'Triple-rule-out' CT angiography for clinical decision making and early triage of acute chest pain patients: use of 320-multislice CT angiography

Amira R. Eltabbakh[1,2*] , Mahmoud A. Dawoud[1], Mathias Langer[3], Mohammed A. Moharm[1], Ehab A. Hamdy[1] and Manal F. Hamisa[1]

Abstract

Background: In our study, we aimed to estimate utility of TRO CTA to guide clinical decision in acute chest pain patients with intermediate risk to acute coronary syndrome (ACS) in the emergency department.

Methods and material: Our study population included 45 acute chest pain patients with intermediate-risk ACS. All these patients had done TRO CTA to access any pathological conditions in the coronary artery, pulmonary artery, aorta and thoracic diseases that may be the cause of their complaint. Follow-up was done in all patients for 60 days.

Results: Among the 45 patients, we were able to discharge 44.4% (20 out of 45) of our population safely to home with no need for further diagnostic cardiac testing. The rest of the patients were classified into significant coronary artery disease 40% (18 out of 45), 8.8% (4 out of 45) had acute aortic lesions and 6.6% (3 out 45) had pulmonary artery embolization.

Conclusions: Triple Role Out CT angiography (TRO CTA) is not only an effective protocol for exclusion of ACS with high specificity compared to dedicated coronary CTA but also in the diagnosis of acute chest pain due to other vascular and non-vascular causes helping decision-making strategy for admission in the emergency department.

Keywords: TRO CTA, Acute chest pain, Emergency department

Background

Acute chest pain is the second most common presentation after abdominal pain in the emergency department (ED) [1], and it accounts for nearly 40% of all emergency department (ED) diagnoses in the USA [2].

Acute chest pain (ACP) represents a major diagnostic challenge in emergency care as it has a broad differential diagnosis varying from benign causes to life-threatening conditions [3].

The most clinically relevant conditions causing chest pain that have to be differentiated are acute coronary syndrome (ACS), pulmonary embolism (PE) and acute aortic syndrome (AAS) [4].

Coronary artery disease is the leading cause of morbidity and mortality in industrialized countries [5]. The diagnosis of acute coronary syndrome (ACS) includes unstable angina, non-ST-elevation myocardial infarction and ST-elevation myocardial infarction [6].

Invasive coronary angiography is the 'gold standard' investigation to detect obstructive coronary artery lesions but carries a small risk of serious complications [7].

Coronary CT angiography (CTA) provides high-quality noninvasive images of the heart, great vessels and coronary vasculature [8, 9].

Thoracic aortic dissection (TAD) is a life-threatening condition that is estimated to occur at a rate of 3 to 4 cases per 100,000 persons per year and is associated with high mortality (Additional file 1). TAD belongs to the

* Correspondence: eltabbakhamira@yahoo.com
[1]Radiodiagnosis and Medical Imaging, Faculty of Medicine, Tanta University Hospital, El Geash Street, Tanta, Gharbya 31511, Egypt
[2]Zefta, Egypt
Full list of author information is available at the end of the article

category of life-threatening pathologies of the aorta, referred to as AAS, which also includes intramural hematoma (IMH) and penetrating aortic ulcer (PAU) [10].

As the third most common cause of cardiovascular death, PE is a potentially fatal condition associated with significant morbidity and mortality [10], and CT angiography has become widespread and became a standard image modality in diagnosis the pulmonary embolism as a leading cause of acute chest pain [11].

In many clinical situations, a definite diagnosis of ED chest pain is not possible solely based on clinical symptoms and laboratory findings. In addition, most diagnostic modalities (i.e., ECG, cardiac enzymes, exercise treadmill testing, radionuclide perfusion imaging and stress echocardiography) other than MDCT are focused on the diagnosis or exclusion of ACS and do not exclude other life-threatening causes of acute chest pain [12].

For this reason, Triple Role Out (TRO) protocol with ECG-gating technology has been proposed to encompass the entire thorax, allowing simultaneous evaluation of coronary arteries, thoracic aorta and pulmonary arteries for improving diagnosis of acute chest pain [13].

Patient and methods
Forty-five patients (26 female and 19 male) with intermediate risk for ACS presented with acute chest pain. Twenty-five patients were referred to the radiological department in Tanta University Hospital in Egypt, and 20 patients were referred to the radiological department in Freiburg University Hospital in Germany to do TRO CTA (from September 2014 to December 2017).

Inclusion criteria
Patients presented with acute chest pain with intermediate risk to ACS. A Thrombolysis in Myocardial Infarction (TIMI) risk score was used to identify patients with intermediate risk profile for ACS.

Exclusion criteria

– High-risk patient for ACS (significant ST segment changes in the ECG, a history of acute myocardial infarction) and patients who underwent coronary stenting or coronary bypass surgery
– Pregnancy
– Creatine level ≥ 1.5 mg/dl
– Known history of contrast agent allergy

Our study TRO CTA protocol was performed using 320-multislice CT (Aquilion 1, Toshiba definition) with 0.5 mm Detector-row dimension, 160 mm beam width, 0.35 s gantry rotation,175 s temporal resolution for each cross-section image.

Pre-exam patient preparation

1. All our patients were first evaluated for HR, blood pressure and careful taking for our patient medical history.
2. Thirty patients with high heart rate were given selective β-blocker metoprolol tartrate [Lopressor], 50–100 mg), 11 patients received one tablet 100 mg and the other 19 patients received one tablet 50 mg. None of our patients had any contraindications for β-blockers; our exams were done by heart rate ranging from 60–75 bpm.
3. When the patient heart rate became suitable, IV access is gained with 16–18 G intravenous catheter in the right antecubital fossa vein.
4. All patients received breath holding training over the CT table for 15 s.
5. All patients were given sublingual nitrates for better visualization of coronary arteries.
6. A standard prospective ECG triggered non-enhanced CT was initially done to obtain coronary calcium score.

'Triple-rule-out' CT angiography imaging protocol

1- In order to opacify both coronary and pulmonary arteries, biphasic injection technique was used; 80 ml of undiluted contrast material was injected (Ultravist 370 ml) was injected at 5 ml/s, followed by 25 ml of the same contrast diluted with 25 ml saline, also injected at 5 ml/s.
2- We used the bolus-tracking technique to get the diagnostic vessel opacification level, the first phase of injection opacifies coronary arteries while the second phase opacifies pulmonary arteries.
3- Prospective ECG triggering (30–80% of the cardiac cycle) was used in patients depending on regular heart rate intervals.
4- Scan acquisition started from the inferior margin of clavicle head to the base of the heart.
5- Images were obtained at 0.5 ml thickness for obtaining coronary details, then all images processed for diagnostic decision-making process.

Imaging post processing reconstructions
The raw data were processed using different reconstruction technique using highly advanced software programs to enable image display and interpretation in various orientations and formats.

First, we chose the best image quality to work on. Optimal image quality was usually achieved in diastole (at approximately 65–70%of the R-R cycle); however, in 13 cases, the right coronary artery was better visualized around 30% or 80% of the R-R cycle. Images were typically

reconstructed with a 2-mm section thickness and a 0.5-mm overlap and with a 0.75-mm section thickness and 0.4-mm overlap. In order to reduce noise, images may sometimes reconstructed with a larger section thickness.

Post processing techniques

1. Multiplanar reformation: We used this technique to generate cross-sectional images of coronary arteries or other typical views, such as short-axis or long-axis views.
2. Curved multi-planar reformation: This technique enabled us to track the entire course of a coronary artery on a single image. The image plane was adjusted to follow the centerline of the vessel. The resultant display was most useful for depicting the lumen of a coronary artery from its ostium to its distal end.
3. Maximum intensity projection: Using this technique, we were able to improve image contrast and decrease image noise. This technique allowed visualization of the lumen of the coronary artery for longer lengths.
4. Volume rendering: Using the entire volume of image data, we were able to display the data from a selected viewer orientation.

Patient follow-up

Major adverse cardiac events and other diagnosis were assessed during next 60 days after examination. The evaluation was based on patient discharge summaries or review of hospitalization records and direct contact with the patient by telephone. Patients were asked about further symptoms, including chest pain; other illnesses; and hospitalizations. Patients were asked about any other cardiac and non-cardiac tests or procedures performed, including radiography, stress testing, cardiac echocardiography, CT, cardiac catheterization and coronary artery bypass grafting.

During our study

1. Any expected risks appeared during the study were explained to the patients.
2. Informed consent was obtained from all patients after full explanation of the benefits.
3. Our study was approved by the research ethics committee of Tanta University.

Statistical data analysis

We determined the utility of TRO CTA to guide triage decision in ED using two different analytic groups, coronary and non-coronary findings.

As regards our coronary results, to determine the accuracy of TRO CTA in the detection of obstructive coronary disease, we performed segment by segment level data analysis, then the results were expressed in sensitivity, specificity, positive and negative predictive values. Using the chi-square test, we were able to compare the accuracy of TRO CTA with invasive cardiac catheterization in severe coronary stenosis; p value was found to be 0.23 where p values of less than 0.05 were considered to indicate statistically significant difference.

The other non-coronary findings were expressed in numbers and percentage. The following significant variables were included: age, sex, obesity, smoking and history. Demographics and traditional risk factors and prevalence of coronary disease and other non-coronary diseases were expressed in numbers and percentage.

Results

TRO CTA was done in 45 patients with chest pain with mean age of 51 ± 14 with 42.2% in male patients ($n = 19$) and 57.8% in female patients ($n = 26$).

In our patients, we found many risk factors such as smoking, hyperlipidemia, diabetes, positive family history of coronary artery disease hypertension and obesity. Sixty percent of our population were smokers while 37.7% of our populations were hyperlipidemic. 33.3% were diabetics while positive family history was found in 33.3% of our patients. All these factors overlapped together to make our patient of intermediate risk to ACS in our selected population (Table 1).

Our result was divided into three main groups (Table 2):

1. Group with negative examinations, this was found in 17.7% of our patient (8 out 45).
2. Group with positive coronary findings, this was found in 57.7% of our patient (26 out 45).
3. Group with positive non-coronary findings, this was found in 24.4% of our patient (11 out 45).

As regards to our coronary results

A 57.7% (26 of 45) of our patients had coronary artery disease. Our coronary findings are then divided into

Table 1 Patient baseline characteristics and risk factors

Patient baseline characteristics and risk factors	No.	Percentage
Current smoking	27	60
Hyperlipidemia	17	37.7
Diabetes	15	33.3
Family history of CAD	15	33.3
Hypertension	11	24.4
Obesity (BMI)	10	22.2
History of coronary artery disease	0	0

Table 2 Number of patients with coronary and non-coronary findings

Results	No.	Percentage
Diagnostic images	45	100
- Negative results	8	17.7
- Coronary artery disease	26	57.7
- Non coronary disease	11	24.4

three groups as regards grade of vessel stenosis into significant and non-significant.

Forty precent 40% (18 of 45) had a significant coronary stenosis < 50% while 17.7% (8 of 45) of our patients had non-significant coronary lesions < 50%. Then, we divided significant coronary lesions into moderate lesions 50–70% stenosis (8 of 45) and severe lesions ≥ 70% stenosis (10 of 45) (Table 3).

On performing segmental analysis for our positive coronary results, 15 patients with significant coronary stenosis in different 29 segments underwent invasive catheterization. Invasive catheterization showed true positive result in only 20 segments while the other 9 segments showed lower grades of stenosis than CTA diagnosed (Table 4).

Our non-coronary findings that explained chest pain in our population

Four patients (8.8% of our populations) had acute aortic disease, the first patient had dissection in the arch and descending aorta, the second showed dissection in descending the aorta, the third patient had intramural hematoma in the ascending aorta and the fourth had partially thrombosed aortic aneurysm in the descending thoracic aorta.

Three patients (6.6% of our patients) had pulmonary artery embolism, two of them showed pulmonary embolization in major pulmonary vessels while the other one patient showed embolization in pulmonary terminal branches.

Only one of our patients had pulmonary nodule which proved to be lung cancer and another one had right middle lobe lung collapse,while 4.4% of our patients (2 out of 45) patients had a diaphragmatic hernia that caused chest pain to them (Table 5).

Table 3 Number of patients with different degrees of coronary artery disease

Coronary findings	No.	Percentage
Non-significant stenosis >50%	8	17.7
Significant stenosis <50%	18	40
- Moderate stenosis 50–70%	8	17.7
- Severe stenosis ≥ 70%	10	22.2

Table 4 Detailed positive result of CTA as regard to catheterization

	CTA		Catheterization		
	Severe	Moderate	Severe	Moderate	Mild
Segment 2	5 patients	0	3 patients	2 patients	0
Segment 3	3 patients	0	2 patients	1 patient	0
Segment 6	10 patients	0	7 patients	3 patients	0
Segment 7	5 patients	2 patients	5 patients	1 patient	1 patient
Segment 4	0	1 patient	0	0	1 patient
Segment 13	3 patients		2	1 patient	0

There were other significant incidental findings that required further evaluation but did not explain the presentation of acute chest pain (Table 6).

As regards our radiation dose

The mean value of effective radiation dose in our population was 9.7 mSv, with mean DLP value for estimating 693 mGy (Table 7).

Follow-up for our cases for 60 days showed the following:

Follow-up was done in all cases (complete 100%). Every patient was accessed during the period of follow-up (60 days) for any major adverse cardiac events (MACE). Our evaluation was based on patients discharge summaries and review of hospitalization records or by direct contact with the patient by telephone.

Among the 45 patients, we were able to discharge 44.4% of our population safely to home with no need for further diagnostic testing. 17.7% of those patients had negative examinations, while 17.7% of them had mild coronary disease that required no other diagnostic cardiac testing. None of those patients showed any significant symptoms that required any other diagnostic tests during the follow-up period. The two other discharged patients had a diaphragmatic hernia.

All 10 patients we diagnosed to have severe coronary stenosis (> 70% stenosis in at least one segment) underwent invasive angiography, which revealed severe lesions in only 8 of them, while two of them showed only moderate lesions.

Table 5 Number of patients with non-coronary positive findings that explained their complaint

Diagnosis	No.	Percentage
Acute aortic disease	4	8.8
Acute pulmonary embolism	3	6.6
Pulmonary nodule	1	2.2
Hernia	2	4.4
Pulmonary disease	1	2.2

Table 6 Number of patients with significant incidental findings did not explain the presentation of acute chest pain in our population

Diagnosis	No.	Percentage
Pulmonary pneumoconiosis	1	2.2
Coronary anomalies	3	6.6
Cardiac valve disease	1	2.2
Mediastinal lymphadenopathy	2	4.4
Pulmonary artery aneurysm	1	2.2

The 8 patients we diagnosed to have moderate coronary stenosis (50–70% stenosis in at least one segment) did not have all do invasive catheterization. Three patients were discharged after negative stress tests and received intensive medical treatments. The other five patients with moderate lesions underwent invasive angiography. Moderate lesions were found only in three patients and mild in the two other patients.

In our study populations, we were able to diagnose obstructive coronary artery disease with high specificity reaching to 96% and high positive predictive value reaching to 69% based on per segmental analysis and in comparison to invasive angiography. In our study, the absence of coronary disease or the presence of only minimal to mild disease accurately predicted the absence of ACS, with high sensitivity and negative predictive value reaching to 95% and 99% respectively, on per segment basis analysis (Table 8).

Discussion
Acute chest pain is one of the most frequent clinical problems in the ED. ACS is an important life-threatening condition causing acute chest pain. Multiple factors with interfering symptoms can cause chest pain, so the exclusion of ACS in ED is often a prolonged process requiring monitoring of cardiac serum markers especially in intermediate risk patients. This makes this process long and costly. This process is not only expensive,

Table 7 Our follow-up results

Follow-up results	No.	Percentage
Discharged to home without further investigations	20	44.4
Admitted to hospital	25	55.5
- Due to coronary disease	15	33.3
- Due to non-coronary disease	10	22.2
Cardiac investigations done in follow-up period		
- None	27	60
- Stress tests	3	6.6
- Invasive angiography	15	33.3
- Coronary artery bypass grafting	0	0

but also time-consuming for both physicians and patients. On the other hand, up to 11% of patients are inadvertently discharged from the ED with a missed AMI (average 2.1%), and unstable angina pain is missed in up to 4%. This misdiagnosis and inappropriate discharge leads to increased mortality for those patients [14].

Studies had demonstrated the application of TRO protocol with 16 sections in CT technology in the emergency department. The advent of 64-, 256- and 320-multislice CT scanners has improved imaging of the coronary artery. The latest generation of 320-multislice CT allows simple, rapid acquisition of the aorta, pulmonary arteries and coronary arteries in a single breath hold [15].

In patients who do not appear to be typically presenting with an ACS, other important provisional diagnoses for the cause of their chest pain that needed to be considered include non-ACS cardiac conditions such as acute pericarditis, life-threatening non-cardiac conditions such as acute pulmonary embolism, aortic dissection and perforating ulcer. The usefulness of TRO in ED has been suggested in some studies, and other studies failed to show superior clinical outcomes to TRO CT [16–18].

In this study, we aimed to demonstrate the diagnostic yield of TRO CTA in acute chest pain in emergency department patients and its utility to provide a definitive non-coronary diagnosis as well as its use to exclude coronary artery disease. As our main direction in this study was to access the process of clinical triage and its diagnostic outcome for our patient, our study differs from other coronary CT angiography studies that compare multislice CT with an angiographic assessment of stenosis.

Multiple studies have demonstrated that a normal coronary CT angiography 'allows the clinician to rule out the presence of hemodynamically relevant coronary artery stenosis with a high degree of reliability' and that no further work up is required to demonstrate the absence of coronary disease [19, 20].

Furthermore, in those patients with coronary disease, the likelihood that an individual coronary plaque will result in ACS is related to many factors independent of the degree of vascular narrowing [21].

The accepted 'gold standard' for the grading of coronary stenosis, conventional catheter angiography, is limited by geometric factors that may result in underestimation or overestimation of the degree of coronary stenosis in over one-third of patients [22].

On the basis of these considerations, we opted to focus mainly on clinical outcomes of patients suspected of having ACS in the ED rather than a direct comparison to catheter angiography for assessment of the degree of stenosis.

As regards the behaviour of TRO CTA in assessing coronary artery disease, we were able to say confidentially that 42% of our population had negative coronary results and non-significant coronary disease; this did not seem to be surprising as regards our included population with moderate risk to ACS.

TRO CTA behaviour in the assessment of coronary disease

As regards our positive coronary findings, we diagnosed 40% (18 of 45) of our population had significant coronary stenosis. 17.7% (8 of 45) of our patients had moderate coronary stenosis, and 22.2% (10 of 45) had severe coronary stenosis

We used 50% as a cut off value to define obstructive lesion or significant lesion, we chose this cut off value because this threshold usually requires further evaluation either with non-invasive testing to determine functional significance or with catheter angiography. This cut off has been used in many published studies, e.g., Hoffmann et al [23]. Patients with significant lesions were further subclassified as moderate disease (50–70% stenosis) and severe stenosis (> 70% stenosis).

In Thomas et al. [24] TRO CTA study, they were able to diagnose 19% of their patients who have significant coronary stenosis, they also used 320-multislice CT scanner, but they included larger population in their study.

A recent TRO CTA study was done using 320-multislice CT on 25 low to intermediate acute chest pain patients. Using TRO CTA, they were able to diagnose 50% of their patients of having coronary lesions [25]. Our result is perfectly matching with their result as we found 57.8% of our patients having coronary artery disease, but we included only intermediate risk patients in our study and larger study population.

In Kevin et al. [26] study done over 197 low to intermediate risk to access the role of TRO CTA in the emergency department, 11% of their population was found to have significant coronary artery lesions. Their study was done on 64-multislice CT, and they also included low to intermediate risk in their population. This seemed the real cause of having lower percentage with significant coronary disease.

In our study done in over 45 patients having acute chest pain with intermediate risk to ACS, 15 patients with significant coronary disease have entered invasive catheterization. Based on per segmental analysis comparison, we were able to estimate sensitivity and specificity of our study.

We were able to diagnose obstructive coronary artery disease with high specificity reaching 96%, positive predictive value reaching 69%, based on per segmental analysis and in comparison to invasive angiography. We had also high levels of sensitivity and negative predictive values reaching 95% and 99% respectively.

We compare our results with the following dedicated coronary CTA studies:

Hoffmann et al. [23] study was done in over 368 patients using 64-mutislice CT which showed high specificity and high negative predictive value in exclusion obstructive coronary artery lesions reaching to 87% and 100% respectively; this agreed with our result because their result also showed high sensitivity of 77% in the diagnosis of obstructive lesions but they got only 35% as a positive predictive value.

Our result goes well with Nieman et al. [27] and Ropers et al. [28] results with high sensitivity and specificity reaching 95% and 86% respectively in Nieman et al.'s study and 92% and 93% respectively in Ropers et al.'s study and both studies were done to assess coronary luminal stenosis greater than 50% using only 16-detector CT.

Leber et al. [29], Leschka et al. [30] and Fine et al. [31] made studies in detection of coronary artery disease over 64-mutislice CT with high sensitivity 91% and specificity 96%; they also got high negative predictive value reaching 97%.

Han et al. [32] study which was done on 345 patients using 64-multislice CT found higher specificity and positive predictive value reaching 99% and 87% respectively than we found in our results, but they got the same negative predictive value 99% and our sensitivity result was higher than they got, as they got 81%.

Raff et al. [33] and Puglise et al. [34] studies showed also high sensitivity and specificity in their studies done to detect coronary artery disease, they did their studies using 64-multislice CT and they got 91% sensitivity and 96% specificity.

Our negative predictive value agrees also with Kevin et al. [26] which was 99.4%, and they also based their study on the clinical follow-up at 30 days and further diagnostic testing in a minority of patients.

So, our TRO CTA study shows comparable results to dedicated coronary artery CTA as regards exclusion of ACS with high sensitivity and specificity.

Our TRO CTA study showed the same result of another systematic review study done by Ayaram et al. [35]; they showed that TRO CTA helped them in the diagnosis of coronary artery disease in patients with acute chest pain with 94.3% sensitivity, 97.4% specificity and 99% negative predictive value.

TRO CTA behaviour in assessment of non-coronary disease

In our study, we found 24.4% (11 out of 45) of our patients that were suspected to have ACS, having another diagnosis that explained their symptoms. 17.7% of them had clinically important non-coronary findings that explained their symptoms. This is not surprising given that ACS symptoms such as chest pain

and shortness of breath can mimic a number of other diseases.

In 17.7% of our population, we were able to diagnose life-threatening conditions as aortic dissection, aortic intramural hematoma and pulmonary embolism. We were able to save the life of these patients by directing them toward the accurate cause of chest pain and from then to accurate treatment direction using single-shot acquisition imaging without any other time-consuming tests.

Among those non-coronary life-threatening conditions, we identified pulmonary embolism in 6.6% of our population and aortic dissection in 4.4%, 2.2% had intramural hematoma and 2.2% had partially thrombosed aortic aneurysm. We found that our detection rate of aortic dissection and pulmonary embolism may have been reduced by the exclusion of patients when treating physician chooses to order a dedicated CT scan rather than triple role out protocol.

Our non-coronary results agreed also with the non-coronary results in Thomas et al. [24] study. This study was done on 100 emergency patients using 320-multislice CT, in his study 20 patients demonstrated other non-coronary findings that explain chest pain including PE, pleural effusion, left ventricular hypertrophy with pleural effusion and pneumonia. They differed from us as they included pneumonia and left ventricular hypertrophy with pleural effusion as causes for chest pain.

In our study, we were able to diagnose pulmonary embolism, aortic intramural hematoma and aortic dissection as emergency causes of acute chest pain. In Soliman TRO CTA study [25] done on acute chest pain patients, he diagnosed 17 cases with non-coronary findings including pulmonary embolism (12.5%), aortic dissection (22.5%) and aortic aneurysm (10%).

White et al. [36] and Savino et al. [37] agreed also with our result that TRO CTA can diagnose non-coronary chest pain causes as well as coronary causes. White et al. TRO CTA study was done on 69 patients with acute chest pain showed significant non-coronary findings as pericarditis, pneumonia and pulmonary embolism that could account for chest pain in 4.3% of patients in their studies, while Savino et al. study done over 23 acute chest pain patients using TRO CTA found 8.7% of their populations to have pulmonary embolism.

A previous study was done by Halpern [15] and Takakuwa [16] included 201 acute chest pain patients evaluated with TRO CT, which identified a non-coronary diagnosis as the explanation for acute chest pain in 11% of patients.

Additional diagnosis in patients undergoing coronary CT angiography may be clinically important. Some diagnosis, such as hiatus hernia, may seem to be of less clinical importance than other diagnosed life-threatening conditions that should be excluded first, but may

nonetheless represent the true cause for the representing complaint. Identifications of these abnormalities allow the emergency department physician to direct the patient to an appropriate physician to treat and monitor disease progression.

Among our population, two patients (4.4% of our population) had pulmonary parenchymal lesions and the first had pulmonary nodule that proved to be pulmonary malignancy while the other had right middle lobe collapse. Another two patients (4.4% of our population) were diagnosed to be complaining due to diaphragmatic hernia.

In Gruettner et al. [38] TRO CTA study, they showed even higher numbers of their patients having non-coronary disease reaching to 36%, 5 patients had pulmonary embolism, 1 patient had severe right ventricular dysfunction with pericardial effusion and one patient had incidental bronchial carcinoma. They diagnosed only 19% of their population to have significant coronary stenosis. In their study, they included intermediate risk patients as we did, but their follow-up period was for 90 days.

The ability to identify an alternative non-coronary diagnosis in patients suspected of having ACS is a major strength of the triple rule-out scan. In our study, we were able not only to diagnose other life-threatening conditions causing chest pain as pulmonary embolism and acute aortic syndrome, but the larger field of scanning helped us to diagnose other non-emergency conditions as hernia in two patients and pulmonary nodule in one patient and directing those patients toward the right physicians helping them to treat the true cause of their chest pain.

On the basis of the frequency of clinically important non-coronary findings in our study, the detection of extra coronary findings in moderate risk ACS population provided the true cause of chest pain more frequently than was expected. Although many of these non-coronary causes might have been diagnosed after further observations and diagnostic testing, the triple rule-out protocol provided these diagnoses quickly and without the need for additional testing, such as ventilation-perfusion scanning.

We found that TRO CTA is a very useful protocol in emergency department helping in rapid discharge in ED as we were able to safely and rabidly discharge 44.4% of our population based on their negative results or non-significant coronary findings and confirmed by 60 days follow-up. Our results agreed with Thomas et al. results [24], in his study 60 of 100 patients were discharged on the same day based on their negative results. None of the discharged patients showed MACE during the 90-day follow-up.

Amelia M. Wnorowski et al [39] wide study on 970 low to moderate risk patients using 256 multi-detector CT study agreed with our result as regard behaviour of TRO CTA in the emergency department as they showed that

they were able to discharge 81.4% of their patients based on their negative results. They stated also in their result that they were able to diagnose 8.9% of their patients with non-coronary diagnosis as pulmonary embolism and aortic disease.

Our high negative predictive value reaching 99% enables us to recommend TRO CTA protocol to be used as a guide discharging intermediate-risk patients in acute chest pain emergency department.

Based on per segmental analysis, having a positive predictive value of 69% indicate that our TRO CTA did not completely correlate with cardiac cauterization result in severe coronary artery disease .In our opinion, this may be caused by overestimation of severity of stenosis in severely calcified lesions.

We found that despite of good result of TRO studies in dealing with rapid and accurate diagnosis in acute chest pain patients in ED, yet it is not ordered in the same frequency as dedicated coronary CTA, this was in our opinion due to lack of popularity of technique to clinicians who are accustomed to request dedicated coronary CTA in ACP patients with possible risk to ACS. Also lack of patients standardization criteria and knowledge of which patients are proposed to do this examination.

One of drawbacks of TRO examination that may lower its clinical significance is the degraded image of RCA due to patient's respiratory motion artefacts, seen in patients suffering from dyspnoea and chest pain. In spite of very rapid scanners, RCA image may be still at motion risk.

TRO CTA and radiation exposure

We found that our estimated effective dose value (EDV = 9.7 mSv) was slightly lower than of Soliman [25] and Gruettner et al. [38] TRO studies who had EDV reaching to 10 and 12.4 mSv respectively. Our EDV was still higher than EDV of patients underwent dedicated coronary CTA in the Joachim Gruettner study as they got 8.7 mSv.

TRO study radiation exposure values pushed us to recommend this examination only in certain patients, who are of high suspicion to have an alternative diagnosis that may explain their chest pain other than acute coronary syndrome. This suspicion may be based on clinical symptoms as severe dyspnoea and high risk for pulmonary embolism (history of DVT), or based on laboratory data as positive D-Dimer test.

Limitations

1. Our study was faced with several limitation factors. First, our study is a prospective observation study, so most patients did not have additional comparative tests performed to verify the result of most of coronary CTA and we were able to verify the result of only severe cases compared to catheter result done to them and based on per segmental analysis.

2. We are the one of few studies that showed the diagnostic accuracy of TRO CTA in detection of obstructive coronary artery disease.

3. The 60 days follow-up should be followed with longer interval and the number of study population should be extended for better evaluation.

Notwithstanding these limitations, our study clearly demonstrates the utility of TRO CTA protocol in emergency department in diagnosis of both coronary and non-coronary causes of acute chest pain patients and to limit additional diagnostic testing to a small proportion of population.

So based on our experience we consider that TRO CTA is a very useful protocol to be used in acute chest pain patients in the emergency department especially those patients who are less likely to have acute coronary syndrome.

Conclusion

1. TRO CTA is not only an effective protocol for exclusion of ACS with high specificity that is comparable with dedicated coronary CTA, but also in the diagnosis of chest pain due to other vascular and non-vascular causes that would be missed in dedicated coronary CTA.

2. TRO CTA can help in rapid safe discharge of patients from ED and when compared with many protocols of acute chest pain in ED, it can help in rapid making of decision-saving patient life and time, ED cost and multiple exposures to radiation.

3. In addition to the intermediate risk to ACS at baseline, the ideal patient for TRO CT should has a presentation for which alternative diagnosis to ACS is to be considered.

Additional file

Additional file 1: Different cases. (DOCX 1608 kb)

Recommendations
1. Based on high radiation dose of TRO examinations, we recommend TRO CTA for patients whose chest pain may have other causes other than ACS other patients of acute chest pain who are more likely to have ACS with no suspicion for other associated pathology should do dedicated coronary CTA.
2. Good knowledge of which patients should go TRO CTA should be put into consideration of each clinician and radiologist based on clinical data or laboratory test, this may raise the clinical importance of TRO in ED acute chest pain patients.
3. Many steps should be taken toward raising the sensitivity and positive predictive value of TRO CTA protocol through improving software programs that can help in reducing motion effect and blooming artefact of calcified plagues.
4. Appropriate patient selection is important for the effective application of TRO CT and raising the level of its clinical significance.

Authors' contributions
ARE contributed to the concepts, design, definition of intellectual content, data acquisition, data analysis, statistical analysis, manuscript preparation, manuscript editing and manuscript review. MAD contributed to the definition of intellectual content, data analysis and manuscript review. ML contributed to the data acquisition, data analysis and manuscript review. MAM, EAH and MFH contributed to the concepts, definition of intellectual content, data analysis, statistical analysis, manuscript preparation, manuscript editing and manuscript review. All authors have read and approved the final manuscript and all agreed to be personally accountable for the authors' own contributions and to ensure the questions related to accuracy or integrity of any part of the work.

Availability of data and materials
All data generated or analysed during the study are included in this published article.

Ethics approval and consent to participate
Consents and ethics of the research are mentioned in the 'Patient and methods' section.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]Radiodiagnosis and Medical Imaging, Faculty of Medicine, Tanta University Hospital, El Geash Street, Tanta, Gharbya 31511, Egypt. [2]Zefta, Egypt. [3]Radiodiagnosis and Medical Imaging, Freiburg University Hospital, Hugstetter Str.55, 79106 Freiburg im Breisgau, Germany.

References
1. McCaig LF, Nawar EW. Emergency department summary. Adv Data .National ambulatory medical care survey 2004 -2006;372:1–29.
2. Pitts SR, Niska RW, Xu J et al (2008) National Hospital Ambulatory Medical Care Survey: 2006 emergency department summary. Natl Health Stat Report 7:1–38
3. Dedic A, Kate G-J, Neefjes AL et al (2013) Coronary CT angiography outperforms calcium imaging in the triage of acute coronary syndrome. Int J Cardiol 167:1597–1602
4. Blanke P, Apfaltrer P, Ebersberger U et al (2012) CT Detection of Pulmonary Embolism and Aortic Dissection. Cardiol Clin 30:103–116
5. Hassana A, Nazir SA, Hatem A (2011) Technical challenges of coronary CT angiography: Today and tomorrow. Eur J Radiol 79:161–171
6. Pope JH, Selker HP (2005) Acute coronary syndromes in the emergency department: diagnostic characteristics, tests, and challenges. Cardiol Clin 23(4):423–451
7. Coles DR, Smail MA, Negus IS (2006) Comparison of Radiation Doses From Multislice Computed Tomography Coronary Angiography and Conventional Diagnostic Angiography. J Am Coll Cardiol 47:1840–1845
8. Weustink AC, Meijboom WB, Mollet NR et al (2007) Reliable high-speed coronary computed tomography in symptomatic patients. J Am Coll Cardiol 50:786–794
9. Ueno K, Kawamura A, Onizuka T et al (2012) Effect of preoperative evaluation by multidetector computed tomography in percutaneous coronary interventions of chronic total occlusions. Int J Cardiol 156:76–79
10. Zipes DP, Libby P, Bonow RO et al (2017) Abdominal aortic aneurysms section of Diseases of the aorta in: Braunwald's Heart Disease: A Textbook of Cardiovascular Medicine. Elsevier, pp 1458–1469
11. Tsai C-J, Chen L-K, Mokd Greta SP et al (2011) Dose reduction in 256-slice triple rule-out CT angiography. Radiat Meas 46:2065–2068
12. Schussler JM, Smith ER (2006) Sixty-four-slice computed tomographic coronary angiography: will the "triple rule out" change chest pain evaluation in the ED? Am J Emerg Med 25:367–375
13. White CS, Kuo D (2007) Chest pain in the emergency department: role of multidetector CT. Radiology 245(3):672–681
14. Lindsell CJ, Anantharaman V, Diercks D et al (2006) The internet tracking registry of acute coronary syndromes: a multicenter registry of patients with suspicion of acute coronary syndromes reported using the standardized reporting guidelines for emergency department chest pain studies. Ann Emerg Med 48(6):666–677
15. Halpern EJ (2008) Technique, protocols and instrumentation. In: Halpren E.J. Clinical cardiac CT: anatomy and function. Thieme, New York, pp 254–280
16. Takakuwa KM, Halpern EJ (2008) Evaluation of a "triple rule-out" coronary CT angiography protocol: use of 64-section CT in low-to-moderate risk emergency department patients suspected of having acute coronary syndrome. Radiology 248:438–446
17. Goldstein JA, Chinnaiyan KM, Abidov A et al (2011) The CT-STAT (Coronary Computed Tomographic Angiography for Systematic Triage of Acute Chest Pain Patients to Treatment) trial. J Am Coll Cardiol. 58(14):1414–1422
18. Madder RD, Raff GL, Hickman L et al (2011) Comparative diagnostic yield and 3-month outcomes of "triple rule-out" and standard protocol coronary CT angiography in the evaluation of acute chest pain. J Cardiovasc Comput Tomogr 5:165–171
19. Budoff MJ, Achenbach S, Blumenthal RS, et al. American Heart Association Committee on Cardiovascular Imaging and Intervention; American Heart Association Council on Cardiovascular Radiology and Intervention; American Heart Association Committee on Cardiac Imaging, Council on Clinical Cardiology. Assessment of coronary artery disease by cardiac computed tomography: a scientific statement from the American Heart Association Committee on Cardiovascular Imaging and Intervention, Council on Cardiovascular Radiology and Intervention, and Committee on Cardiac Imaging, Council on Clinical Cardiology. Circulation. 2006;114:1761–1791.
20. Achenbach S (2006) Computed tomography coronary angiography. J Am Coll Cardiol 48:1919–1928
21. Bittner DO, Mayrhofer T, Puchner SB et al (2018) Coronary Computed Tomography Angiography–Specific Definitions of High-Risk Plaque Features Improve Detection of Acute Coronary Syndrome. Results From the ROMICAT II Trial Circulation: Cardiovascular Imaging 11:e007657
22. Grondin CM, Dyrda I, Pasternac A et al (1974) Discrepancies between cine angiographic and post mortem findings in patients with coronary artery disease and recent myocardial revascularization. Circulation 49:703–708
23. Hoffmann U, Bamberg F, Chae CU et al (2009) Coronary computed tomography angiography for early triage of patients with acute chest pain: the ROMICAT (Rule Out Myocardial Infarction using Computer Assisted Tomography) trial. J Am Coll Cardiol 53:1642–1650
24. Thomas H, Joachim G, Mathias M et al (2013) Coronary computed tomography and triple rule out CT in patients with acute chest pain and an intermediate cardiac risk for acute coronary syndrome: Part 2: Economic aspects. Eur J Radiol 82:106–111
25. Soliman HH (2015) Value of triple rule-out CT in the emergency department. The Egyptian Journal of Radiology and Nuclear Medicine 46:621–627
26. Kevin M, Ethan J (2008) Evaluation of a "Triple Rule Out" coronary CT angiography protocol: use of 64-section CT in low to moderate risk emergency department patients suspected of having acute coronary syndrome. Radiology 248(2):438–446
27. Nieman K, Cademartiri F, Lemos PA et al (2002) Reliable non invasive coronary angiography with fast sub millimetre multislice spiral computed tomography. Circulation 106:2051–2054
28. Ropers D, Baum U, Pohle K et al (2003) Detection of coronary artery stenosis with thin-slice multi-detector row spiral computed tomography and multiplanar reconstruction. Circulation 107:664–666

29. Leber AW, Knez A, von Ziegler F et al (2005) Quantification of obstructive and non-obstructive coronary lesions by 64-slice computed tomography: a comparative study with quantitative coronary angiography and intravascular ultrasound. J Am Coll Cardiol 46:147–154

30. Leschka S, Scheffel H, Desbiolles L et al (2007) Image quality and reconstruction intervals of dual-source CT coronary angiography: recommendations for ECG-pulsing windowing. Invest Radiol 42:543–549

31. Fine JJ, Hopkins CB, Ruff N et al (2006) Comparison of accuracy of 64-slice cardiovascular computed tomography with coronary angiography in patients with suspected coronary artery disease. Am J Cardiol 97:173–174

32. Han S-C, Fang CC, Chen Y et al (2008) Coronary Computed Tomography Angiography–A promising Imaging Modality In Diagnosing Coronary Artery Disease. J Chin Med Assoc 71:241–246

33. Raff GL, Gallagher MJ, O'Neill WW et al (2005) Diagnostic accuracy of noninvasive coronary angiography using 64-slice spiral computed tomography. J Am Coll Cardiol 46:552–557

34. Pugliese F, Mollet NRA, Runza G et al (2006) Diagnostic accuracy of non-invasive 64-slice CT coronary angiography in patients with stable angina pectoris. Eur Radiol 16:575–582

35. Ayaram D, Bellolio MF, Murad MH et al (2013) Triple rule-out computed tomographic angiography for chest pain: a diagnostic systematic review and meta-analysis. Acad Emerg Med 20(9):861–871

36. White C, Kuo D, Kelemen M et al (2005) Chest pain evaluation in the emergency department: can MDCT provide a comprehensive evaluation? AJR Am J Roentgenol 185:533–540

37. Savino G, Herzog C, Costello P et al (2006) 64 slice cardiovascular CT in the emergency department: concepts and first experiences. Radiol Med 111:481–496

38. Gruettner J, Fink C, Walter T et al (2013) Coronary computed tomography and triple rule out CT in patients with acute chest pain and an intermediate cardiac risk profile .part 1:impact on patient management. Eur J Radiol 82:100–105

39. Wnorowski AM, Halpern EJ (2016) Diagnostic Yield of Triple-Rule-Out CT in an Emergency Setting. AJR 207:295–301

Publisher's Note