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Retrospective Correlation of the Circulation Time of Test Bolus Injections in MR Angiography and Cardiac Function

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Abstract: This retrospective study examines 248 test bolus examinations preceding contrast-enhanced magnetic resonance angiography (CE-MRA) to extract clinically relevant data for critical limb ischemia (CLI) management. The method involved a retrospective review of test bolus exams, analysing 60 graphs for time to peak (TTP), full-width half-maximum (FWHM) time, and time to continual rise in signal intensity. These values were correlated with heart function parameters (ejection fraction, ASA classification, Lee index, and MET score). The results indicate a mean TTP of 31.2 ± 7.3 s, showing a correlation between the ejection fraction and ASA classification. Patients with atrial fibrillation exhibited prolonged TTP compared to those without. Despite population heterogeneity, these findings facilitate risk stratification for limb-saving interventions in CLI. TTP emerges as a potential clinical cardiovascular parameter and a risk factor for vascular interventions. Given the variation in injection protocols across centres, this study underscores the importance of precise bolus arrival time documentation for future multicentre studies.

Keywords: test bolus examination; magnetic resonance angiography; time to peak; peripheral arterial disease

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1. Introduction

Peripheral arterial disease (PAD) poses significant challenges due to its high risk of limb and tissue loss as well as cardiovascular events, particularly in cases of critical limb ischemia (CLI) [1,2]. Magnetic resonance angiography (MRA) is crucial in evaluating PAD, aiding treatment decision-making, and guiding revascularisation procedures. MRA, especially contrast-enhanced magnetic resonance angiography (CE-MRA), provides immediate, actionable data for clinical decision-making. For instance, CE-MRA can swiftly visualize critical vascular areas, such as the pelvis and leg arteries, to determine the necessity and type of urgent interventions like thrombectomy. Moreover, insights into cardiac impairments obtained during the scan can influence decisions regarding the choice of surgical procedures and anaesthesia, tailoring treatment to each patient's specific needs and enhancing overall patient management. Patient management strategies should be further improved and, for this matter, studies which explore clinically relevant data are necessary. One of these valuable techniques is test bolus examinations, which can enhance the precision and effectiveness of CE-MRA in clinical settings. Test bolus examinations, conducted before peripheral CE-MRA, present an opportunity to acquire additional insights into the cardiovascular status of patients with PAD. A test bolus examination is a diagnostic procedure used in medical imaging to determine the optimal timing for contrast media injection. A small amount of contrast is administered to visualize the flow through the blood vessels, helping to calculate the delay before the full contrast injection for the

actual scan. Its key advantages include ensuring optimal contrast enhancement and reducing the risk of motion artifacts. However, it prolongs the overall procedure time and increases radiation exposure or contrast material usage, depending on the used imaging modalities [3–6].

There is an emphasis on assessing and reducing cardiac risk in individuals undergoing surgeries unrelated to cardiac issues [7]. Most authors underscore the significance of diagnostic tools such as transthoracic echocardiography [8], the American Society of Anesthesiologists (ASA) Physical Status Classification System [9], and a variety of risk indices, including the revised cardiac risk index [10], for the prediction and management of cardiovascular risks [11–14]. The critical role of preoperative cardiovascular examination in identifying patients susceptible to complications, for instance, those presenting with asymptomatic left ventricular dysfunction [15] or diminished physical capacity [16], is highlighted. Additionally, some studies stress the importance of physical fitness and exercise capability [17], quantified in metabolic equivalents (METs) [18], in forecasting surgical outcomes and informing preoperative evaluations and planning.

While there are limited studies specifically addressing the relationship between "test bolus examinations" or time to peak (TTP) and cardiac functions, existing research primarily focuses on other aspects of cardiovascular imaging. The novelty aspect of our study is, therefore, that we looked for the correlation between test bolus parameters and cardiac parameters. This indicates an opportunity for the current study to explore this area further, potentially offering new insights into the diagnostic process. Most existing studies on test bolus assessments predominantly utilize computed tomography (CT) as their imaging modality. A distinct advantage of our study is the application of magnetic resonance imaging (MRI) to explore the correlation between test bolus parameters and cardiac function parameters. This approach not only diversifies the technological basis of the research but also enhances the understanding of cardiovascular dynamics in MRI settings, potentially leading to more accurate and specific clinical insights.

Our retrospective study aims to investigate the correlation between the time to peak (TTP) during test bolus MR angiography exams and various cardiac parameters in patients with PAD. By examining how TTP relates to the ejection fraction (EF), ASA classification, Lee index, and MET score, we aim to enhance risk stratification and inform clinical decision-making for CLI interventions. This study focuses on delineating the diagnostic value of TTP, thereby potentially improving treatment strategies and outcomes in high-risk PAD patients.

2. Materials and Methods

Before detailing the study design, it is essential to affirm that all aspects of this research comply with the Helsinki Declaration principles, ensuring that ethical standards are maintained in the conduct of our study involving human participants. Furthermore, it is important to acknowledge that this study adopts a retrospective design, and due to the nature of the data collection process, individual informed consent was not obtained. Instead, a general consent form was available for patients participating in medical procedures at the institution. An ethics committee approval was granted for this study (ethics committee number: 32-017 ex 19/20, date: 27 September 2019).

2.1. Study Design

A data query was carried out at the Institute for Medical Informatics, Statistics, and Documentation. The data collection period was from the first of October 2016 until the first of October 2019. All MR angiographies conducted with contrast media were compiled into two tables from the clinic's documentation system. These lists were organised by the date of the examinations. A patient could appear multiple times in these lists if repeated examinations were performed at different times. The MRA examination that was closest to the time of the cardiac diagnostic test was selected for analysis. The collected data were categorised into three locations: extremities, trunk, and skull. Based on this list, screenings

were conducted. Hereafter, the pseudonymised list with identification numbers is referred to as the "primary file", which can be found in Möller's doctoral thesis [19].

2.2. MRA Protocol for Test Bolus with Peak Determination

Here, the standardised procedure for an MRA, focusing on a test bolus injection for pelvic and leg vessels (referred to as "Step Angio"), is described as an example. Radiological technicians (RTs) execute the protocol for capturing the standardised MRA and, thus, the test bolus. Radiologists always consult with radiology technicians to make necessary adjustments to the procedure.

After establishing intravenous access and correctly positioning the patient in the MRI machine, the injection pump filled with contrast media is connected to the IV access. For CE-MRA, the "MEDRAD® MRXperion" (MEDRAD® MRXperion MR Injection System; Bayer Healthcare, Whippany, NJ, USA) injection pressure pump is used. Initial images are taken without contrast media for a preliminary overview of the body regions. In total, 1–2 mL of contrast media; 0.5–1 mmol/mL gadolinium with 0.5–2 mL/s flow; 30 mL saline 0.9% flush was used. The infusion pump is activated at a flow rate of 1.0 mL/s, 1.5 mL/s, or 2 mL/s, and simultaneously, a sequence of images from the abdominal aorta is captured every second. After 60 to 90 s, the image sequence capture is stopped. The ROI (region of interest) for determining the delay is located over the bifurcation of the abdominal aorta into the right and left common iliac arteries at the level of the kidneys or the branching of the renal arteries (Figure 1). The resulting graph shows the signal intensity's rise, peak, and fall over time (Figure 2). The maximum signal intensity, defined as the TTP, is used as the delay time for the actual angiography. The TTP value is the peak measured by the graph.

The delay used for CE-MRA may differ slightly from the TTP, extended by a few seconds based on the radiology technicians experience, the desired angio sequence (e.g., centre of k-space), and the precise ROI. For instance, 2–3 extra seconds are often added to the TTP for older patients.

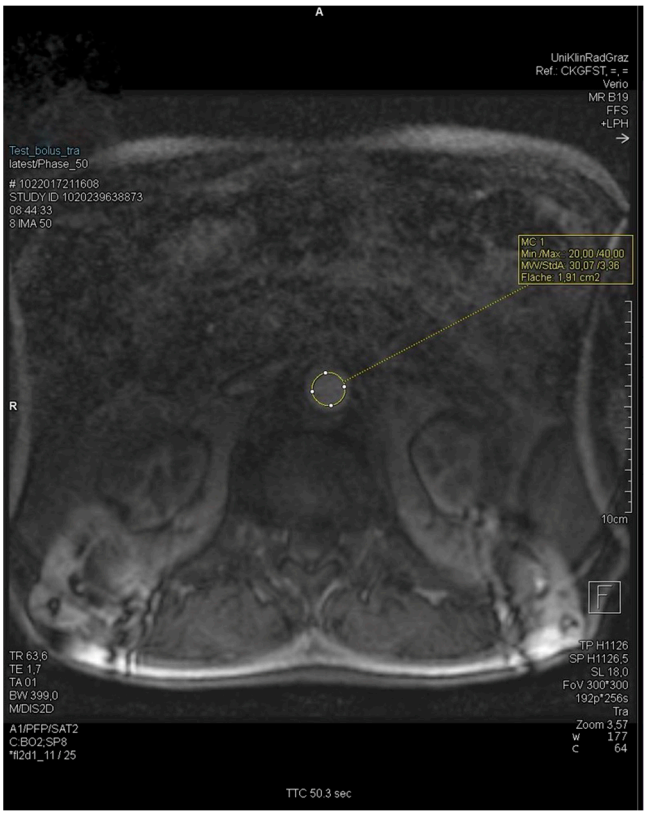

Figure 1. MRI of ROI set in the abdominal aorta at kidney level.

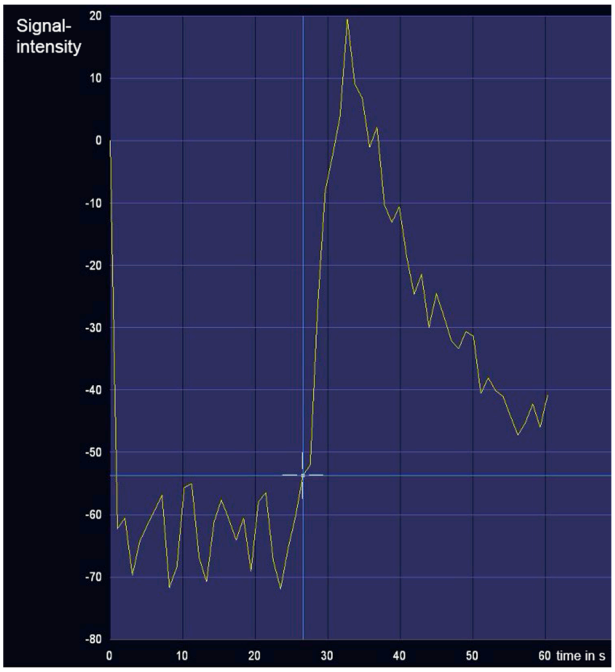

Figure 2. Signal intensity in relation to time in seconds. The cursor shows the start of the continuous signal rise.

2.3. Patient Assessment

Using the provided information, the patient's examination was in MEDOCS® and checked against inclusion and exclusion criteria. The radiology technicians documented the delay as part of the TTP measurement and delay determination in the protocol or entered MEDOCS® (medocs GmbH Medical Data & Software Services, Siegen, Deutschland). The primary cardiac parameter chosen was the EF. Other indices of heart function, such as the MET score, ASA classification, and Lee index, which are part of the preoperative anaesthesia assessment, were collected. The test bolus was stored as an image sequence, which could be evaluated in the subsequent data collection step.

The inclusion criteria were the availability of source data (including test bolus delay) and cardiac examination with a documented ejection fraction (EF), determined by cardiac ultrasound, cardiac MRI, or myocardial scintigraphy. The exclusion criteria were patients under 18 years of age at the time of examination, patients who experienced an acute deterioration of their condition between examinations, including events significantly affecting heart function, such as a heart attack, reversible shock states, pulmonary oedema, recent stroke, or asthma attack, pregnant women, and patients with missing records. No additional inclusion or exclusion criteria were applied in this study. The data collection was carried out regardless of age or gender.

Of the total 1276 examinations, of which the data are available [19], 178 (14.0%) could be included in the study and categorised in the various ROIs, based on the inclusion criteria. A total of 1098 patients were excluded from the study based on the established exclusion criteria. We analysed the ROI abdominal aorta patient collective (123 patients) in more detail. In total, 112 examinations (8.8%) had a time interval that was too long between the MRA and the cardiac examination. In 63 examinations (4.9%), no test bolus for the MRA was performed or documented. In 12 examinations (1.0%), renal angiograms were performed using a much shorter delay time because of the k-space order of the sequence. In these cases, the documented delay does not represent the signal's peak during test bolus acquisition. It cannot be utilised. In total, 2 patients (0.2%) were too young, and the condition deteriorated drastically between the examinations in another 2 (0.2%). Finally, the data for one examination (0.1%) were inaccessible. Most patients lacked cardiac diagnostics

(71.0%, n = 906) and could not be included in the study. This is visually depicted in Figure 3 within the results section.

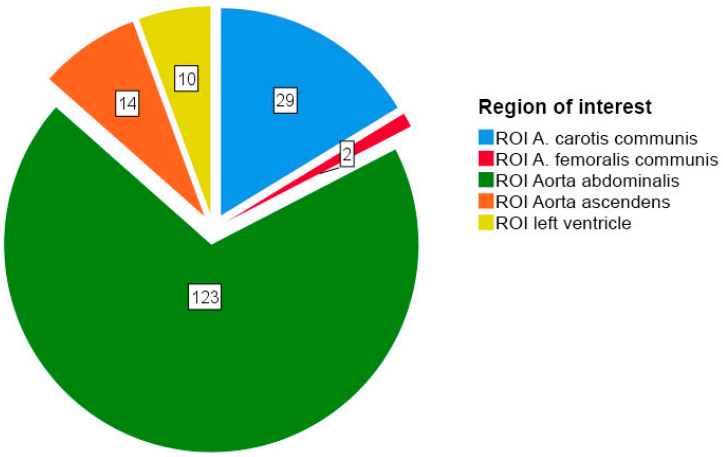

Figure 3. Breakdown of the included examinations according to ROI.

2.4. Data Collection

2.4.1. Classification According to Defined ROI

The required data of a given patient were extracted from the examination documents stored in MEDOCS® and the syngo.via® (Siemens Healthcare, Forchheim, Germany) workstation. All angiographies with different ROIs were summarised in the primary file. It was still being determined at the time which ROI would have the most frequent and accurate data. For this reason, several databases were created with the respective ROIs: *Aorta abdominalis*, *A. carotis communis*, *Ao. ascendens*, *Arteria femoralis communis*, and left ventricle. The abdominal aorta was included in the largest number of examinations, which is why the following detailed correlation analysis and evaluation are also limited to this region.

2.4.2. Test Bolus and Measurement

In MEDOCS®, the delay was documented and recorded either in the documents of the radiology technicians or as part of the scanned protocols. If the test bolus was sent and saved as an image sequence with the MR images, the test bolus graph could also be analysed. The syngo.via® workstation (Siemens®) was used to analyse the TTP, full-width half-maximum (FWHM) time, and the time the continuous signal increase began. For better readability, the start of the continuous signal rise is referred to below simply as "signal start." The height of the test bolus image sequence limited the plane of the ROI in the transverse section. For coronary sectioning, the ROI was set at the level of the kidneys and caudal to the renal arteries. An example of the ROI set in the abdominal aorta is shown here. Figure 1 shows the ROI at the level of the kidneys due to the transverse plane.

The width of the graph calculates the FWHM time at half the height of the maximum amplitude. The value is calculated as follows:

$$\text{FWHM} = 31.7 - 23.5 = 8.2 \text{ s.}$$

This value describes the width of the graph and has been used in publications for correlation calculations between the contrast agent transit time and the heart function [20]. Unfortunately, the image sequence was not sent with every test bolus injection and delay determination. As a result, the test bolus graphs of only about half (60/123 examinations) of the included examinations could be measured by the syngo.via® workstation. For examinations with no image sequence available, we limited ourselves to the delay documented by the radiology technicians as the cycle time. In some test boli image sequences, the delay was so long that the graph only showed an increase. Therefore, the limited 60 s of the image

sequence recording only allowed a limited measurement. This explains why the "start of signal" value was measured most frequently. At least the peak must be visible in the 60 s interval to calculate the TTP. The measurement of the FWHM requires a complete graph.

2.4.3. Selective Collection of Delay Times from the Primary File

To obtain an image of the test bolus delay times used at Graz University Hospital and the flow rates, bolus volumes, average value, normal value/median, distribution, and standard deviation used, delay times from the primary file were collected and analysed selectively and separately. These additional data were collected to determine a statistically more meaningful representation of the test bolus delay times used to increase the number of cases. This was limited to the ROI *aorta abdominalis*, where most examinations were found. In this case, no cardiac diagnostics were required. The standardised protocol of the radiologists and radiology technicians made it possible to determine the delay used, the flow rate in mL/s, bolus volume in ml, and the conduction region of the venous access.

2.4.4. Cardiac Function Parameters

Additional information on cardiac function was obtained from documented cardiac examinations. The most crucial secondary target parameter, EF, could be determined by cardiac ultrasound examinations, myocardial scintigraphy, or cardiac MR examinations. During preoperative anaesthesia examinations, further information on exercise tolerance and, thus, cardiac function could be determined indirectly. The MET score (metabolic equivalent), ASA classification (suitability for surgery or risk and urgency of surgery), and revised cardiac risk index (Lee index), which have been routinely determined for several years, made it possible to collect the values. In addition, the days between the examinations (MRA and cardiac examination) were calculated and documented. From a cardiological point of view, the question arose as to the change in the delay in the (pre-)existence of an atrial fibrillation arrhythmia. This was also investigated.

2.5. Data Analysis

The complete statistics (descriptive statistics, retrospective correlation analysis, and analysis of variance) were performed using SPSS (IBM Corp. Released 2019. IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY, USA). All graphs and figures were also created with this program. To investigate the strength and direction of the association between the variables under study, two tests were employed using SPSS software: Spearman's rank correlation coefficient (Spearman-Rho) and Kendall's tau-b. These tests were chosen due to the ordinal nature of the data and the distribution observed in preliminary analyses. For interpreting the results, a p-value of less than 0.05 was considered statistically significant, indicating a strong likelihood that the observed correlations were not due to random chance.

3. Results

In total, 178 patients could be included in the study and categorised in the various ROIs (Figure 3). A total of 1098 patients were excluded from the study based on the established exclusion criteria. At this point, the ROI abdominal aorta patient collective (123 patients) was researched in more detail. Figure 4 shows the indications for the MRA for these patients.

These 123 patients (40 female and 83 male) constituted the final cohort included in the analysis.

Subsequently, an analysis explored the correlation between the measured TTP and cardiac parameters, including EF and ASA classification regarding the previously mentioned 123 patients with the ROI of the abdominal aorta. A correlation between the delay with the EF and the ASA classification could be seen. The values shown in Figure 5 illustrate the distribution of EF values. With an average EF value of 53%, the population is slightly below the norm (<55). In total, 50% of the values are in the range between an EF of 45–60%.

The extremes are represented by the minimum of 15% and maximum of 78%. The most frequent values were recorded around the EF of 60%.

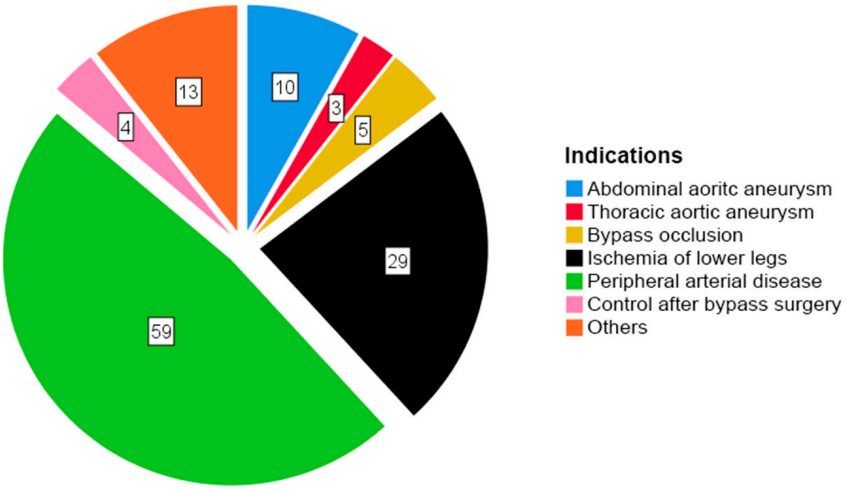

Figure 4. Breakdown of indications for MR angiography from the 123 patients with ROI = abdominal aorta (total number of patients = 123, 40 female and 83 male).

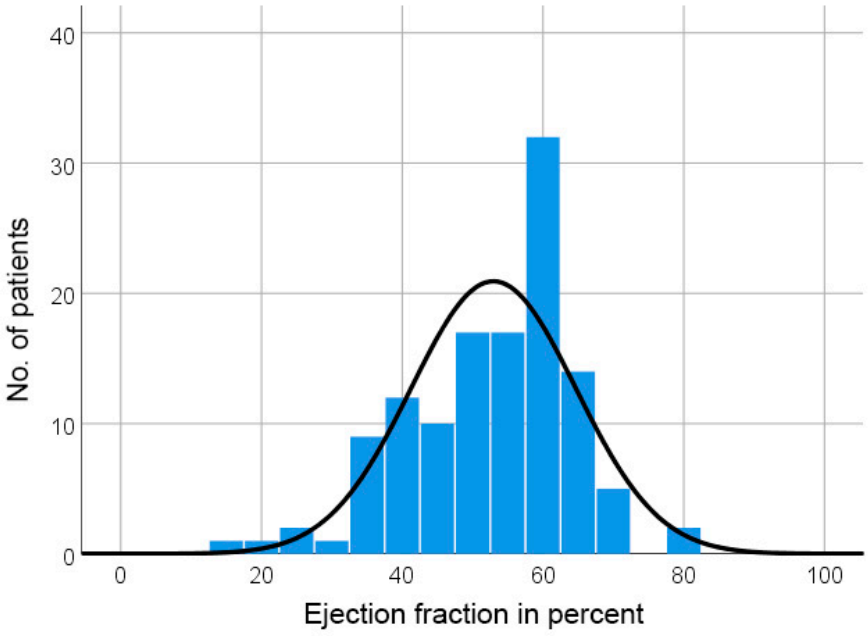

Figure 5. Bar chart for the distribution of the EF values (total number of patients = 123).

Figure 6 presents the delay in seconds regarding the ASA classification. The distribution of ASA classifications within the patient cohort is as follows: 51 patients were classified as ASA 4, 26 patients as ASA 3, and 6 patients as ASA 2. Only one patient was identified with an ASA classification of 0. Additionally, preoperative diagnostic examinations with recorded ASA classifications were absent in 39 patients. The mean values differ between the groups. Groups 2, 3 and 4 show a clear trend with the respective mean values of 26.5 s, 30.69 s, and 33.78 s. This can also be seen in Figure 6 (medians within the boxplots). The maximum values of 35 s, 47 s, and 62 s in the respective Classifications 2, 3, and 4 should also be emphasized. It is noteworthy that ASA Classification 2 has no values above 35 s, but ASA Classification 4 has values of up to 62 s. As ASA Classification 0 was only surveyed once, this group is not shown as a box plot.

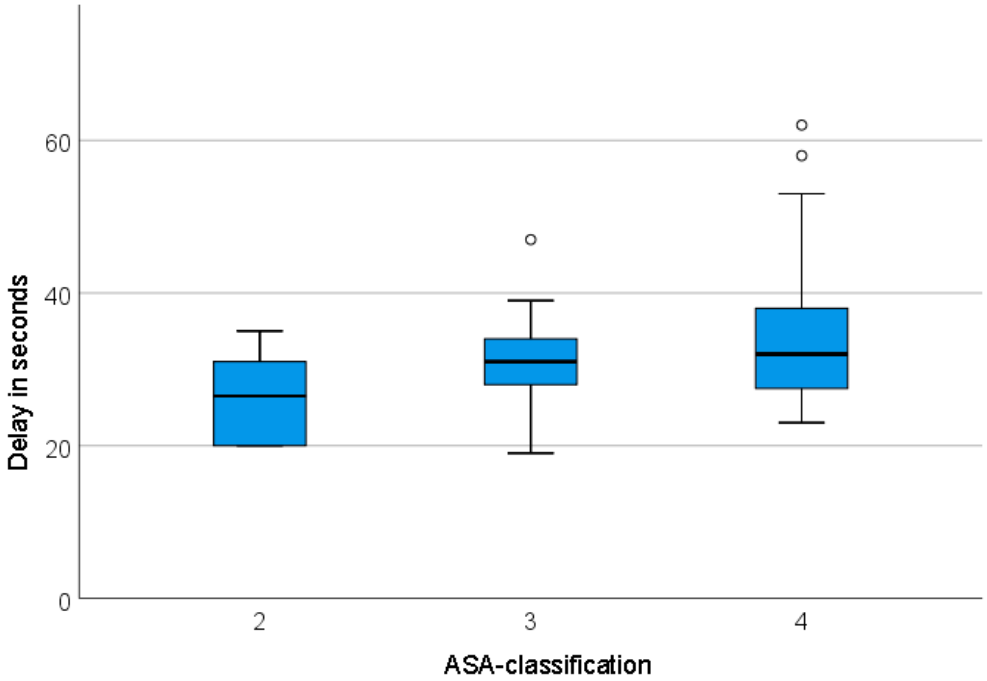

Figure 6. Boxplot for the delay in seconds in the different ASA classification groups. ASA Classification 4, $n = 51$; ASA Classification 3, $n = 26$; ASA Classification 2, $n = 6$. ASA Classification 0 was only identified once. In 39 patients, no preoperative diagnostic examination with a recorded ASA classification could be found (total number of patients = 123).

A deviation was found between the TTP in the used heart failure classifications (heart failure (HF) and the preserved ejection fraction (HFpEF), EF $\geq$ 50%; HF with a mildly reduced ejection fraction (HFmrEF), EF 41–49%; and HF with a reduced ejection fraction (HFrEF), EF $\leq$ 40%). This is presented in Figure 7. The number of cases for the group with EF > 50 is $n = 85$, EF 40–50 $n = 21$, and EF < 40 $n = 17$. The mean values between the groups with EF < 40 and >50 show a large difference (40.47 − 30.11 s = 10.36 s). The division of the EF into the heart failure groups shown in Figure 7 indicates a prolongation of the delay with a lower EF. The median is recognizable as a black horizontal bar and illustrates the opposing trend between the delay and the EF. It is noteworthy that almost no values below 30 s were recorded for an EF < 40. In addition, in the group with EF > 50, apart from one extreme value, no values above 47 s were recorded.

Patients diagnosed with atrial fibrillation had a prolonged TTP compared to those without (mean time 36.7 ± 9.1 s vs. 30.6 ± 7.1 s, respectively, $p < 0.001$). In total, 31 were diagnosed with atrial fibrillation and 92 were not. This is illustrated in Figure 8, which presents the delays in patients with and without AF. Patients with AF had on average a 6 s longer delay compared to patients without diagnosed AF (36.68 − 30.58 s = 6.10 s). Interestingly, however, the group without diagnosed AF had a higher range of values. The longest recorded delay value in this group is 62 s. The deviation of the medians and boxplot heights indicate a considerable difference.

Our further research on other parameters, such as the MET classification and Lee index in relation to TTP and delay, did not show statistically significant results. We cannot determine if a correlation between these parameters and TTP exists. This concludes our research results regarding the 123 patients with the ROI of the abdominal aorta.

In addition to the previously discussed 123 patients with the ROI of the abdominal aorta, our final analysis expanded to include a total of 248 patients from the primary file of 1276 examinations, specifically selected to calculate the delay of the examination protocols. These patients met the criteria for an appropriate ROI and provided necessary data for the calculation, thus forming a comprehensive dataset encompassing both previously included and newly identified subjects. Descriptive statistics were used to describe the distribution

of the documented delays of the radiology technicians in more detail. With a mean (μ) of 31.2 s and a standard deviation (σ) of 7.3 s, it can be calculated that there is a 95% probability that the TTP values lie between the interval [16.9 s; 45.5 s] for repeated examinations (min 18 s, max 63 s). Calculated: $[\mu - 1.96 \times \sigma; \mu + 1.96 \times \sigma]$.

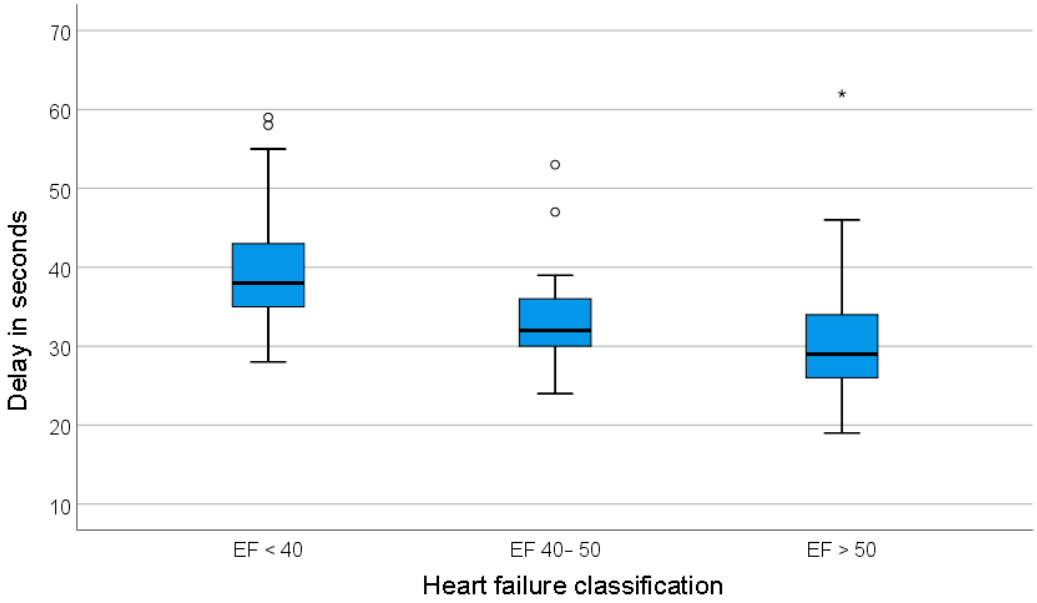

Figure 7. Boxplot for the delay in seconds divided into the different heart failure groups; EF < 40% = HFrEF, EF 40–50% = HFmrEF, EF > 50% = HFpEF. The number of cases for the group with EF > 50 is n = 85, EF 40–50 n = 21 and EF < 40 n = 17 (total number of patients n = 123). Small star (*) indicates an extreme outlier that is more than 3 IQR above the third quartile.

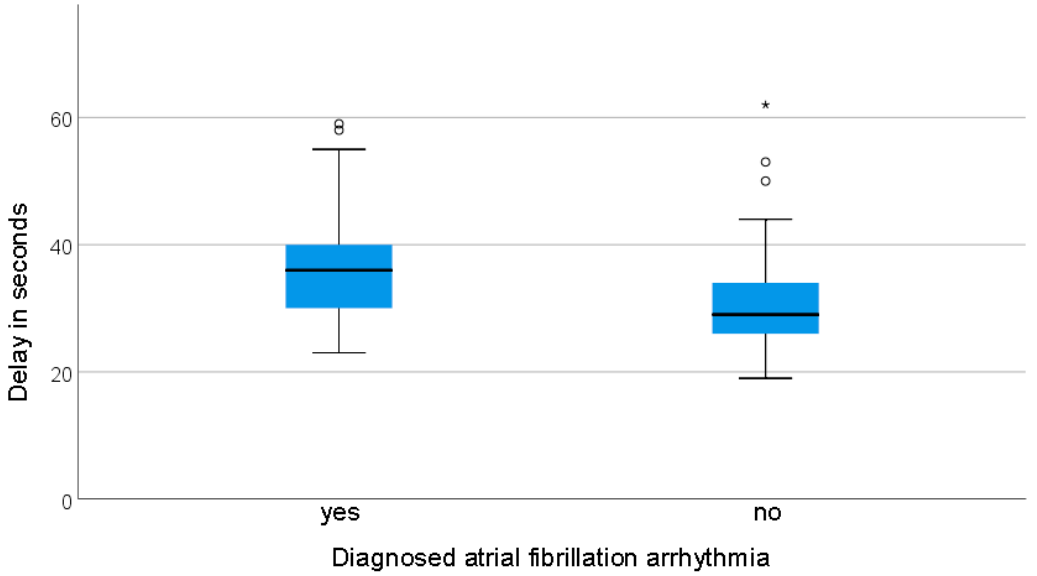

Figure 8. Boxplot of the delay of the groups with diagnosed arterial fibrillation versus undiagnosed arterial fibrillation. In total, 31 were diagnosed with atrial fibrillation and 92 were not (total number of patients = 123). Small star (*) indicates an extreme outlier that is more than 3 IQR above the third quartile.

4. Discussion

This paper investigates the significance of the test bolus delay time for cardiac function in MR angiographies. Specifically, many MRA examinations were conducted in peripheral

arterial occlusive disease (PAD) or acute lower extremity ischemia, where rapid revascularisation and reperfusion are crucial. The standardised determination of the delay/TTP could serve as an additional tool for risk assessment for interventions [20,21]. Our research shows that the delay over 45 s represents a significantly increased risk (ASA 4) for interventions, which has clinical consequences. This should be further investigated in prospective multicentre studies.

The results of this study enable a clinical application of the test bolus in relation to cardiac function. Comparisons with previous studies underscore the importance of the test bolus delay time for distinguishing patients with and without heart diseases [19,22].

Francois et al. [21] compared the test bolus injections of 77 patients with cardiovascular disease before CE-MRA to a healthy cohort of 33 participants. The primary outcome measure was the arm-to-aorta delay time with the bifurcation of the common carotid artery as the defined ROI. They found a mean TTP of 20.8 s $\pm$ 3.9 s in the cardiovascularly preloaded group and a mean of 16.6 s $\pm$ 1.9 s in the control subjects ($p < 0.05$). Their study described a cut-off value of 18s with the highest sensitivity and specificity for detecting patients with cardiovascular disease. In 2003, when this paper was published, the value of these test bolus TTP measurements was recognised, and attempts were made to generate clinically useful information. In this example, this cut-off value makes it possible to differentiate between patients with or without heart disease. Our retrospective study shows the correlation analysis of the delay with the Lee index as a comparison parameter. Here, pre-existing conditions were primarily included in the study. The advantage of Francois' work is the comparison with the control group, which had no previous cardiovascular disease. This makes it possible to calculate this cut-off value, which is the best way to differentiate between the groups studied [19].

Shors et al. [20] examined the pulmonary transit time (PTT) and full-width half-maximum (FWHM) time in CE-MRA for patients with heart disease and compared them with a healthy cohort. They used the left and right ventricle as the ROI. The FWHM times were measured at 11.6 s $\pm$ 3.1 s in the "heart disease" cohort. These values correspond well with the 13.16 s $\pm$ 3.3 s measured in this study [19]. In Shors et al., the colleagues recognised a correlation between PTT and EF. This study also showed a significant correlation between the FWHM time and the EF. The discrepancy in the values (11.6 s vs. 13.2 s) is probably due to the ROI abdominal aorta used compared to the ascending aorta and the resulting longer blood flow distance [19,20]. In our study, we observed a notable deviation from the Gaussian distribution of EF values at the 60% threshold, as illustrated in Figure 5. This deviation may stem from a prevalent bias among cardiologists, who often regard an ejection fraction of 60% as indicative of normal cardiac function.

In their work, Mahnken AH. et al. [22] evaluated the signal curve of test bolus injections in multi-slice spiral computed tomography examinations using a modified Stewart–Hamilton equation (SHE). They compared the cardiac output (CO) values of the CT (computed tomography) images CO determined by measuring the heart dimensions) with the calculated values (using SHE) from the signal curve. The Pearson correlation analysis between the geometric analysis and the corrected contrast dilution (calculated by SHE) yielded an R = 0.87 for CO and R = 0.87 for EF. Thus, their calculations showed a significant correlation between the signal curve and the measured cardiac dimensions and, thus, with the cardiac EF. This analysis method would produce similarly promising results in investigating test bolus injections in CE-MRA [19,22].

Our study suggests interesting directions for future research. Our results show that almost all delay values above 40s are in ASA Classification 4, which leads to an interesting assumption: It is likely that if the delay is above 40 s, the surgical/interventional risk could be categorised by the ASA classification, even though the average delay between the classifications was not significantly different. Further investigations are necessary to analyse and substantiate this statement in more detail. Additionally, our analysis did not find significant correlations between the MET classification, Lee index, and time to peak (TTP) or delay. Additional studies are required in this area. Future research should

focus on developing regression models and standardised protocols for test bolus data collection. The application of the Stewart–Hamilton equation could allow for the non-invasive determination of CO in CE-MRA. In the future, AI could also play an essential role as a tool to aid in the development of regression models [23–25].

Lastly, we would like to discuss the limitations of this study. One limitation of our study pertains to the variability in flow rates (1.0 mL/s, 1.5 mL/s, or 2 mL/s) during test bolus MR angiography exams, potentially impacting the time to peak (TTP) parameter. However, it is noted that the TTP may be less influenced by flow speed further away from the heart. Additionally, the potential variability in determining ejection fraction (EF) across different imaging modalities, such as cardiac ultrasound, cardiac MRI, or myocardial scintigraphy, presents another limitation. Each modality may exhibit differences in accuracy when assessing EF, which is a critical parameter for our study. Moreover, while our study collected data irrespective of age or gender, enhancing the breadth of our dataset, caution is warranted in universal extrapolation due to potential demographic variations and biases. Future studies should strive for a more homogeneous patient population and standardized examination methods. The exact effect of contrast agents on MRI outcomes remains uncertain. Patients likely acclimated to the MRI environment during the test, and stable angiography results imply a consistent ejection fraction. However, extreme agitation may still influence heart function.

5. Conclusions

This retrospective study showed that the calculated mean time of the TTP was 31.2 ± 7.3 s (min 18 s, max 63 s). A correlation between the TTP and the ejection fraction, and between the TTP and the ASA classification, could be found, as well as a deviation between the TTP in the used heart failure classifications (HF-pEF, HF-mrEF, HF-rEF). Patients with a diagnosed atrial fibrillation had a prolonged TTP compared to those without (mean time 36.7 ± 9.1 s vs. 30.6 ± 7.1 s, respectively, $p < 0.001$). Our study reveals the mean TTP or bolus arrival time as a potential clinical cardiovascular parameter correlated with EF and ASA classification, particularly impactful in risk stratification for CLI interventions. These findings advocate for standardised injection protocols to facilitate future multicentre studies and optimise patient care.

6. Suggestions

This retrospective study underscores the significance of the precise documentation of bolus arrival time in every radiology report after performing a CE-MRA.

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Data Availability Statement: Data can be accessed via the thesis [19].

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