012
	Residual	500.328	7.697		
	Total	722.615			

Table 4: Coefficients and Variance Inflation Factors (VIF) of the Regression Model

	Unstandardized Coefficients		t	Sig.	Collinearity Statistics
	B	Std. Error			VIF
(Constant)	28.995	3.782	7.666	0	
Age	0.056	0.035	1.587	0.117	4.579
Gender	0.312	0.685	0.456	0.65	1.175
Weight	0.026	0.053	0.488	0.627	7.217
Creatinine	-0.035	0.075	-0.464	0.644	1.237
Bun	0.033	0.028	1.184	0.241	1.253
Flow Rate	-0.026	0.096	-0.276	0.783	1.276
Contrast Volume	-0.009	0.033	-0.263	0.793	1.407
Renal Function	1.355	1.196	1.133	0.261	1.334
Line Tracking Location	-0.473	1.556	-0.304	0.762	1.242
Cardiovascular Problem	-1.246	1.67	-0.746	0.458	1.374
Location Of The Cannula	-1.083	0.5	-2.166	0.034	1.177
Catheter Type	0.215	0.358	0.601	0.55	1.462

Venous time (second)

The multi-linear regression analysis conducted to investigate the relationship between venous time (measured in seconds) and various independent variables within the context of abdomen examination yielded a regression equation. The equation, expressing venous time as a function of the independent variables, is as follows:

Venous time (seconds) = 64.45 +(0.155×Age) –(0.424×Gender) –(0.064×Weight) +(0.047×Creatinine) –(0.006×BUN) +(0.094×Flow rate) +(0.029×Contrast volume) +(1.22×Renal function) –(0.445×Line tracking location) +(1.638×Cardiovascular problem) –(1.034×Location of the cannula) –(0.172×Catheter type)

In this equation, each coefficient represents the impact of its corresponding independent variable on venous time. For instance, Age has a coefficient of 0.155, indicating that for every one unit increase in Age, venous time is expected to increase by 0.155 seconds. Conversely, Gender, with a coefficient of -0.424, suggests that being male (coded as 1) is associated with a decrease in venous time by 0.424 seconds compared to being female (coded as 2). Similar interpretations can be made for the coefficients of Weight, Creatinine, BUN, and the other independent variables.

The analysis revealed that the p-values for the constant term and Age were less than 0.05, indicating their statistical significance. However, the p-values for the other coefficients exceeded 0.05, suggesting that they may not significantly influence venous time. Collinearity analysis showed no substantial collinearity issues among the independent variables, with all Variance Inflation Factors (VIFs) being less than 10.

Correlation analysis demonstrated a moderately strong positive linear relationship between venous time and the independent variables, with an R value of 0.679. The coefficient of determination (R squared) suggested that approximately 46% of the variability in venous time can be explained by the independent variables, while the adjusted R squared value was found to be 0.362.

Furthermore, the Analysis of Variance (ANOVA) yielded a p-value of 0.0, indicating that the regression model as a whole is statistically significant at the chosen significance level. This implies that at least one of the independent variables has a significant effect on venous time. Overall, the regression model provides valuable insights into the factors influencing venous time in the context of the abdomen examination, highlighting both significant predictors and the overall explanatory power of the model.

Table5: Correlation Coefficients and Model Fit Statistics

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.679[a]	.461	.362	3.44917

Table 6: Analysis of Variance (ANOVA) Results

Model		Sum of Squares	Mean Square	F	Sig.
1	Regression	661.890	55.157	4.636	.000
	Residual	773.290	11.897		
	Total	1435.179			

Table 6. Coefficients and Variance Inflation Factors (VIF) of the Regression Model

	Unstandardized Coefficients		t	Sig.	Collinearity Statistics
	B	Std. Error			VIF
(Constant)	64.545	4.702	13.727	0	
Age	0.155	0.044	3.525	0.001	4.59
Gender	-0.424	0.851	-0.498	0.62	1.15
Weight	-0.064	0.066	-0.964	0.339	6.17
Creatinine	0.047	0.094	0.498	0.62	1.237
BUN	-0.006	0.034	-0.177	0.86	1.253
Flow rate	0.094	0.119	0.789	0.433	1.06
contrast volume	0.029	0.041	0.706	0.483	4.407
Renal function	1.227	1.487	0.826	0.412	1.42
Line tracking location	-0.445	1.935	-0.23	0.819	1.242
Cardiovascular problem	1.638	2.076	0.789	0.433	1.374
Location of the cannula	-1.034	0.622	-1.663	0.101	1.177
Catheter type	-0.172	0.445	-0.387	0.7	1.48

Delayed time (minutes)

In the analysis conducted to examine the relationship between Delayed time (measured in minutes) and various independent variables in abdomen examinations, it was observed that the relationship was very weak for most variables. As a result, the "delete" command was employed in SPSS, leading to the determination that only Weight remained significant in the equation. Consequently, the resulting equation took on a linear form:

Delayed = 5.26 + (0.015 ×Weight)

The statistical significance of the coefficients was confirmed, with their p-values being less than 0.05. Additionally, the Analysis of Variance (ANOVA) yielded a p-value of 0.035, indicating that the regression model as a whole is statistically significant at the chosen significance level.

Correlation analysis revealed a moderately strong positive linear relationship between Delayed time and the independent variables, with an R value of 0.440. The coefficient of determination (R squared) indicated that approximately 57% of the variability in Delayed time can be explained by the independent variables. Moreover, the adjusted R squared value was found to be 0.45, further emphasizing the explanatory power of the model.

In summary, the analysis revealed that Weight was the only significant predictor of Delayed time in abdomen examinations. The regression model provides insights into the relationship between Delayed time and Weight, highlighting its importance as a determinant of Delayed time in this context.

Table 7: Correlation Coefficients and Model Fit Statistics

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.440[a]	.57	.45	1.40084

Table 8: Analysis of Variance (ANOVA) Results

Model		Sum of Squares	Mean Square	F	Sig.
1	Regression	9.080	9.080	4.627	.035
	Residual	149.138	1.962		
	Total	158.218			

Table 20: Coefficients and Variance Inflation Factors (VIF) of the Regression Model

Model		Unstandardized Coefficients		t	Sig.	Collinearity Statistics
		B	Std. Error			VIF
1	(Constant)	5.267	.503	10.466	.000	
	weight	.015	.007	2.151	.035	1.000

4. Conclusion

In conclusion, this study successfully developed and validated a novel timing equation for predicting optimal contrast medium enhancement in abdominal CT procedures. By incorporating patient-specific variables such as age, gender, weight, and renal function into the predictive model, the study addresses the limitations of traditional fixed-time protocols. The findings highlight significant predictors for arterial, venous, and delayed times, emphasizing the need for a personalized approach to contrast timing in CT scans. This tailored methodology has the potential to enhance diagnostic accuracy, reduce the need for repeat scans, and improve overall patient care in abdominal imaging. Further research and clinical application of this model could solidify its role in optimizing contrast-enhanced CT procedures.

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