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TECHNICAL NOTE

Targeted post-mortem computed tomography cardiac angiography: proof of concept

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Abstract With the increasing use and availability of multi-detector computed tomography and magnetic resonance imaging in autopsy practice, there has been an international push towards the development of the so-called near virtual autopsy. However, currently, a significant obstacle to the consideration as to whether or not near virtual autopsies could one day replace the conventional invasive autopsy is the failure of post-mortem imaging to yield detailed information concerning the coronary arteries. To date, a cost-effective, practical solution to allow high throughput imaging has not been presented within the forensic literature. We present a proof of concept paper describing a simple, quick, cost-effective, manual, targeted in situ post-mortem cardiac angiography method using a minimally invasive approach, to be used with multi-detector computed tomography for high throughput cadaveric imaging which can be used in permanent or temporary mortuaries.

Keywords Forensic · Post-mortem · Computed tomography · Angiography · Cardiac

Introduction

The use of computed tomography (CT) was first reported in association with post-mortem practice in 1983 [1]. Since then the use of multi-detector computed tomography (MDCT) and magnetic resonance imaging has been widely reported within the forensic and radiological literature [2–12]. Despite the advances in this field, a significant obstacle to the acceptance of so-called near virtual autopsies relates to the diagnosis of cardiac death and the failure of standard post-mortem imaging to yield detailed information concerning the coronary arteries. This is often put forward as the principle reason why a ‘near virtual autopsy’ currently does not provide a realistic alternative to the invasive autopsy.

In clinical practice, cardiac MDCT including contrast-enhanced CT coronary angiography is fast emerging as a powerful diagnostic tool for the assessment of coronary disease in both acute and chronic cases [13, 14]. Cardiac MDCT has been demonstrated to be excellent at identifying the course of anomalous coronary arteries, congenital heart disease, pericardial disease, cardiac masses, thrombi and aortic disease. The benefit of MDCT compared to conventional angiography is that the artery wall can be visualised in addition to the lumen [14, 15]. The degree of wall calcification can be quantified (so-called calcium scoring) and used to stratify risk of future cardiac events [16, 17]. The implementation of cardiac MDCT coronary angiography in the post-mortem setting is impaired by the lack of an active circulation to deliver suitable contrast agents via an intravenous route. Thus, vessel lumen and wall pathology, as well as course, are currently difficult to determine. To overcome this, a method of post-mortem MDCT coronary angiography must be used.

A number of studies have demonstrated the feasibility of post-mortem MDCT angiography in animals and humans [18–21]. The main body of work has been performed on single organs systems, with imaging of the organ either by injection in situ and then removal for imaging, or injection

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of the organ after removal (i.e. invasive techniques). A handful of studies have looked at minimally invasive whole-body angiography [18–21]. Whole-body MDCT angiographic imaging was first published by the Virtopsy® group [22] who, along with a number of other groups, have shown that post-mortem MDCT angiography is feasible [23]. These methods are based on a complex system of whole-body angiography using a modified heart and lung bypass machine [20, 23]. This method allows detailed assessment of the entire circulatory system which will have an important role in specific cases. However, if minimally invasive autopsy with angiography is to be implemented for routine coronial autopsies, the numbers of cadavers to be examined at centres will run into thousands, and such complex approaches under these circumstances may be impractical.

To date a cost-effective method allowing high throughput cardiac CT imaging has not been presented within the forensic literature. We present a proof of concept paper describing a simple, quick, cost-effective, targeted in situ post-mortem cardiac angiography method using a minimally invasive approach, to be used with MDCT for high throughput cadaveric imaging.

Materials and methods

This work is funded by a grant from the National Institute of Health Research (NIHR) under its Research for Innovation, Speculation and Creativity (RISC) Programme (Grant Reference Number RC-PG-0309-10052). The trial is being conducted within local guidelines with approval by the local research ethics committee (LREC 04/Q2501/64, UHL 09523) and supported by the local Coroners' offices. Cases for the first part of the study involving the development of the cadaver angiography method were selected for potential coronary angiography by the authors (GR or SS) from the routine coronial post-mortem request forms faxed to the Leicester Royal Infirmary mortuary. Exclusion criteria included significant neck trauma (to ensure method was assessed on normal individuals), previous complex cardiac surgery such as bypass grafting (for the same reason) and bodies weighing over 125 kg (due to the weight capacity of the CT scanner table). Cases with a short post-mortem interval were selected where possible. The next of kin was contacted by the trial consenter (an advanced nurse practitioner with counselling experience) on the day prior to the autopsy. Informed consent was obtained by telephone with information leaflets being sent to next of kin the next working day.

To develop the method for cadaver MDCT angiography, we had to consider and overcome a number of issues, which we present below:

Site and method of vascular access

All canulations were performed within a Human Tissue Authority licensed mortuary. The first consideration was site selection for access to the vascular system. A number of sites were considered, including the femoral, axillary and subclavian arteries. The carotid artery was chosen due to its lack of branches making it easier to raise. It is also the vessel closest to the arch of the aorta allowing a shorter catheter to be selected. The method for raising the carotid artery was adapted from standard embalming techniques [24], and used standard mortuary equipment (Fig. 1a). Access to the carotid artery initially involved an oblique incision to the neck, approximately 5 cm above the clavicle to the lateral side of the neck. The subcutaneous tissue was blunt dissected with an aneurysm hook. The soft tissue was divided down inferior to the left sternocleidomastoid muscle. The jugular vein and vagus nerve were dissected free and pulled laterally (a string sling can be used to facilitate this). The soft tissue was further dissected inferiorly and medially until the carotid artery was located. The carotid artery was dissected free of the soft tissue and elevated by means of an aneurysm hook. Once raised, a piece of string was passed under the artery and used to tie off the most superior aspect of the artery to prevent flow of contrast into the head. A second piece of string was threaded under the artery and pulled inferiorly and loosely tied to act as a sling or a marker for the lower aspect of the artery. The artery was held in place during this process by threading the aneurysm hook underneath the artery. A horizontal cut was made across the anterior wall of the artery. The posterior wall was left intact, to prevent retraction of both ends of the artery. The lower cut aspect of the carotid artery wall was held with toothed forceps, and the catheter inserted. The aim was to place the catheter tip in the ascending aorta, just above the aortic valve and adjacent to the coronary ostia. A balloon could then be inflated in the ascending aorta above this. During the refinement of the method, both carotid arteries were accessed to assess the better side to develop the final protocol.

Catheter choice

Different types of catheter available within medical practice were tried over the first 12 cases, including a variety of pigtail angiographic catheters, large balloon size catheters including an endovascular aneurysm repair balloon catheter and a transcatheter aortic valve implantation balloon catheter. These were initially chosen for their directional capability, as it was thought that this would be useful to navigate the aortic arch and ensure correct placement into the ascending aorta.

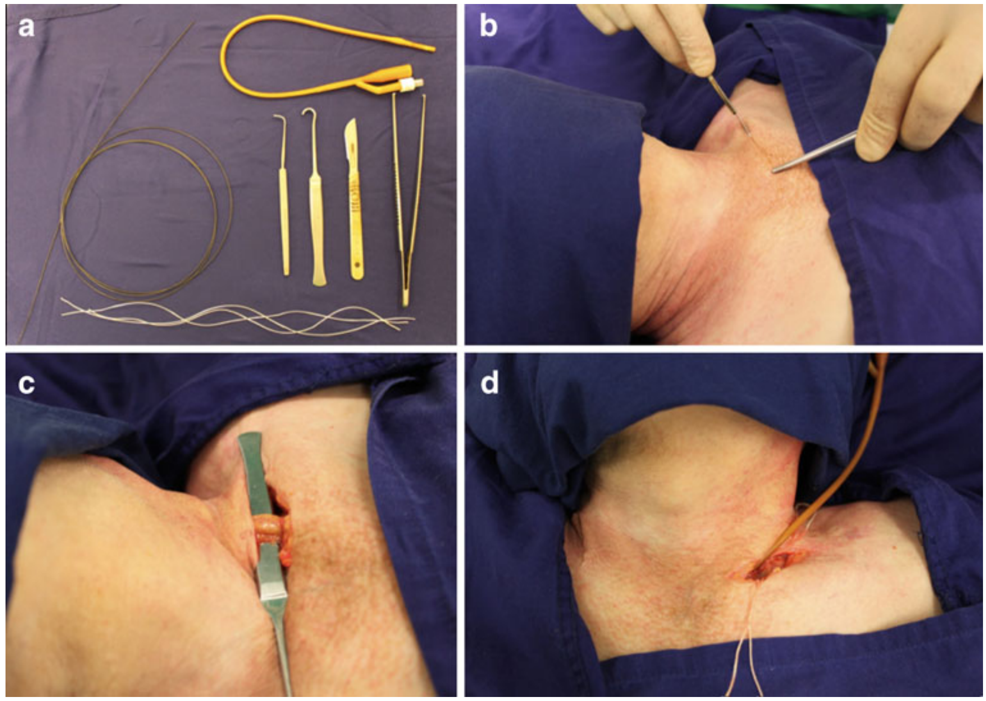

Fig. 1 **a** Basic mortuary equipment used for cannulation prior to angiography; 14 Fr silicone male Foley catheter, scalpel, toothed forceps, two aneurysm hooks, two lengths of string and a standard radiographic guide wire. **b** Supraclavicular incision made on the left side, based on a standard embalming technique. **c** Following blunt dissection of the soft tissue, the left carotid artery is elevated by means of an aneurysm hook prior to incision of the anterior arterial wall. **d** The Foley catheter is inserted into the carotid artery. Pieces of string are used to tie off the superior aspect of the artery and as a marker for the inferior aspect

After trialling these catheters, we changed to a 14 Fr silicone-coated male urinary catheter (Bardia Foley catheter) with standard guide wire (Cook; fixed core wire guide, straight). We initially used the guide wire to determine the catheter position on MDCT, rather than to facilitate introduction. The balloon was inflated with water initially, but this was changed to dilute water-soluble radiographic contrast (1 in 50 dilution of Urografin®) to ascertain the position of the balloon in the aorta on localiser scans. This removed the necessity for the use of the guide wire except in difficult cases.

Contrast medium choice

The literature relating to post-mortem angiography describes a number of different contrast agents being used, each with its own advantages and disadvantages [18]. The Virtopsy® group advocates the use of lipid-based contrast agents (polyethylene glycol and iodized oil) in conjunction with the use of a modified heart–lung bypass machine to create a 'circulation' [20, 23]. This process is complex and appears time consuming. We wanted to produce a quick and simple method that could be used in any mortuary, be it permanent or temporary, in any country, using readily available materials requiring minimal training. Furthermore, we wished to use contrast media known to have little physiological impact in the extravascular extracellular space as this could affect any subsequent histological examination. Water-based contrast agents have been reported to cause tissue oedema leading to significant artefact generation on CT. This appears to increase if there is a long delay between the injection of the contrast and the completion of the scan. Delays such as this are not applicable to this study [18–20, 23]. We therefore decided to use the water-soluble iodinated contrast media Urografin® 150 mgI/ml (Bayer Healthcare, approximately £20 per 500-ml bottle). We used a 1 in 10 dilution, which we calculated would be similar to concentrations achieved in clinical CT coronary angiography [25].

As vessels are often well delineated by the development of air in the post-mortem period, we used injected air as a 'negative' contrast agent. This was hypothesised to be potentially superior to 'positive' contrast agents due to better delineation of areas of calcification. Using repeated injections with a 60-ml syringe, a variety of volumes and infusion rates of air and Urografin® were researched.

Scanning protocol

The MDCT scan was undertaken under our standard post-mortem protocol using a Toshiba Aquilion 64 slice scanner (120 kVp, 300 mA and 64×0.5-mm slice thickness, matrix 512×512) reconstructed to either 1 or 2-mm thick slices. Cardiac images were then performed with a narrow field of view covering the heart and aortic arch with 1-mm slice reconstructions pre and post contrast injection. Scan time was recorded for the final 14 cases (after the initial learning curve). Times were recorded as whole scan time (from arrival to leaving the CT scan room) and were divided into two sections relating to the time to complete the standard CT scan and the extra time of the angiography.

Positioning of the body

All the bodies were initially scanned within a labelled body bag in the supine position with the arms at either side. Bodies were scanned at variable post-mortem intervals and in various states of rigor mortis. Access to the body was provided through an opening at the head end of the body bag for the angiography.

As previous studies have used rotation of the body to assist contrast agent dispersal, we experimented with different body positions during injection. The positioning of the body was facilitated by foam blocks and secure strapping (standard radiographic equipment). The body was handled within the body bag so there was no risk of contamination of the scanner suite with body fluids.

Evaluation of angiography

Cardiac imaging was reported by two radiologists, one a consultant cardiac radiologist and the other with 5 years experience of post-mortem imaging. Image analysis was performed on workstations using multiplanar reconstructions (MPR) and 3D analysis. The optimum filling of the vessels by either air or positive contrast media was assessed subjectively on the ability to see the right coronary artery (RCA), posterior descending artery (PDA), left main stem (LMS), left anterior descending (LAD) and circumflex (Cx) arteries by positive or negative contrast. The initial cases were used to improve the protocol. A more formal assessment of artery delineation was undertaken for the final 10 cases, although minor changes were still being made to the protocol. Consistent with clinical practice and standardised cardiac dissection at autopsy, intramural vasculature was not assessed in this part of the study. After 25 cases a final protocol was agreed in order to evaluate the use of CT coronary angiography in post-mortem investigation.

Results

A total of 25 cases were recruited to develop the final present method and protocol.

Cannulation

After feedback from the anatomical pathology technologists (APTs) that incisions higher up on the side of the neck were difficult to conceal with a standard shroud, the approach was modified to a lower one based on the anterolateral (supraclavicular) embalming technique[24] (Fig. 1b). An almost horizontal incision was made above the clavicle on the inferior aspect of the neck and the artery was raised as before (Fig. 1c). An additional benefit of this new approach was that the catheter insertion into the ascending aorta was easier than further up the neck as manipulation of the artery was easier, allowing the vessel to be pulled laterally and inferiorly to align the vessel with the arch of the aorta (Fig. 1d). The visual exposure of the vessel at this location was better, and allowed easier repositioning of the catheter in the scan room if required.

Both sides of the neck were used in 7 cases, the right only in 6 and the left side only in 12. In 5 out of 13 cases, there was failed access to the ascending aorta using the right approach and in 1 out of 9 cases using the left-sided approach. The left-sided approach therefore had a significantly higher success rate (chi-squared test $p=0.02$). The single failure on the left side was due to inadvertent cannulation of the internal jugular vein, a mistake that was considered unlikely to be repeated. For the last 12 cases, only the left side was accessed and a guide wire was used on only one occasion to assist placement of the catheter. With right-sided cannulation, there were problems with advancing the catheter out of the carotid artery, into the aortic arch and down the ascending aorta. The catheter would often hit the inferior wall of the aortic arch and fail to advance or go down the descending aorta. Access to the ascending aorta from the right side could be achieved by an interventional radiologist with guide wires and angled catheters, but this is time consuming compared to the easier access from the left side.

Catheter

We initially used angiographic guide wires and catheters to aid manipulation of the catheter position. We used these catheter systems with a rigid 'introducer'; however, we found that it caused damage (specifically perforation of the carotid artery in one case and of the aortic arch in a second). We found that it was relatively easy to introduce the guide wire or catheter from the left-sided approach without the introducer; therefore, we abandoned its use early on. The catheter system was time consuming and we found that, if we adopted access via the left carotid artery just above the level of the clavicle, the directional capability was unnecessary.

It soon became evident that the most important part of the catheterisation was the balloon inflation in the ascending aorta to prevent flow back down the descending aorta.

Balloon inflation below 3 cm in diameter proved unsatisfactory. Due to the easier access experienced from the left-sided approach, we were able to change to a silicone-coated 14 Fr Foley male urinary catheter to allow larger balloon inflation. To allow the use of a guide wire, we made an oblique incision to the rounded tip of the catheter. This modified tip-assisted catheter introduction into the artery. We found that the flexibility of the catheter, along with the length and inflatable capacity of the balloon, was adequate for our angiographic needs. Latterly, the guide wire was used only for difficult cases.

In the early cases, it was difficult to 'feel' whether the catheter was positioned correctly and we relied on the CT scan to determine this. As the operators became more experienced, it was possible to confidently feel whether the catheter was in the correct position. If the catheter contacted the inferior wall of the arch of aorta, a very clear obstruction to the advancement of the catheter was felt. If it was possible to insert the entire length of the catheter without meeting any resistance, it was more likely that the catheter had gone down the descending aorta and repositioning was required. If the catheter went down the ascending aorta, the catheter would inevitably contact the leaflets of the aortic valve, producing a sensation of a 'bounce' after advancing 10–15 cm. The process of learning this haptic feedback ('to feel the bounce') is a key stage in order to perform the technique independently. Catheter position was confirmed using the initial chest CT scan, and was modified as above and confirmed with a repeat scan if necessary.

We experienced no problems with catheter movement during the transportation of the body from the mortuary to the CT scanner. A simple piece of adhesive tape across the end of the catheter secured to the side of the neck was sufficient to prevent movement. A towel could be folded and wrapped around the neck to absorb any leakage of blood during transportation. A second towel could be wrapped around the patient's head, hiding the face to preserve patient dignity and prevent any distress to the radiographers.

Contrast injection

We scanned immediately after injecting the contrast and did not see any artefacts related to the contrast. The injection of Urografin® did not cause any damage to the vessels or organs detectable at autopsy. As we used a targeted system, the contrast did not alter post-mortem toxicology as it entered the heart and aorta only. It did not cause the artefactual fat emboli seen when using other contrast types [23] and would not interfere with the diagnosis of air embolus as the right side of the heart and pulmonary arterial vessels are not investigated by this approach. This means that there is no need to take samples from the body prior to angiography being performed.

In the early cases using the angiographic catheters, we tried 60-ml manual injections of positive contrast at varying speeds from 5 to 20 s (Fig. 2). We found that the slower manual injections with continued pressure were much better at circulating the contrast than the fast, high-pressure injections. After a few test cases, larger volumes were administered giving better images. We found no significant improvement in positive contrast filling of the vessels over 120 ml. Our final protocol was for manual injection of 120 ml of positive contrast in two injections in approximately 40 s (20 s per syringe).

Urografin® contrast agent is of the same opacity as the calcification seen within the wall of the coronary arteries making assessment of vessel lumen difficult. Also, positive contrast filling of the RCA and PDA was often incomplete but the vessels filled well when air was used (see below). The former could be well demonstrated by 3-D MPR by maximal intensity projection (MIP) while the latter required minimum intensity projection (Fig. 3). Air had the distinct advantage of showing a patent lumen in the middle of a calcified plaque (Fig. 4). With this in mind, we adopted a double contrast method, an initial injection with air followed by a further injection of Urografin®. For the first few cases, air was injected in 60-ml increments until good filling was achieved. Our final protocol was for 300 ml of

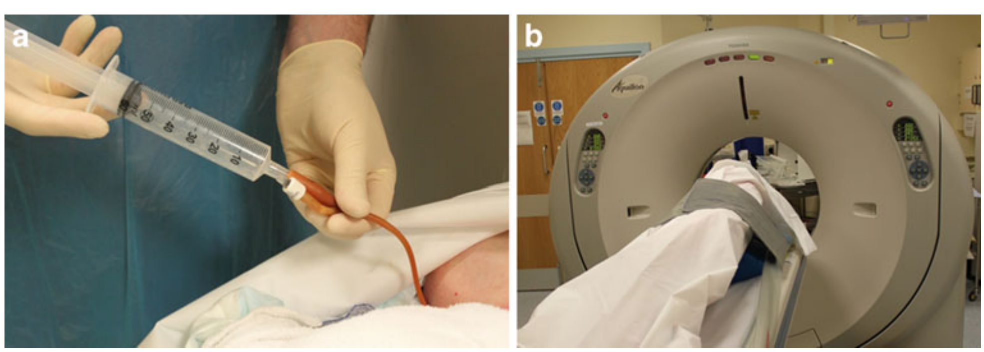

Fig. 2 **a** Injection of contrast (air) by means of a 60-ml syringe whilst on the CT scanner table. **b** The body is rolled 90° to the right lateral decubitus position (whilst still in the body bag) and held in place with foam blocks and securing straps

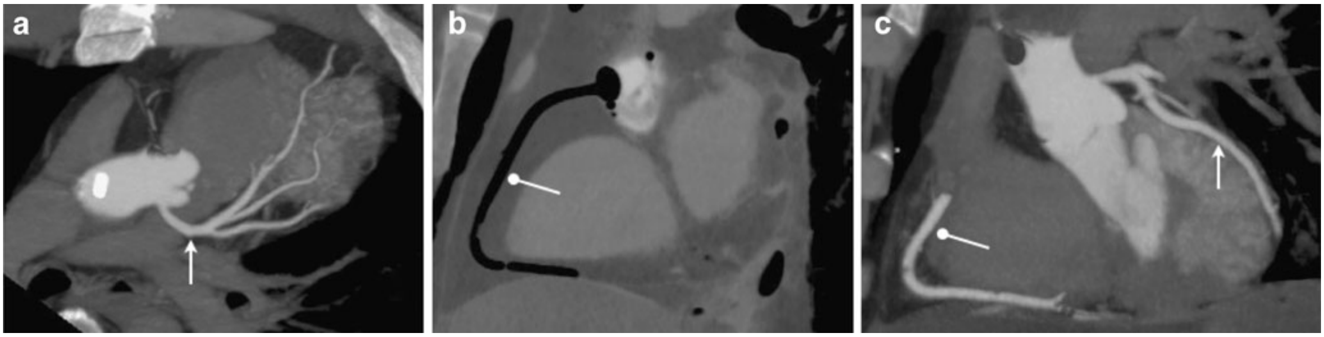

Fig. 3 Images from different post-mortem coronary angiographies showing normal vessel anatomy and luminal patency. **a** Curved MPR, MIP image showing normal left coronary system (*arrow*), **b** curved MPR, minimum intensity projection image showing normal RCA (*arrow with round head*), **c** curved MPR, MIP image showing normal left (*arrow*) and right coronary artery segments (*arrow with round head*)

air in five manual injections using a standard 60-ml bladder syringe using gentle constant hand pressure over a period of 2–3 min.

Body position

Initially, the body remained in the supine position throughout all stages of contrast injection. Injection of air in the supine position resulted in consistent filling of the RCA, but not the LMS and its branches. Likewise, positive contrast media filled the left-sided branches, but not the RCA (Fig. 4). The body was inclined 90° to the right lateral decubitus position as this was shown to improve filling of the RCA with positive contrast and filling of the LMS, LAD and Cx with air (Fig. 2). We did not perform contrast injection in the right lateral decubitus position as we found filling of the RCA with air and contrast was sufficient with the above body position.

Pathology

One concern is that injection of air/Urografin® may dislodge thrombi, misplacing them for autopsy study or open stenosed segments (Fig. 5). One of our cases showed a complete occlusion of the LAD throughout the air and contrast studies, and at subsequent autopsy, it was shown to be an occlusive thrombus. Although a single case, it perhaps negates the above concern. We are currently correlating our CT angiography with post-mortem findings.

Timing

The average time for cannulation was 15 min (range 5–30 min). The longer time periods reflect the earlier cases and the initial learning period for the technique. In later cases, when the operators were confident with the technique, the cannulation could be performed in approximately 5 min with minimal blood spillage using standard mortuary equipment. Certain cases proved more problematic for cannulation such as obese patients with short fat necks and cases with advanced rigor where the neck was flexed in an abnormal position.

For the final 14 cases, whole scan time ranged from 39 to 90 min (mean 60 min). The standard post-mortem imaging time was 18–40 min (mean 28 min), and the angiography time was 15–55 min (mean 32 min). For the

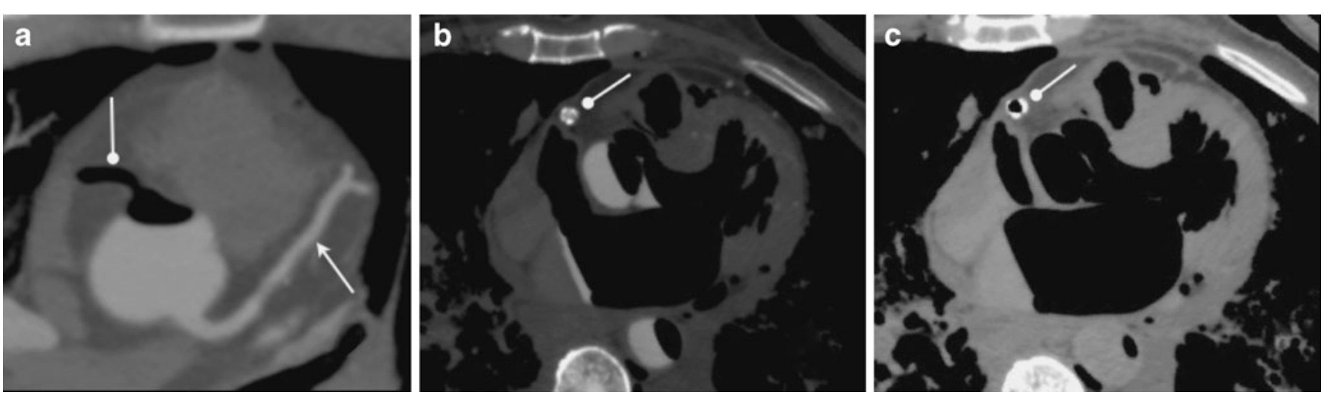

Fig. 4 **a** Preferential filling of RCA (*round head*) with air and LAD (*arrow*) with contrast. Luminal delineation of coronary artery in the presence of calcified plaque is inferior with positive (**b**) compared to negative contrast (**c**)

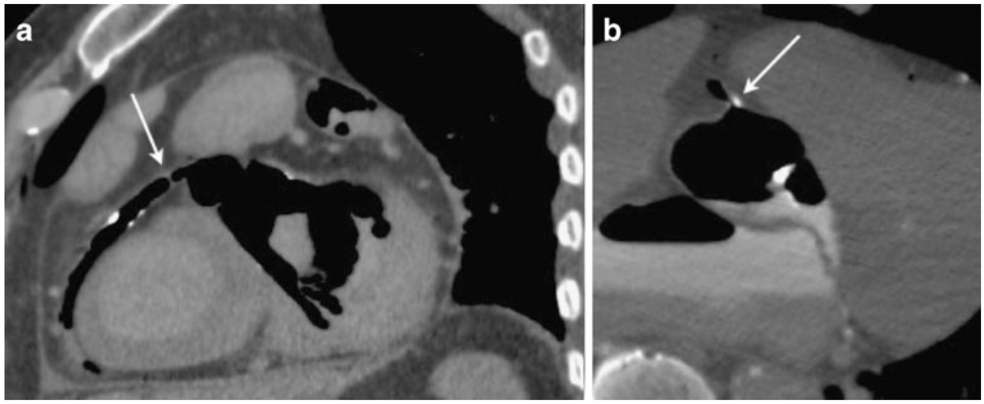

Fig. 5 Curved MPR image (**a**) showing proximal RCA stenosis (*arrow*) with mild calcified plaque disease distally. Axial image (**b**) demonstrating moderate ostial stenosis of the RCA due to a mixed plaque disease (*arrow*)

last six cases, the whole scan time improved to 39–63 min (mean 48 min).

Discussion

This paper outlines the developmental stages and our final method for targeted in situ post-mortem cardiac angiography. The cannulation can be performed with easily accessible autopsy/hospital equipment in a permanent or temporary mortuary by an APT or pathologist with minimal training. The CT scan can be performed by suitably trained radiographer or APT. Ideally, the operator should be able to assess the success of the angiography at the time of the scanning and whether further air or contrast injections are required. The operator can be any suitably trained individual. In this trial it was either a radiologist or a pathologist but it could be a radiographer or APT. At the beginning of the trial, the pathologists involved had a poor understanding of cardiac CT axial anatomy and disease. However, following a period of teaching under the supervision of a radiologist, the pathologists were confidently able to assess catheter position and vessel filling, hence our assertion that any suitably trained health care professional could undertake this work. Thus, after the first 10 cases, a radiologist was no longer required to be present at the time of scanning.

Although the coronary vessels could often be opacified completely by air, we have persisted with positive contrast as well. This is because the presence of positive contrast in the distal vessels is a good sign of patency in clinical practice whereas distal air may simply relate to post-mortem changes.

With increasing experience we found that the time for post-mortem whole-body scanning including coronary angiography reduced to an average of 48 min. We anticipate that mortuary preparation time will eventually be less than 10 min and the entire period in the scanning suite less than 45 min.

Evaluation of CT scans in comparison to autopsy findings form part of the ongoing study and are not presented here. It was, however, essential that a standardised protocol be developed at the beginning of this trial to enable visualisation of the coronary arteries prior to the next stage of the project.

Thus, we present a proof of concept paper describing a simple, quick, cost-effective, manual and targeted in situ post-mortem cardiac angiography method using a minimally invasive approach, to be used with MDCT for high throughput cadaveric imaging in permanent or temporary

Table 1 The Leicester protocol for targeted in situ post-mortem cardiac angiography which can be adopted to suit any mortuary, scanning suit or legal jurisdiction

Protocol for angiography
1. Consent
2. Cannulation of left common carotid artery at the supraclavicular location in the mortuary
3. Transport body to CT scanner
4. Scout and system scanning and catheter positioning scan
5. Angiography
(a) Ensure correct placement of catheter
(b) Body supine: inject 300 ml air, scan and evaluate
(c) Body rolled into right lateral decubitus position: inject 300 ml air, scan and evaluate
(d) Body rolled back to supine: inject 120 ml Urografin®, scan and evaluate
6. Transport body back to mortuary in preparation for autopsy (if required)
7. Images reported independently by radiologist(s)

mortuaries. We believe the protocol described (Table 1) can be adopted by practitioners working in any mortuary to obtain diagnostic images of the coronary arteries. Ongoing research is still needed to evaluate whether cardiac MDCT is comparable to current autopsy practice. However, the use of methods such as presented in this paper will assist those considering this problem.

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Conflict of interest None.

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