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Post-mortem computed tomography (PMCT) and PMCT-angiography after transvascular cardiac interventions

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Background and Purpose: During the last years, Post Mortem Computed Tomography (PMCT) has become an integral part of the autopsy. PMCT-angiography may augment PMCT. Both exams have proven their value in visualizing complications after heart surgery. Therefore, they should also show complications after transvascular interventions. This assumption initiated our project: to evaluate the possibilities of PMCT and PMCT-angiography after transvascular cardiac interventions.

Material and Methods: In our archives of characteristic and typical PMCT findings, we searched for observations on preceding transvascular cardiac interventions. Additionally, we reviewed our PMCT-angiographies (N=140).

Results: After transvascular cardiac interventions, PMCT and PMCT-angiography visualized bleeding, its amount and its origin, cardiac tamponade, free and covered perforations, transvascular implanted valves and their position, catheters and pacemakers with fractures, abnormal loops and bending. Bubbles in the coronary vessels (indicating air embolism) become visible.

Conclusion: After transvascular cardiac interventions, PMCT and PMCT-angiography show complications and causes of death. They prove a correct interventional approach and also guide autopsy. In isolated cases, they may even replace autopsy.

Key words:
PMCT, Angiography, Autopsy, Angioplasty, Heart, Transvascular Intervention

BACKGROUND AND PURPOSE

During the last years, Post Mortem Computed Tomography (PMCT) has become an integral part of autopsy [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11]. In the Institute for Legal Medicine of the University of Hamburg, PMCT complements inspection of the body and guides the autopsy. PMCT-angiography adds further information. After transthoracic cardiac surgery, both examinations have are capable of furnishing relevant information [12]. Evidently, this should be the case for transvascular interventions, too. This initiated our project: to determine the diagnostic possibilities of PMCT and PMCT-angiography after transvascular cardiac interventions.

MATERIAL AND METHODS

In our collection of PMCT cases, we searched for observations showing characteristic findings after transvascular interventions on the heart. Additionally, we analyzed our PMCT-angiographies (n=140).

Since 2008, in the Institute for Legal Medicine, more than 4000 PMCT have been performed: till 2012, with a 6-slice MDCT (MX 8000, Philips), thereafter with a 16-sclice MDCT (Brilliance, Philips). A whole body CT (slice thickness 1mm, Pitch 1.5, 130kV, 180-230mAs) is the basis; additionally, dedicated scans of the heart/chest and of the brain with high resolution (slice thickness 0.8mm, pitch 1.0, 130kV, 180-230mAS) may complement the examination. The procedure for PMCT-angiography follows the description of Grabherr [13, 14, 15]: after a non-contrast whole body CT, 1.2 liter contrast medium (CM) is injected into the arterial sys-

tem via the femoral artery and a whole body CT documents the vascular morphology ("arterial phase").

Thereafter, 1 liter CM is injected into the femoral vein ("venous phase") and a third whole body CT is performed. Finally, a special pump enforces circulation ("dynamic phase", "circulation phase") and a whole body CT completes the PMCT-angiography. To clarify or better document findings on those whole body studies, additional dedicated series of brain and heart may be performed.

RESULTS

Our observations concern findings after coronary angiography, coronary angioplasty (PTCA), stent placement, transarterial valve implantation (TAVI), mitral clips, transvascular annuloplasty, and pacemaker placement.

CORONARY ANGIOGRAPHY

CM injection: After coronary angiography, deceased patients repeatedly showed an area of CM-enhanced myocardium and CM-enhanced aortic wall (Fig. 1a and b). In the heart, this area corresponded to the supply zone of the coronary artery. Since the circulation did not wash out the CM from this zone, one may conclude that death occurred during the CM injection. This may lead to the consideration if the CM injection itself could have caused death [16].

Catheter-induced trauma: Once, an injury of one aortic leaf was observed (Fig. 2). The finding became visible after filling the cardiovascular system with air and inspecting the aorta and the cardiac cavities by virtual endoscopy.

Virtual endoscopy of the heart and vessels [17, 18]: Via a catheter in place or via a vascular puncture, 1.5-2.5 liters of air are injected into the cardiovascular system. The vessels and the cardiac cavities are "blown-up". Virtual endoscopy becomes possible, e. g. an inspection of the inner surface of vessels and cardiac cavities: The endoscopic images can be displayed on a video screen – as has also become popular for the diagnosis of (early) colon cancer.

Air embolism: Once we diagnosed an air embolism that had occurred during coronary angiography. The diagnostic criteria were air bubbles in the coronary arteries (Fig. 3a and b) and the absence of bubbles in other sites of the cardiovascular system. In our case, such bubbles were visible only in the coronary arteries. The differential diagnosis includes bubbly gas formation due to post mortem decay. Decay gas appears first in those vessels of organs positioned anteriorly, provided the corpse is in the supine position: these are the hepatic vessels, the right heart, and the ascending aorta. When bubbles are not visible at these sites, air injection must be considered. Decay gas does not show first in the coronary arteries! Another differential diagnosis concerns air having replaced blood in a vessel after death. This can happen via a vascular injury or a catheter without a lock. In our case, bubbles were present in the coronary arteries only. There was no evidence pointing towards these other differential diagnoses. Therefore, we stated apparent air embolism.

CORONARY ANGIOPLASTY – BALLOON DILATATION – STENT PLACEMENT

In coronary angioplasty, in balloon dilatation of the aortic valve, and in stent placement, the catheter traumatizes vessels and valves on purpose. This happens with the expansion of the balloon, with the guide wire, or with the stiffened tip of the catheter. Perforation, rupture, bleeding, and cardiac tamponade are possible non-desired complications. Of course, PMCT and PMCT-angiography show these complications.

Perforation and cardiac tamponade: In coronary angioplasty, a balloon situated at the end of the catheter dilates a coronary artery stenosis. One possible complication is the rupture of the artery. This complication can result in bleeding (Fig. 4a and b) or in vascular occlusion. Blood is visible in the pericardium. If the heart stops beating at the moment of an injection accompanied by an undue perforation, PMCT easily shows the CM track in the epicardium (Fig. 4b) and a CM collection in the pericardial sac. CM by virtue of its lower weight lies on top of the blood. Blood (without CM) shows a higher density in the dorsal part of the pericardium, due to sedimentation of the iron-containing erythrocytes. PMCT-angiography visualizes the source of the bleeding.

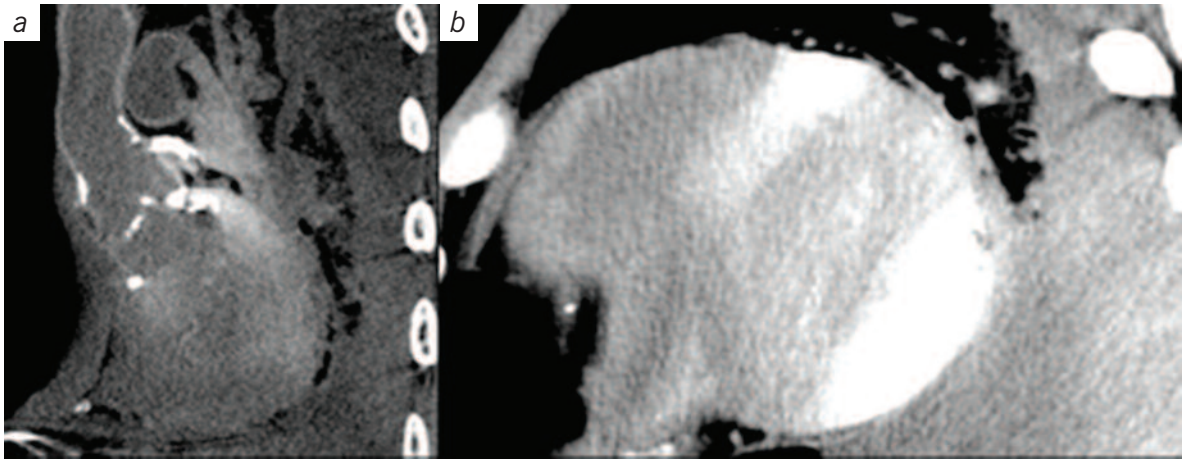

Fig. 1 a and b. CM enhanced myocardium and CM enhanced aortic wall. Death during coronary angiography. a: coronary plane. b: plane showing the maximum extension of the zone with contrast enhancement (septum and left ventricular wall).

Covered perforation: A pre-existing stenosis of the aortic valve may hamper the passage of the catheter from the aorta into the left ventricle. Repeated attempts (especially done with increasing force) may injure the wall of the aortic sinus just above the insertion of the aortic valve. Such an injury must not necessarily perforate into a cardiac cavity, the pericardium, the pleural space or the mediastinum (Fig. 5a and b). PMCT may just show a hematoma. PMCT-angiography thus documents the injury visualizing the abnormal depot. The localization of this injury allows for analyzing if the conduction system might also be injured, or if an injury of the conduction system is improbable topographically. With the information "sudden death", this analysis allows for formulating a statement about a probable cause and effect.

Bleeding into the pleural space and into the mediastinum: The dilatation of a calcified aortic valve means a local disruption. When this disruption reaches the external wall of the aorta, bleeding may continue into the mediastinum and/or the pleural space (Fig. 6a and b), which may be fatal.

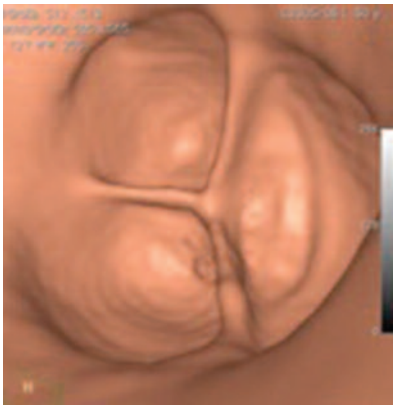

Fig. 2. Injury of the posterior leaflet of the aortic valve due to attempted catheter passage into the left ventricle. Virtual endoscopy. The aortic valve is seen from the ascending aorta.

TAVI (TRANSCATHETER AORTIC VALVE IMPLANTATION)

An aortic valve with stenosis (and/or insufficiency) can be disrupted with a balloon catheter [19, 20, 21]. This catheter can be inserted via the

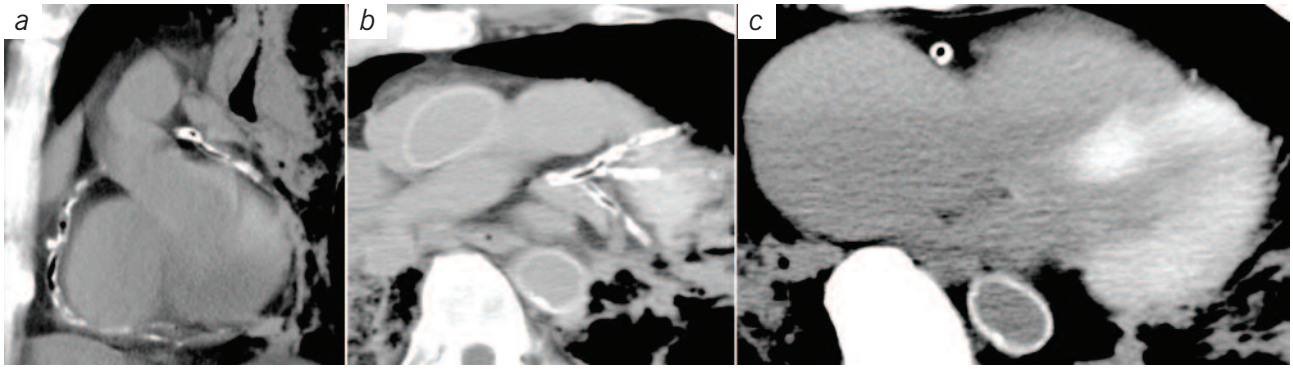

Fig 3a-c. Air embolism during coronary angiography. a and b: Air in the RCA, the LAD and the RCX. Stents with calcification in the LCA-LAD and RCX. No bubbles in other sites of the cardiovascular system. c: Contrast enhancement of the myocardium resulting from selective injection into the LCA.

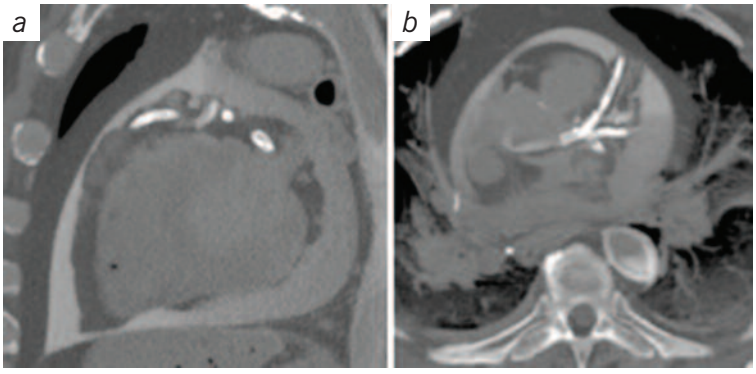

Fig. 4a and b. CM extravasation into the pericardium out of the LAD. Layer formation with CM near the anterior chest wall above the blood. Perforation of the LAD. Attempt to dilate a stenosis situated between two calcified stents. Stents in the LCA and LCA-diagonal branches. PMCT. a: MIP, sagittal reconstruction. b: MIP, axial view.

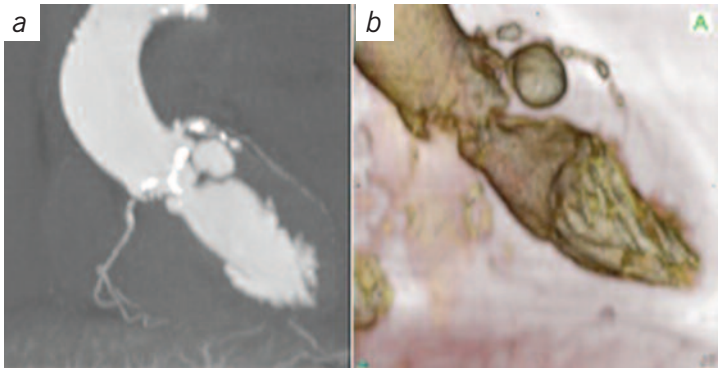

Fig. 5a and b. Covered perforation into the myocardium at the insertion of the aortic valve with stenosis and calcification, due to enforced catheter passage. CM depot between the LCA and the left ventricle. PMCT-angiography arterial phase. a: MIP. b: 3D display.

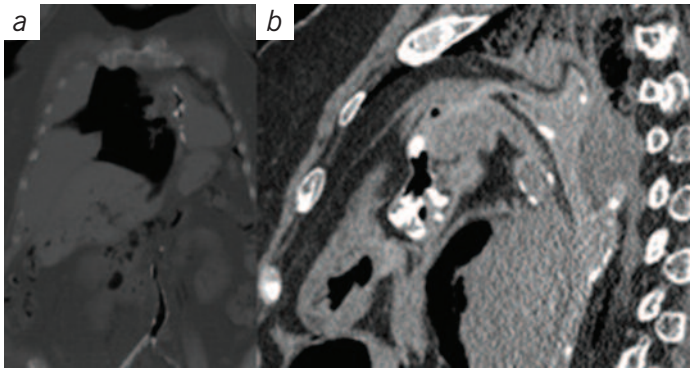

Fig. 6a and b. Bleeding into the left and right pleural space and into the mediastinum. An attempt to dilate the aortic valve with stenosis and calcifications. Air in the thoracic and abdominal aorta, possibly due to air passage via a sheath in the right femoral artery.

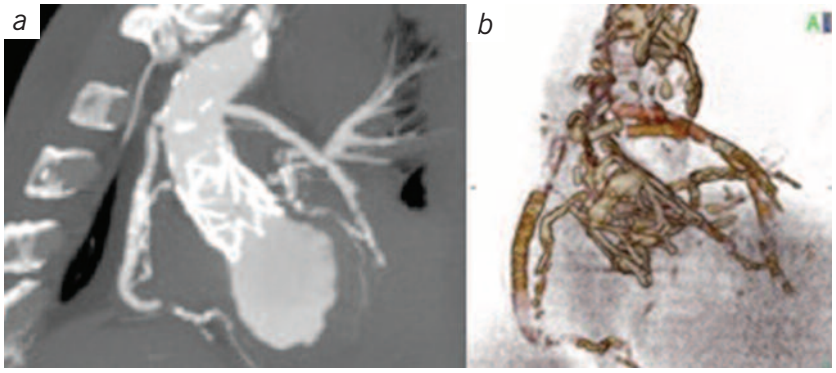

Fig. 7a and b. Encroached outlets of the LCA and the RCA by the implanted aortic valve (TAVI, JenaValve). Aorto-coronary bypass to the RCA with outlet stenosis. Bypasses to the LAD and RCX with several stents. PMCT-angiography. a: MIP. b: 3D display.

Fig. 8. Deformed insertion of the mitral valve by the implanted aortic valve (TAVI, JenaValve). The leaves of the mitral valve and the papillary suspension are visible in the CM. PMCT-angiography. Arterial phase. Display through the aortic and the mitral valve.

femoral artery, or through the ascending aorta, or the cardiac apex. A rupture of the aortic ring is a possible complication of this disruption combined with massive bleeding. A wrong position of the implanted valve also may occur. And obviously the inserted valve may not properly function.

Wrong position of the implanted valve: The implanted valve may be falsely positioned in the aorta and/or in the left ventricle. PMCT shows these wrong positions. More common are abnormal positions raising questions about iatrogenic compromising of coronary artery perfusion and of an impairment of the mitral valve. In these cases, PMCT-angiography offers more information than PMCT: the upper border of the implanted valve can reach or cover the ostia of the coronary arteries (Fig. 7a and b). The lower border can disfigure the anterior sail of the mitral valve and its papillary suspension (Fig. 8). In case of possible encroachment of the coronary artery ostia by the implanted valve, PMCT-angiography documents or excludes an impaired blood flow. Virtual endoscopy allows for visualizing the wires at the coronary ostia, which, in the living subjects would complicate catheterization or stent placement. The deformation of the anterior sail of the mitral valve and its papillary suspension is usually associated with mitral valve insufficiency.

Disruption and bleeding: A disruption of the aortic valve may rupture the wall of the aorta. A bleeding may result into the pleural space, the mediastinum and into the pericardium with successive cardiac tamponade. Balloon dilatation alone produces the same complication (see coronary angioplasty, Fig. 6a and b). The implantation of the valve via the cardiac apex and a left sided thoracotomy may induce complications typical of cardio-myotomy and thoracotomy. They have been already described [12]. The rupture of the aortic ring with shunt formation to other cardiac cavities is rare [21, 22, 23]. Such a shunt is visible in PMCT-angiography (Fig. 9a-d).

Dysfunction of the implanted valve: A mismatch of the implanted valve and the aortic ring induces an insufficiency of the aortic valve. PMCT-angiography shows this insufficiency. Aortic valve insufficiency may also be due to a malfunction of the implanted valve. The coaxial implantation of another valve into this malfunctioning valve may be a therapeutic option ("valve-in-valve", Fig. 10a-c). PMCT shows these two valves. PMCT-angiography informs about their position and probable ante mortem function.

MITRAL CLIP

A transvascular approach makes it possible to treat mitral regurgitation also in high-risk patients [24]. An arterial catheter perforates the atrial septum. A clip at the tip of the catheter captures the two mitral leaves. Thereafter, the clip closes, and reduces the size of the mitral valve opening. Ultrasound controls the manipulation. In general, one or two clips are inserted. Three clips indicate technical difficulties during the procedure. PMCT (Fig. 11a-c) shows the clips and their position. The size of the mitral valve opening can be grossly estimated. PMCT-angiography visualizes the sails of the mitral valve and their papillary suspension. A statement concerning treatment success or failure is possible.

MINIMAL INVASIVE ANNULOPLASTY

At present, mitral valve clipping seems the favored concept for treating mitral insufficiency with a transvascular approach. Procedures similar to TAVI are investigated. Transvascular annuloplasty of the mitral-valve (Fig. 12a-f) is another concept, which aims at remodeling the mitral valve annulus [25, 26]: Given the immediate proximity of the coronary sinus to the mitral valve annulus, dilatation of the venous sinus with subsequent pressure of the adjacent mitral valve ring may reduce or abolish its insufficiency: an elastic wire is placed into the coronary-sinus by a catheter. This wire has two anchors in the form of stents at its end. One anchor (the smaller) is inserted and fixed in the coronary vein, the other (larger) is inserted into the coronary sinus. The tension of the wire and/or expansion of the stent shall remodel the mitral valve annulus by pressure from the outside. So far, the results do not seem promising. In our observations, the larger anchor had perforated the coronary sinus. PMCT identifies the devices, shows their localization, and visualizes bleeding.

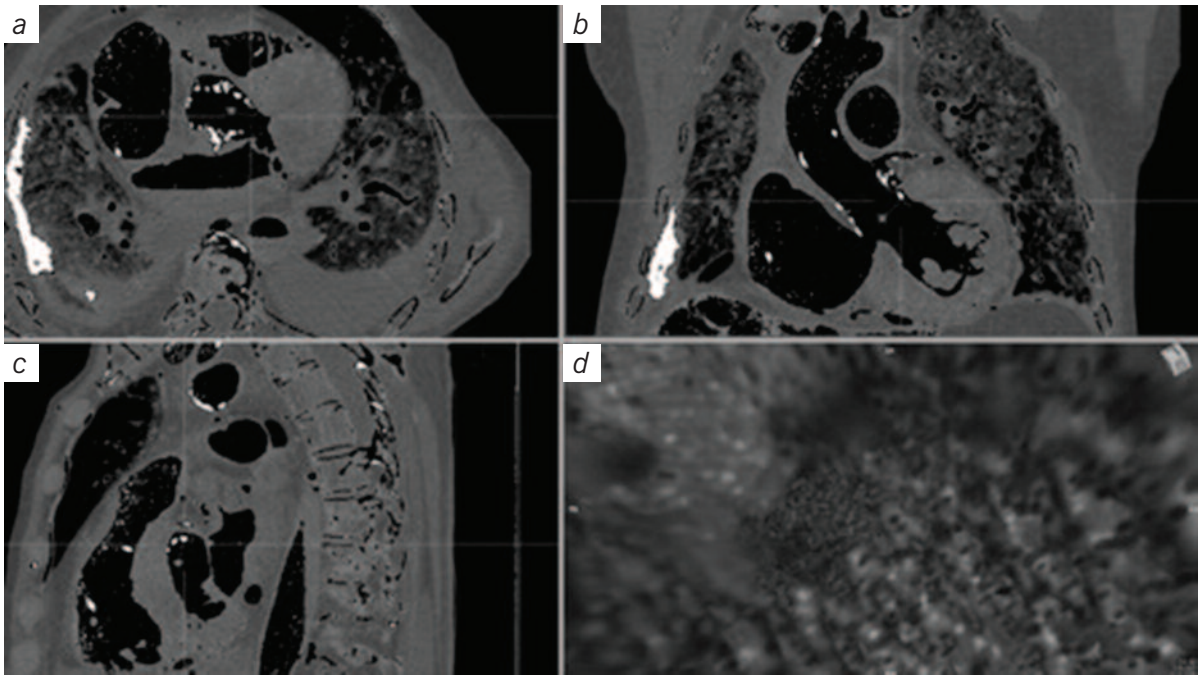

Fig. 9a-d. Rupture of the aortic ring with shunt formation between the left ventricle and the right atrium. TAVI. PMCT-angiography. Virtual endoscopy after attributing values of air density to the cavities filled with CM. a-c: Simultaneous filling of the left ventricle and the right atrium. 3 plane display. d: Virtual endoscopy: Looking through the rupture, the wire-mesh of the implanted valve becomes visible.

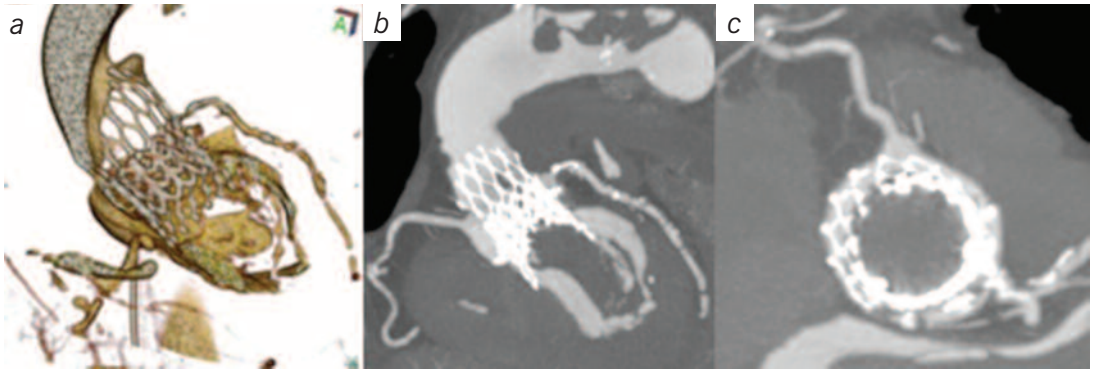

Fig. 10a-c. "Valve-in-valve". TAVI. A second valve has been implanted into the first valve due to its malfunction. The first valve did not close properly during diastole, thus insufficiency resulted. The valves cover the outlet of the coronary arteries. PMCT-angiography. a: The cover of the outlet of the coronary arteries does not hinder the filling of the coronary arteries due to sufficient patency of the wire-mesh. 3D display. b and c: MIP.

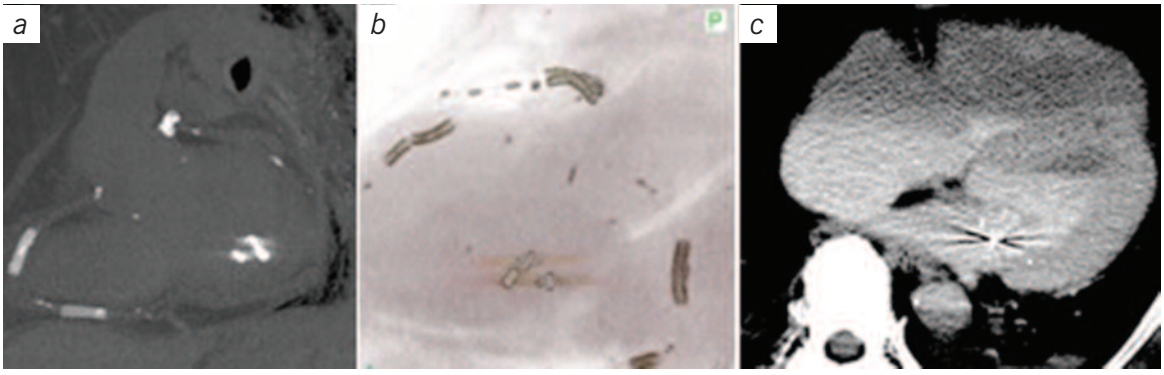

Fig. 11a-c. Mitral clip at the posterior border of the mitral valve. Stents in the RCA, the LAD and RCX. a: MIP sagittal oblique display with mitral clips and stents in the RCA. b: 3D display. Mitral clips and stents in the LCA and RCX. c: Modified 4-chamber view through the outlet of the mitral valve. Clips at the posterior limit of the mitral valve.

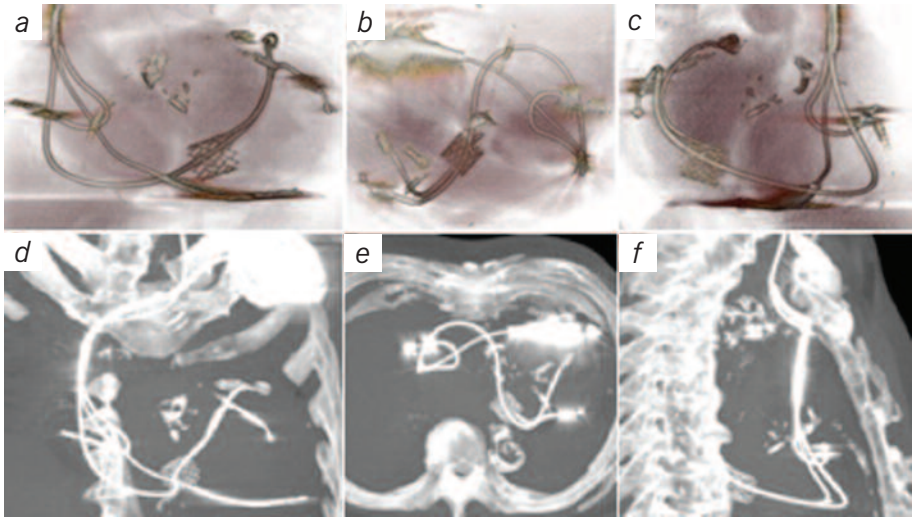

Fig. 12a-f. Minimal invasive annuloplasty of the mitral valve. PMCT. a-c: the elastic wire with its anchors in the large coronary vein (vena cardiaca magna) and the coronary venous sinus. Pacemaker with a probe in the atrium and the ventricle. Stent in the LAD. 3D display. d-f: MIP, similar projections as in a-c.

PACEMAKER

The placement of pacemakers, central venous catheters and peripheral pulmonary probes has some similarities with arterial catheterization. PMCT allows for identification and documentation of defects. Examples are an abnormal loop (Fig. 13) and a rupture of the cable. PMCT differentiates between a rupture during autopsy and a pre-existing one (Fig. 14). Perforations are visible. PMCT-angiography demonstrates the source of a bleeding and its path.

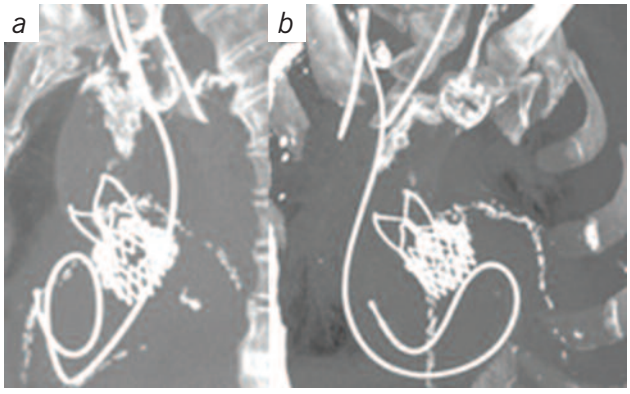

Fig. 13a and b. Pacemaker with the end in the right atrium forming a loop into the right ventricle via the tricuspid valve. TAVI (JenaValve).

DISCUSSION

After transvascular interventions, PMCT and PMCT-angiography offer the chance to visualize the cause of death. These concern those causes due to complications of the transvascular interventions and other causes of death. Complications due to the transvascular intervention should be more frequent and apparent in deceased patients than in survivors. However, PMCT and PMCT-angiography probably do not visualize every cause of death. Which one of these causes of death is documented reliably, remains to be determined: Examples have shown the possibilities and contributions of PMCT and PMCT-angiography in determining causes of death connected to a transvascular cardiac intervention [12].

Proof of the (preceding) transvascular intervention with a catheter: PMCT and PMCT-angiography prove a preceding CM application [16], and make manipulation with a catheter probable. CM-enhanced myocardium (Fig. 1and b, and 3a-c), corresponding to a supply zone of the coronary artery, indicates selective coronary angiography before death. The stopping of circulation did not wash out the CM. Therefore, death must have occurred in a short interval after the injection or with the injection. Missing contrast enhancement of the myocardium indicates either a longer interval (long

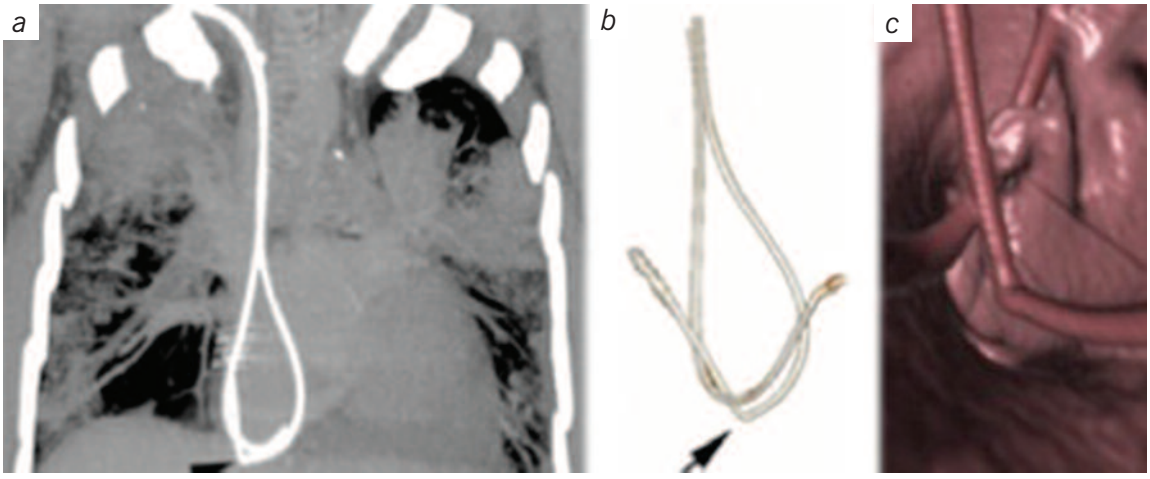

Fig. 14a-c. Fracture of a pacemaker cable in the right atrium. a: MIP. b: 3D. c: Virtual endoscopy proving the existing fracture before autopsy.

enough to wash out the CM) or the absence of any injection. A late adverse reaction to the CM, however, is still possible. An interval of minutes to hours between contrast injection and death is plausible, when there are signs of renal CM excretion, but no contrast enhanced myocardium. Signs of extrarenal CM excretion correspond to an interval of hours and days.

Typical injuries are another criterion indicating a preceding transvascular catheter intervention: Perforation of the coronary artery (Fig. 3a and b) is an example. In isolated cases, a path marked by CM shows the route leading to extravasation into the pericardial sac. PMCT-angiography also visualizes typical lesions: a covered and a free perforation into the pericardium and/or the mediastinum and/or the pleural space, or an intracardiac rupture with subsequent shunt formation (Fig. 9a-d).

Cause and effect: A short interval advocates causality between contrast injection and/or manipulation on the one hand and death on the other. A lesion typical for a catheter intervention and known to be possibly associated with lethal complications is another argument in favor of causality. This is true for perforation of the coronary artery (Fig. 4a and b). In isolated cases, a path marked with CM visualizes such a perforation connecting the artery with the pericardium. PMCT-angiography may show a covered perforation (Fig. 6a and b), a free perforation into the pericardium (Fig. 4a and b) and/or the pleural space and the mediastinum, or even an intracardiac rupture with shunt formation (Fig. 9a-d). A lesion with topographic involvement of the conduction system of the heart may cause death with a high probability. This probability is valid, too, for a sudden large pericardial effusion containing blood and/or CM, which compress the heart (Fig. 4a and b). Cause and effect seem likely if PMCT-angiography shows an obstruction of the coronary arteries, if these were patent in an angiogram done within a reasonable time before death.

Risk factors become visible to a varying degree. These factors augment the risk of a transvascular intervention with a catheter with an increased threat to the patient's survival. There may be a connection to another disease. These considerations do not allow for a sharp distinction. A cardiac dilatation has to be important for being proven by PMCT. The findings of the deceased differ from those found in the living: with increasing time between death and PMCT, the myocardium changes its tonus. The heart modifies its form. Furthermore, body fluids shift in the corpse; and the diaphragm changes its position. This also induces changing the form and the size of the heart. PMCT demonstrates calcifications of the aortic and mitralvalve. This is also true for calcifications of the coronaries and of cardiac thrombi, neoplasms, and aneurysms. With fluid migration to the descendent parts of the corpse, dilatation of vessels and cardiac cavities near the anterior chest wall disappears. However, PMCT-angiography fills these vessels and dilates them. Any analysis must take this into consideration. Post mortem fluid migration can mimic cardiac insufficiency with pulmonary edema and pleural effusion – and even the cooling of the corpse by standard pre-autopsy refrigeration does not prevent these changes!

Appropriate conduct: PMCT and PMCT-angiography permit to prove appropriate technical conduct by the medical personal involved. After TAVI, they document correct position of the valve and absence of bleeding. The images show the upper margin of the implanted valve and the ostia of the coronary arteries, and they show the lower margin in relation to the mitral valve and its papillary suspension. A stent in relation to a former stenosis is visible. Furthermore, the reaction to an initial problem is documented: e. g. a second valve implanted in a first with prior dysfunction. The information produced with PMCT and PMCT-angiography has, of course, a potential to contribute to quality control. Moreover, they help to decide to do an additional autopsy or to omit it, given the satisfactory information of these PMCT-examinations always done initially.

PMCT has its strength in proving a previous CM application and in determining the interval (immediate, minutes, hours, days) between this application and death. Blood is well visible. Its localization (pleura, mediastinum, pericardium, groin) indicates the source of the bleeding and thus its cause. The amount of blood is a strong criterion for danger. This is also true for compression of the heart by bleeding into the pericardium (cardiac tamponade). Air is also well visible. PMCT is unique in visualizing air bubbles in vessels and in proving their ab-

sence in others. By the way: decay gas is different from abnormal peri-mortal air collections: The differentiation between these two is made by an analysis of their pattern/distribution. Chemical analysis is available in isolated cases only and needs some ml of gas at least. PMCT is also capable of visualizing cables, tubes and catheters, their position, loop formation and bending. It localizes meshwires, electrodes, and implanted valves and their effect on the natural mitral or aortic valve.

PMCT-angiography shows the source of a bleeding, the passage of blood through abnormally compromised ostia, occlusion of coronary arteries, covered and free perforation. The impairment of the anterior mitral valve sail by an implanted aortic valve becomes visible. The papillary suspension of the mitral valve can also be analyzed. PMCT-angiography in general complements PMCT.

PMCT and PMCT-angiography do not replace histology; this means they do not prove myocardial infarction. However, they confirm clinical diagnosis of myocardial infarction in certain cases.

CONCLUSION

After transvascular interventions with a catheter, PMCT and PMCT-angiography show complications and cause of death. They topographically evaluate the involvement of the cardiac conduction system. They visualize bleeding, its quantity, and its source, cardiac tamponade, free and covered perforation, implanted valves and their localization; and fractures, abnormal loops and bending of cables, tubes and catheters. Air embolism is visible by bubbles. PMCT and PMCT-angiography guide autopsy and, in isolated cases, replace autopsy.

REFERENCES

1. Krantz P., Holtas S.: Postmortem computed tomography in a diving fatality. J Comput Assist Tomogr. 1983, 7: 132-134.

2. Dirnhofer R., Jackowski C., Vock P., Potter K., Thali M. J.: VIRTOPSY: minimally invasive, imaging-guided virtual autopsy. Radiographics. 2006, 26: 1305-1333.

3. Thali M., Dirnhofer R., Vock P., editors: The virtopsy approach: 3D optical and radiological scanning and reconstruction in forensic medicine. New York: CRC, 2009.

4. Weustink A. C., Hunink M. G., van Dijke C. F., Renken N. S., Krestin G. P., Oosterhuis J. W.: Minimally invasive autopsy: an alternative to conventional autopsy? Radiology. 2009, 250: 897-904.

5. Jeffery A. J.: The role of computed tomography in adult postmortem examinations: an overview. Diagn Histopathol. 2010, 16: 546-551.

6. O'Donnell C.: An image of sudden death: utility of routine postmortem computed tomography scanning in medico-legal autopsy practice. Diagn Histopathol. 2010,16: 552-555.

7. Poulsen K., Simonsen J.: Computed tomography as a routine in connection with medico-legal autopsies. Forensic Sci Int. 2007, 171: 190-197.

8. Jacobsen C., Lynnerup N.: Craniocerebral trauma-congruence between postmortem computed tomography diagnoses and autopsy results: a 2-year retrospective study. Forensic Sci Int. 2010, 194: 9-14.

9. Roberts I. S., Benamore R. E., Benbow E. W. et al.: Postmortem imaging as an alternative to autopsy in the diagnosis of adult deaths: a validation study. Lancet. 2012, 379: 136-142.

10. Okuda T., Shiotani S., Sakamoto N., Kobayashi T.: Background and current status of postmortem imaging in Japan: Short history of "Autopsy imaging (Ai)". Forensic Sci Int. 2013, 225: 3-8.

11. Kasahara S., Makino Y., Hayakawa M., Yajima D., Iti H., Iwase H.: Diagnosable and non-diagnosable causes of death by postmortem computed tomography: A review of 339 forensic cases. Leg Med. 2012, 14: 239-245.

12. Vogel B., Heinemann A., Tzikas A., Poodendaen Ch., Gulbins H., Reichenspurner H., Püschel K., Vogel H.: Post Mortem Computed Tomography (PMCT) and PMCT-angiography after cardiac surgery. Possibilities and limits. Arch. Med. Sąd. Kryminol. 2013 63 (3): 155-171.

13. Grabherr S., Djonov V., Yen K., Thali M. J., Dirnhofer R.: Postmortem angiography: Review of former and current methods. AJR. 2007, 188: 832-838.

14. Grabherr S., Djonov V., Friess A., Thali M. J., Ranner G., Vock P., Dirnhofer R.: Postmortem angiography after vascular perfusion with diesel oil and a lipophilic contrast agent. AJR. 2006, 187: W515-W523.

15. Grabherr S., Gygax E., Sollberger B., Ross S., Oesterhelweg L., Bolliger S., Christe A., Djonov V., Thali M. J., Dirnhofer R.: Two-step post-mortem angiography with a modified heart-lung machine: preliminary results. AJR. 2008, 190: 345-351.

16. Vogel H., Heinemann A., Höpker W., Tzikas A., Poodendaen Ch., Gulbins H., Reichenspurner H., Püschel K., Bartels D., Vogel H.: Patterns and Findings in Post Mortem CT (PMCT) and PMCT-Angiography due to Ante Mortem Intravascular Injection of Contrast Medium; Forensics, Radiology Society. X-Rays: Tool and Document. Kovac Verlag 2014 Hamburg, 174-185.

17. Vogel B.: Das traumatisiserte Herz: Befunde der bildgebenden Diagnostik bei Verstorbenen und Lebenden. Suewestdeutscher Verlag fuer Hochschulschriften 2011.

18. Scharf L.: Virtuelle endoskopie mit Computertomographie post mortem: Herz, Aortenklappe, Mitralklappe. Verlag Dr. Kovac 2011.

19. Webb J. G., David A., Wood D. A.: Current Status of Transcatheter Aortic Valve Replacement. J Am Coll Cardiol. 2012, 60 (6): 483-492.

20. Thomas M., Schymik G., Walther Th., Himbert D., Lefevre Th., Treede H., Eggebrecht H., Rubino P., Michev J., Lange R., Anderson W. N., Wendler O.: Thirty-Day Results of the SAPIEN Aortic Bioprosthesis European Outcome (SOURCE) Registry. A European Registry of Transcatheter Aortic Valve Implantation Using the Edwards SAPIEN Valve. Circulation. 2010, 122: 62-69.

21. Shannon J., Mussardo M., Latib A., Takagi K., Chieffo A., Montorfano M., Colombo A.: Recognition and management of complications during Transcatheter Aortic Valve Implantation. Expert Rev Cardiovasc Ther. 2011, 9 (7): 913-926.

22. N. Al-Attar Complications of transapical aortic valve implantation. ESC Councils Council for Cardiology Practice, E-journal of Cardiology Practice, E-journal Volume 9. 2011 (9); 29. Mar. 2011. http://www.escardio.org/communities/councils/ccp/e-journal/volume9/Pages/complications-of-transapical-aortic-valve-implantations-Al-Attar-Nawwar.aspx#.UhmslLyjXbF

23. Neragi-Miandoab S., Michler R. E.: A review of most relevant complications of Transcatheter Aortic Valve Implantation ISRN Cardiology 2013, Article ID 956252, 12 pages. http://dx.doi.org/10.1155/2013/956252

24. Franzen O., Baldus St., Rudolph V., Meyer S., Knap M., Koschyk D., Treede H., Barmeyer A., Schofer J., Costard-Jäckle A., Schlüter M., Reichenspurner H., Meinertz Th.: Acute outcomes of MitraClip therapy for mitral regurgitation in high-surgical-risk patients: emphasis on adverse valve morphology and severe left ventricular dysfunction. European Heart J. 2010, 31: 1373-1381.

25. Feldman T., Clinigiroglu M.: Percuteanous leaflet repair and annuloplasty for mitral regurgitation. J Am Coll Cadio. 2011, 57 (5): 529-537.

26. Ruiz C., Kronzon I.: The wishful thinking of indirect mitral annuloplasty. Will it ever become reality? Circulation: Cardiovascular interventions 2009, 2: 271-272.

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