Journal of Critical Reviews

ISSN- 2394-5125 Vol 7, Issue 1, 2020

**Research Article**

# SCAN TIMING OPTIMIZATION FOR AORTIC COMPUTED TOMOGRAPHY ANGIOGRAPHY USING THE TEST-BOLUS INJECTION METHOD

**SANAZ ASADIAN [1], BAHAREH JAHANSHAHI [1], ALI MOHAMMADZADEH [1], YASER TOLOUEITABAR [2], NAHID REZAEIAN [1], LEILA HOSSEINI [3], KIANOSH KASANI [1], ZAHRA FOOSHERIAN [4], AMIRHOSEIN HEYDARI [5], FATEMEH VARZDAR [5] ***

[1] Department of Radiology, Rajaie Cardiovascular Medical and Research Center, Iran University of Medical Sciences, Tehran, Iran
[2] Department of Congenital Cardiac Surgery, Rajaie Cardiovascular Medical and Research Center, Iran University of Medical Sciences, Tehran, Iran
[3] Cardiology Department, North Khorasan University of Medical Sciences, Bojnurd, Iran
[4] Shahid Beheshti University of Medical Sciences, Tehran, Iran
[5] Iran University of Medical Sciences, Tehran, Iran

**Email: Varzdaar@gmail.com**

***Received: 10 Oct 2020 Revised and Accepted: 14 Dec 2020***

**ABSTRACT**

Introduction: Computed tomography angiography (CTA) is the imaging method for assessing aorta and other peripheral arteries in recent years. Accurate timing of the contrast administration leads to better quality and less radiation to the patient and operator. This study aimed to evaluate the optimal time of scanning after contrast medium administration through the test-bolus injection method and investigate how individual factors could affect the aortic contrast enhancement timing on aorta CTA. Design: In this cross-sectional study, one hundred consecutive patients who underwent CTA were included. Individual factors such as gender, age, height, weight, BMI, and cardiac function were measured. The optimal time (i.e. aortic peak-time (APT)), the starting time of the scan, the contrast arrival time of the monitoring level, and duration of CTA scanning were reported and the correlation of these variables and patients' factors were evaluated. Results: The Patient's mean age was 66.39 ± 10.91 years. The mean APT was 19.17 ± 3.14s (ranged 14-30.1s). The CTA start and arrival time was 9.46 ± .98s and 12.02 ± 1.71s, respectively. In this research, The CTA mean duration was 23.35 ± 2.77s. There was no correlation between aortic peak-time and patients' factors such as gender, age, weight, BMI, and cardiac function. Conclusions: According to the results, the aortic peak time following test-bolus contrast media injection was 19.17s which was not influenced by gender, age, weight, BMI, and cardiac function.

***Keywords:*** Computed Tomography (CT), Aortic CT Angiography, Aortic Peak Time, Test-Bolus Technique


DOI: http://dx.doi.org/10.22159/jcr.07.01.01

## INTRODUCTION

Computed tomography angiography (CTA) is an accurate non-invasive imaging technique for vascular disease evaluation. Recently, CTA is the imaging method for assessing aorta [1, 2]. The intravenous contrast media administration has improved the image quality of CTA [3-6] and using multi-detector CT (MDCT) devices has led to the shorter scan time, higher speed, and higher resolution [7-9].

The first MDCT scanners with 2–10 rows had some limitations because the execution of CTA required administration of large volumes of contrast medium due to their acquisition speed restriction [2]. With the development of CT devices and the 384-MDCT scanners introduction, the scanning time has been reduced significantly accompanying with less contrast medium administration [10]. The small time-window for data gathering during aortic CTA scanning due to the 384-MDCT devices' high-speed nature along with a small amount of contrast media administration could cause the scanning to outpace the contrast medium bolus before reaching the endpoint of the scanning range. Therefore, the CTA image quality is degraded [11]. For optimal timing of scanning and proper contrast medium injection, predicting the aortic enhancement pattern including the APT and the aortic peak enhancement (APE) is significant [12].

Bolus-timing techniques could ensure accurate timing of the contrast bolus in CTA [1]. The test-bolus injection (TBI) method and the bolus tracking (BT) method are the two most available bolus-timing techniques. Even though these techniques are helpful to determine the scanning delay for the optimized starting time scan; they cannot reduce the outpacing risk because they can not provide vital information regarding the contrast medium transit time in the aorta [11]. Furthermore, various factors affect the contrast enhancement including the contrast medium parameters and the patients' physical condition such as weight, height, and cardiovascular functions, especially cardiac output and the vascular disease presence [1, 12].

The proper calculation of contrast arrival time and its maximum concentration in the aorta could lead to better CTA image quality and less radiation to the patient and operator. In this study, we aimed to evaluate the optimal scanning time after contrast medium administration through the test-bolus injection method and investigate how individual factors could affect the aortic contrast enhancement timing on aorta CTA.

## MATERIAL AND METHODS

### Study design

This cross-sectional study was performed at Rajaie Cardiovascular Medical and Research Center, Iran University of Medical Sciences (IUMS) during 2017 and 2018.

One hundred consecutive patients suspicious for CAD who underwent CTA examination were included in this study. The exclusion criteria were patients with previous severe reactions to radiographic contrast agents, renal dysfunction, uncooperative or pregnant patients, and those with unstable clinical condition [1]. Sex, age, height, and weight of all patients were evaluated before contrast media administration. The body mass index (BMI) was calculated for all patients using weight (kg) / [height (m)] $^2$ formula. Patients were also categorized based on BMI as 19-25 Kg/m$^2$, 25-30 Kg/m$^2$ and > 30 Kg/m$^2$ (World Health Organization (WHO) classification [13]). The cardiac function was also reported as normal, mild, moderate, or severe heart failure (HF) [14].

**CTA study**

All CTA scans were performed using a 384-MDCT scanner.

- First, the peak enhancement time of the ascending aorta was determined using the test-bolus method, and then the exact start time of the main CT angiography procedure of coronary arteries was calculated and executed using the ~~the~~ test-bolus methods' information.
- The dose of the drug in the test phase for all patients was fixed at 12 cc and a flow rate of 5.6 ml/sec in the main stage of the scan was calculated based on the patients' weight and according to the same injection conditions as the test phase.
- All patients were injected with 300 mg / mL iodine concentration using a 20-gauge catheter through an antecubital vein. Following the injection of contrast material, both the test and the main injection phase of 30 mL saline solution were performed in the same way. The monitoring level for the ascending aorta was at the level of the tracheal bifurcation. CT scans were then performed with a 384-slice device.
- Scan monitoring was done based on the protocol (100 kV and 50 mAs) 1sec interval and scan start time 10 seconds after contrast injection.

The region of interest (ROI) in the ascending aorta was selected to achieve a time-attenuation curve for APT measurements (Figure 1) [11, 15]. The optimal time was measured from the initial contrast bolus administration until the aortic peak enhancement (APE) was reached the 200 HU threshold. The scanning start time, the contrast arrival time of the monitoring level and CTA scanning duration were also measured and reported.

**Statistical analysis**

This analysis was carried out using SPSS software V22, SPSS Inc., Chicago, IL, USA. The Kolmogorov-Smirnov test showed a normal data distribution. Unpaired t-test, Chi-square, and repeated measures ANOVA were used for statistical comparisons. In the case of non-normal distribution, non-parametric tests were used. The notable threshold was considered to be less than 0.05.

## RESULTS

One hundred patients (48 male and 52 female, with a mean age of 66.39 ± 10.91 years, ranged 38-92 years) with suspected CAD underwent CTA using the TBI method. The demographics of patients are summarized in table 1. Patients' mean weight and height were 80.78 ± 16.58 Kg and 170.41 ± 10.49 cm, respectively. The mean BMI was 27.67 ± 4.15 Kg/m$^2$. The mean optimal time (APT) was 19.17 ± 3.14s (ranged 14-30.1s). The CTA start and arrival time was 9.46 ± 0 .98s and 12.02 ± 1.71s, respectively. The CTA mean duration was 23.35 ± 2.77s in this study.

We evaluated the correlation between patients' factors and the mean optimal time (Table 2). Patients were categorized in ≤ 65 years and > 65 years old (51 and 49 cases, respectively). The optimal time was higher in patients younger than 65 years (19.23 ± 2.91s compared to 19.10 ± 3.39s). This difference was not significant with p-value=0.539. The APT was higher in female patients (19.40 ± 3.16s compared to 18.91 ± 3.13s) with no significant difference with p-value = 0.322. Twenty-three patients had a BMI of 19-25 Kg/m$^2$, fifty-three had a BMI of 25-30 Kg/m$^2$ and twenty-four had a BMI > of 30 Kg/m$^2$. The highest mean optimal test was observed in patients with BMI of 19-25 Kg/m$^2$ (19.44 ± 2.54s) and the lowest in patients with BMI of > 30 Kg/m$^2$ (18.54 ± 2.74 s), but no significant correlation was found between BMI and the APT (p-value = 0.461). Eighty-six patients had a normal cardiac function, eight patients were diagnosed with mild, moderate, and severe HF each was observed in three patients. The highest APT was observed in patients with moderate HF (20.00 ± 2.00s) and the lowest was observed in patients with severe HF (18.07 ± 1.95s). There was no significant relation between cardiac function and optimal aortic time. (p-value = 0.908).

The effect of individual factors on start, arrival, and duration times were also measured. As shown in table 3, no significant correlation existed between patients' characteristics, and the above-mentioned CTA variables (all with p-value > 0.05).

## DISCUSSION

For the best result in CTA, the scanning should be performed in optimal time during the arterial phase after intravenous injection of the contrast media with its constant intra-arterial concentration [12, 16]. The advancement of CT technologies has led to the reduction of the time-window for the data acquisition also the entire aorta imaging has been reduced to less than 10 seconds for 384-MDCT [10]. Thus, the optimization of contrast media injection protocols and the timing of the scanning based on aortal peak pattern (APE and APT) are vital for achieving the proper results [10, 17]. Based on previous studies, the intra-arterial contrast media concentration and enhancement were associated with patients' characteristics including body weight, BMI, heart rate (HR), and cardiac output (CO) [1, 18, 19]. This study aimed to evaluate the optimal time of scanning after contrast medium administration (APT) via the TBI method and the correlation between patients' characteristics and the APT.

In the present study, one hundred patients with suspected CAD underwent CTA, and findings (optimal time, start time, arrival time, and duration) were evaluated. According to the findings, the CTA optimal time (APT) was 19.17 ± 3.14s. Although, the APT was higher in female patients, aged < 65 years, with BMI of 19-25 Kg/m$^2$ and HF with moderate severity, there was no correlation between APT and other CTA variables evaluated in this study with patients' characteristics.

Masuda et al. studied the effect of two different test bolus techniques, diluted and undiluted contrast media on the aortic enhancement during coronary CTA [15]. The arrival time (the duration from the scan delay to the APE) was 19.0s and 20.0s in the undiluted and diluted group, respectively which was in line with the measured optimal time of the present study. The median CT number in the ascending aorta was significantly higher in patients receiving diluted TBI (217.1 vs. 157.4 HU) and there was a strong linear correlation between the CT number after diluted TBI and CT number obtained during coronary CTA. According to their study, the APE value can be used for predicting enhancement on coronary CTA images by using a diluted TBI method. Furthermore, The TBI method yields not only the aortic time density curve but also predicts peak enhancement before coronary CTA. In a study by Zhou et al. a high positive correlation was observed between aortic enhancement and hemodynamic parameters obtained through TBI (e.g. peak enhancement and the time to peak enhancement of the right ventricle and left ventricle) during coronary CTA [17]. Hoshino et al. introduced a new TBI method (femoral artery test injection (FTI) method) and found that the enhancement was significantly higher with the FTI compared to the BT method (388.3 ± 52.4 HU vs. 281.2 ± 59.1 HU). The percentages of cases with good image quality were 86% and 46% in FTI and BT method, respectively [11]. They concluded that the FTI method with the prediction of proper scan start time could reduce the risk of outpacing of contrast media during aortic CTA.

Tang et al. studied on 116 patients undergoing coronary CTA via the dual-source CT (DSCT) [1]. The delay time (duration between contrast administration to the density threshold of > 100 HU in ascending aorta at the level of right main pulmonary artery reaching a threshold of 100 HU) was 16.0 ± 3.0s ranged 11.16 – 25.08s. It shortened with increasing HR (with a coefficient of -0.110) and in female patients it was 1.902s shorter than the male patients (P < 0.001) and increased with an increasing transversal cardiac diameter (TCD) (with a

ISSN- 2394-5125 Vol 7, Issue 1, 2020

coefficient of 0.394) with P = 0.015. Other evaluated factors in this study were age, height, weight, body surface area, transversal thoracic diameter (TTD), and cardiothoracic ratio (TCD/TTD) which could not influence the delay time. Among the cardiac function variables, stroke volume (SV) was associated with the delay time, but there was no relationship with the CO. According to this study, the delay time could be predicted by gender, HR, and TCD. Although the delay time was shorter than the mean APT of our study, it should be noted that the enhancement threshold was set at 100 HU in the study by Tang et al., but for a diagnostic assessment as in the present study, an intra-arterial target threshold higher than 200 HU is required [20]. So, this difference is justifiable. Furthermore, similar to the findings of our study, the enhancement time was independent of height, weight, and, age.

Puskás et al. determined that neither systolic blood pressure, diastolic blood pressure, HR, body length, body weight nor body surface could influence the blood circulation time of intracranial CTA [16]. In another study by Kirchner et al. optimized enhancement following bolus-triggered contrast administration was not correlated with age, body weight, and body surface in 548 patients undergoing abdominal and chest CTA [21].

In 2009, Sakai et al. evaluated the effect of cardiac functions on aortic peak patterns during coronary CTA [12]. According to their findings, the mean APT and APE were 38.3±7.5s, and 390.4±72.1 HU, respectively. There was a negative correlation between the cardiac index with either APT ($r = -0.698$, $p < 0.0001$) and APE ($r = -0.573$, $p = 0.0009$). A significant correlation was observed between the patients' body weight, APT (negative relation) and APE (positive relation). This finding is inconsistent with the findings of our study. In the present study, even though the APT decreased with increasing weight, no significant relationship between the weight and the optimal time was reported. Besides, the optimal time was shorter compared to the calculated APT of the Sakai study [12]. It should be noted that the present study had a larger sample size (100 cases compared to 29). Furthermore, the contrast media volume and concentration were greater in the Sakai study (an iodine concentration of 350 mg of I/mL with 90 mL volume), and the tube voltage and current were also different (120 kV and 60 mA, respectively) which explain the difference between the two studies. Also, according to the study of Kim et al. the mean peak time of the abdominal aorta was 37±4s using a similar contrast administration protocol as Sakai et al [22,12].

We had some limitations consisting of the small size of the study population and that other important factors influencing APT, including blood pressure, HR, and CO not evaluated. We recommend further studies with larger sample sizes, which also include other parameters to achieve more reliable results.

## CONCLUSIONS

According to the findings of this study, the aortic peak time following test-bolus contrast media injection in a 384-slice multi-detector scanner was 19.17s, which was not influenced by the patient's gender, age, weight, BMI, and cardiac function.

## ACKNOWLEDGMENTS

The present study was supported by a grant from the Vice-chancellor for Research, IUMS, Iran.

### Conflicts of interest

There is no conflict to declare.

## REFERENCES


1. Tang L, Zhu X, Xu Y, Yu T, Xu H, Tang J, Dogra V, Wang D. Factors influencing delay time and coronary arterial density during coronary angiography with DSCT. Acta Radiologica. 2011 Feb; 52(1):59-63.
2. Baxa J, Vendiš T, Moláček J, Štěpánková L, Flohr T, Schmidt B, Korporaal JG, Ferda J. Low contrast volume run-off CT angiography with optimized scan time based on double-level test bolus technique–feasibility study. European journal of radiology. 2014 Mar 1; 83(3):e147-55.
3. Dreizin D, Munera F. Blunt polytrauma: evaluation with 64-section whole-body CT angiography. Radiographics. 2012 May 5; 32(3):609-31.
4. Kertesz JL, Anderson SW, Murakami AM, Pieroni S, Rhea JT, Soto JA. Detection of vascular injuries in patients with blunt pelvic trauma by using 64-channel multidetector CT. Radiographics. 2009 Jan; 29(1):151-64.
5. Lell MM, Anders K, Uder M, Klotz E, Ditt H, Vega-Higuera F, Boskamp T, Bautz WA, Tomandl BF. New techniques in CT angiography. Radiographics. 2006 Oct; 26(suppl_1):S45-62.
6. Matsumoto K, Jinzaki M, Sato K, Tanami Y, Nakatsuka S, Hashimoto S, Kuribayashi S. Multidetector-row Ct angiography of lower extremities: Usefulness in the diagnosis of and Intervention for Peripheral arterial disease. Annals of vascular diseases. 2010 Dec 24; 3(3):202-8.
7. Schoepf UJ, Becker CR, Hofmann LK, Das M, Flohr T, Ohnesorge BM, Baumert B, Rolnick J, Allen JM, Raptopoulos V. Multislice CT angiography. European radiology. 2003 Aug 1; 13(8):1946-61.
8. Dalrymple NC, Prasad SR, Freckleton MW, Chintapalli KN. Introduction to the language of three-dimensional imaging with multidetector CT. Radiographics. 2005 Sep; 25(5):1409-28.
9. Flohr TG, Schaller S, Stierstorfer K, Bruder H, Ohnesorge BM, Schoepf UJ. Multi–detector row CT systems and image-reconstruction techniques. Radiology. 2005 Jun; 235(3):756-73.
10. Tomizawa N, Ito S, Nakao T, Arakawa H, Yamamoto K, Inoh S, Nojo T, Nakamura S. Double ROI Timing Bolus Technique to Perform Aortic CT Angiography With a 9-Second Contrast Injection Duration. American Journal of Roentgenology. 2019 Mar 27:1-8.
11. Hoshino T, Ichikawa K, Hara T, Terakawa S, Hosomi K, Nishimura K, Takayama K. Optimization of scan timing for aortic computed tomographic angiography using the test bolus injection technique. Acta Radiologica. 2016 Jul; 57(7):829-36.
12. Sakai S, Yabuuchi H, Chishaki A, Okafuji T, Matsuo Y, Kamitani T, Setoguchi T, Honda H. Effect of cardiac function on aortic peak time and peak enhancement during coronary CT angiography. European journal of radiology. 2010 Aug 1; 75(2):173-7.
13. World Health Organization. Obesity: preventing and managing the global epidemic. World Health Organization; 2000.
14. Tripoliti EE, Papadopoulos TG, Karanasiou GS, Naka KK, Fotiadis DI. Heart failure: diagnosis, severity estimation and prediction of adverse events through machine learning techniques. Computational and structural biotechnology journal. 2017 Jan 1; 15:26-47.
15. Masuda T, Funama Y, Imada N, Sato T, Yamagami T, Tatsugami F, Awai K. Prediction of aortic enhancement on coronary CTA images using a test bolus of diluted contrast material. Academic radiology. 2014 Dec 1; 21(12):1542-6.
16. Puskas Z, Schuierer G. Determination of blood circulation time for optimizing contrast medium administration in CT angiography. Der Radiologe. 1996 Sep; 36(9):750-7.
17. Zhu X, Zhu Y, Liu W, Yang G, Su Z, Tang L, Xu Y. Improved image-quality consistency in coronary CT angiography using a test-bolus-based individually tailored contrast medium injection protocol. Clinical radiology. 2016 Nov 1; 71(11):1113-9.
18. Zhu X, Chen W, Li M, Xu Y, Xu H, Zhu Y, Wang D, Tang L. Contrast material injection protocol with the flow rate adjusted to the heart rate for dual source CT coronary angiography. The international journal of cardiovascular imaging. 2012 Aug 1; 28(6):1557-65.

ISSN- 2394-5125 Vol 7, Issue 1, 2020


19. Zhu X, Zhu Y, Xu H, Wan Y, Choo KS, Yang G, Tang L, Xu Y. An individualized contrast material injection protocol with respect to patient-related factors for dual-source CT coronary angiography. Clinical radiology. 2014 Feb 1; 69(2):e86-92.
20. Macari M, Israel GM, Berman P, Lisi M, Tolia AJ, Adelman M, Megibow AJ. Infrarenal abdominal aortic aneurysms at multi–detector row CT angiography: intravascular enhancement without a timing acquisition. Radiology. 2001 Aug; 220(2):519-23.
21. Kirchner J, Kickuth R, Laufer U, Noack M, Liermann D. Optimized enhancement in helical CT: experiences with a real-time bolus tracking system in 628 patients. Clinical radiology. 2000 May 1; 55(5):368-73.
22. Kim T, Murakami T, Takahashi S, Tsuda K, Tomoda K, Narumi Y, Oi H, Nakamura H. Effects of injection rates of contrast material on arterial phase hepatic CT. AJR. American journal of roentgenology. 1998 Aug; 171(2):429-32.

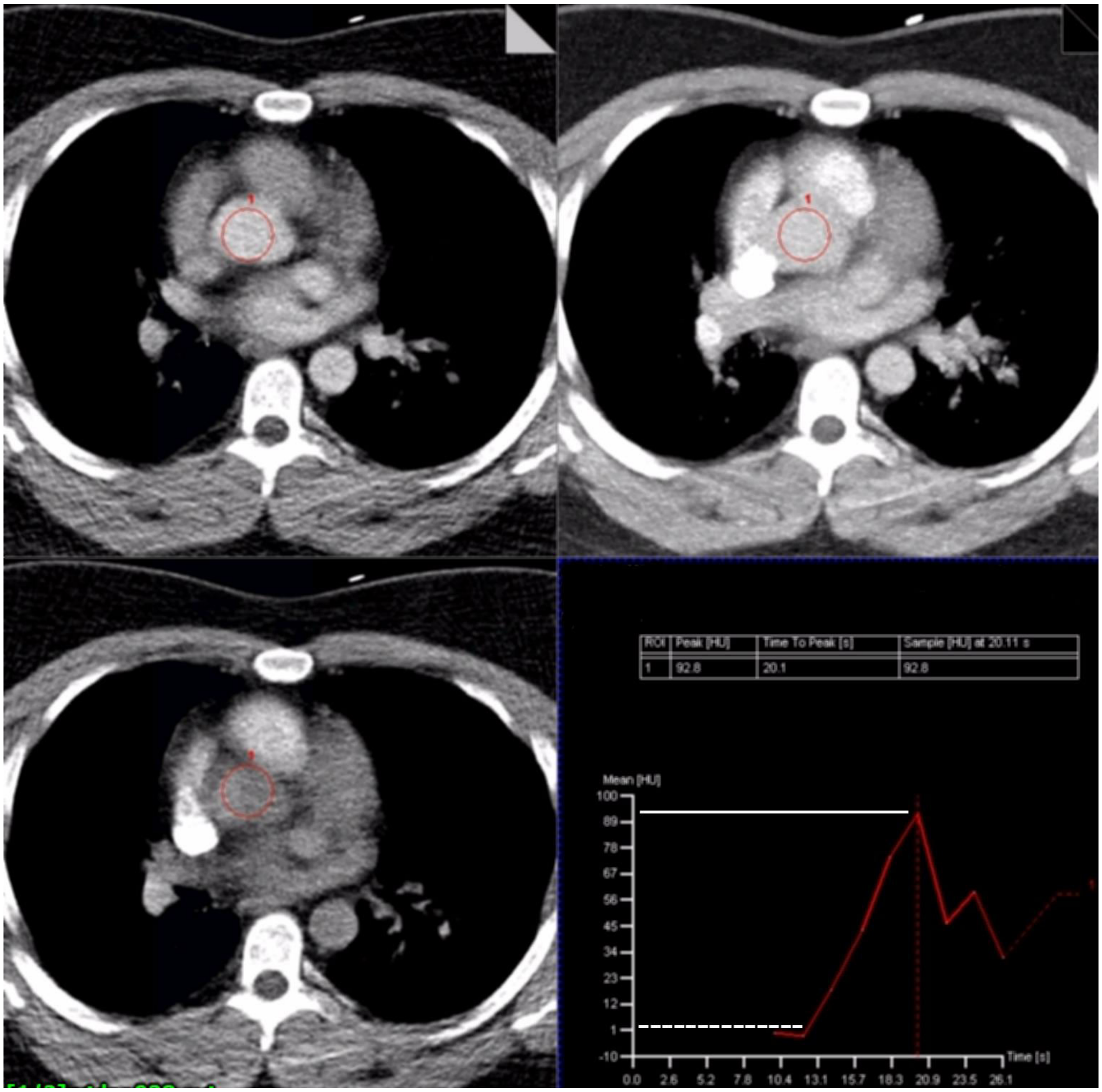


**Fig. 1: The graphical illustration of the test-bolus tracking method. (The dashed line reveals contrast arrival time and the continuous line represents the time to peak contrast enhancement).**

**Table 1: Participants demographics**

| Characteristic | Minimum | Maximum | Mean | Standard Deviation |
|---|---|---|---|---|
| **Age (years)** | 38.0 | 92.0 | 66.39 | 10.91 |
| **Weight (Kg)** | 52.0 | 135.0 | 80.78 | 16.58 |
| **Height (cm)** | 150.0 | 20.0 | 170.41 | 10.49 |
| **BMI (Kg/m$^2$)** | 19.57 | 41.91 | 27.67 | 4.15 |

BMI: body mass index

**Table 2: Participants CTA characteristics**

| Characteristic | Minimum | Maximum | Mean | Standard Deviation |
|---|---|---|---|---|
| **Optimal time** | 14.00 | 30.10 | 19.17 | 3.14 |
| **Start time** | 8.0 | 13.0 | 9.46 | 0.98 |
| **Arrival time** | 10.0 | 16.0 | 12.02 | 1.71 |
| **Duration time** | 18.0 | 32.0 | 23.35 | 2.77 |

CTA: computed tomography angiography

ISSN- 2394-5125 Vol 7, Issue 1, 2020

**Table 3: Analysis of Optimal time by demographics**

| Characteristic | N | Mean | SD | P-value |
|---|---|---|---|---|
| **Age** | | | | |
| **≤ 65 years** | 51 | 19.23 | 2.91 | 0.539 |
| **> 65 years** | 49 | 19.10 | 3.39 | |
| **Sex** | | | | |
| **Male** | 48 | 18.91 | 3.13 | 0.322 |
| **Female** | 52 | 19.40 | 3.16 | |
| **BMI** | | | | |
| **19-25 Kg/m²** | 23 | 19.44 | 2.54 | 0.461 |
| **25-30 Kg/m²** | 53 | 19.33 | 3.53 | |
| **> 30 Kg/m²** | 24 | 18.54 | 2.74 | |
| **Cardiac function** | | | | |
| **Normal** | 86 | 19.21 | 3.33 | 0.908 |
| **Mild dysfunction** | 8 | 18.78 | 1.01 | |
| **Moderate dysfunction** | 3 | 20.00 | 2.00 | |
| **Severe dysfunction** | 3 | 18.07 | 1.95 | |

N: number, SD: standard deviation, BMI: body mass index