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Post-mortem cast angiography in the diagnostics of graft complications in patients with fatal outcome following coronary artery bypass grafting (CABG)

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Abstract The advantages and limitations of a novel post-mortem angiographic method using solidifying silicone rubber and lead oxide as a contrast medium in detecting coronary artery graft complications on a routine basis were evaluated in a series of 223 consecutive patients with fatal outcome within 30 days following coronary artery bypass grafting (CABG). Of these patients, 166 (74.4%) were male and 57 (25.6%) female (mean age 61.9 ± 9). Coronary grafts totalled 660 (3.0 per patient) with 517 aortic and 838 coronary anastomoses. At autopsy, the rubber cast model of the grafts and coronary arterial tree was exposed by a bend scalpel and sites of possible complications were examined. Post-mortem angiographs were re-evaluated and compared with preoperative angiographs and dissection findings. By combining the findings of angiography and heart dissection, 122 (54.7%) of the 223 patients were found to have some type of complication of the graft or the anastomosis. The diagnostic sensitivity and specificity of postmortem angiography was 100% in assessing narrowing or twisting of the graft as well as narrowing of the aortal anastomosis, whereas these findings were revealed with difficulty by autopsy dissection only. In cases with correct x-ray projection, narrowing and occlusion of the proximal aortal and distal coronary anastomosis were also reliably revealed by angiography. In contrast, graft thrombosis was clearly overdiagnosed by angiography, leading to a lower specificity (84%) but high sensitivity (100%) in detecting this complication. Post-mortem angiography also failed to detect dissection of the wall of the graft or anastomosis. Technical problems with this angiographic method were due to too low perfusion pressure, too rapid polymerizing of the silicone rubber, leakage of contrast medium into the ventricles, or faulty x-ray projections. These results suggest that our post-mortem angiographic technique, yielding a permanent rubber- cast model of the graft and anastomosis site, improves the accuracy of diagnostics of postoperative CABG complications and eases postoperative autopsy dissection, which can now be directed to confirm suspected complications.

Key words Angiography · Coronary artery bypass grafting (CABG) · Operative complications · Malpractice · Pathology

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Introduction

The mortality of patients who have undergone coronary artery bypass grafting (CABG) is reported to vary widely from 0–40% depending on patient selection and presence of risk factors in the patient series [1, 2]. The rising number of litigations against medical personnel, as well as the constantly growing body of claims to obtain patient insurance compensations [3] makes it important to develop new and more accurate methods to reliably exclude possible surgical accidents and negligence. In most cases, the reason for fatal outcome is obvious, but often the contribution of the technical details of surgery remains unknown. For instance proximal or distal anastomosis of the graft may be too tight. Despite the importance of knowing the frequency and type of cardiovascular and graft complications, only a few clinical or autopsy studies have focused on this problem [4–9].

Graft complications and the narrowness of anastomoses may be difficult to demonstrate by normal autopsy dissection only. Cardiac angiography is routinely used clinically for evaluation of the severity of coronary artery

Table 1 Characteristics of 223 patients dying within 30 days after coronary artery bypass grafting (CABG) during 1980–1993 in Helsinki

	Female	Male	Total
Number of patients	57 (25.6%)	166 (74.4%)	223
Mean age (± SD)	64.9 (± 8.1)**	60.8 (± 9.0)	61.9 (± 9.0)
Mean survival time (hours)	61.9 (± 91)	89.9 (± 157)	88.7 (± 143.1)
Mean time from death to autopsy (days)	5.9 (± 1.9)	6.0 (± 2.0)	6.0 (± 2.0)

**$P < 0.01$

disease and planning of the cardiac procedures. Post-mortem angiography, however, while being widely applied in studies of atherosclerosis and the anatomy of coronary arteries, has been only rarely [4–6, 8] applied to evaluation of surgical results in autopsies of CABG patients. Neither the applicability nor the sensitivity and specificity of post-mortem angiography has ever been studied.

The aim of the present study was to evaluate the applicability, limitations, and accuracy of a novel post-mortem angiographic technique using vulcanizing contrast medium for identifying and distinguishing fatal graft complications associated with CABG.

Patients and methods

Patients

The prospective series comprised 223 consecutive patients with fatal outcome within 30 days following CABG during 1980–1993 at the Department of Thoracic and Cardiovascular Surgery, Helsinki University Central Hospital, the Mehiläinen Hospital, and the Deaconess Hospital in Helsinki. These hospitals perform all the cardiac surgery in the greater Helsinki area and surroundings, an area covering more than one-fourth of the five million population of Finland.

Of the patients, 166 (74.4%) were male and 57 (25.6%) female, mean age 61.9 (± 9.0) (Table 1), with females older than males ($p < 0.01$). The number of grafts for myocardial revascularization was 660 (3.0 per patient, range 1–6) with 517 (2.3 per patient) aortic anastomoses and 838 (3.8 per patient) coronary anastomoses (Table 2).

Of the 223 patients, 5 (2.2%) had only arterial grafts (1 or 2), whereas 86 (38.6%) had only vein grafts (1–6). Both arterial and vein grafts were used in 132 (59.2%) patients.

This mean postoperative survival time was 88.7 h with a large variation (range 0–678.4) and the survival time tended to be shorter in females. The medico-legal autopsy was performed 6.0 (± 2.0) days after death at the Department of Forensic Medicine of the University of Helsinki. Clinical data relevant for evaluation of the operative and postoperative course of each patient were retrospectively analysed from hospital records. Preoperative angiographic films were re-analysed and compared to the post-mortem angiographic findings, which we also re-evaluated.

Post-mortem angiographic technique

At autopsy, a post-mortem angiography of coronary vessels and grafts was performed on site. The perfusion device for the angiography (Fig. 1) was constructed of a pressure regulator (Atlas Copco) connected to a blood-pressure manometer on a portable mounting bracket, equipped with quick couplings (Atlas Copco) to a compressed air line. Quick couplings were also used at either end of a plastic tube that connected the perfusion device to the disposable contrast medium container, which was cut from a wide diameter PVC hose.

Table 2 Types of grafts for revascularization in 223 patients with fatal outcome following CABG, Helsinki, 1980–1993

Type of graft	Grafts $n = 660$	Aortic anastomoses $n = 517$	Coronary anastomoses $n = 838$
ITA	151 (22.9%)	9[a] (1.7%)	166 (19.8%)
GEA	1 (0.2%)	–	1 (0.1%)
Vein	508 (77.0%)	508 (98.3%)	671 (80.1%)

ITA = internal thoracic artery, GEA = gastroepiploic artery
[a] free internal thoracic artery (ITA) grafts

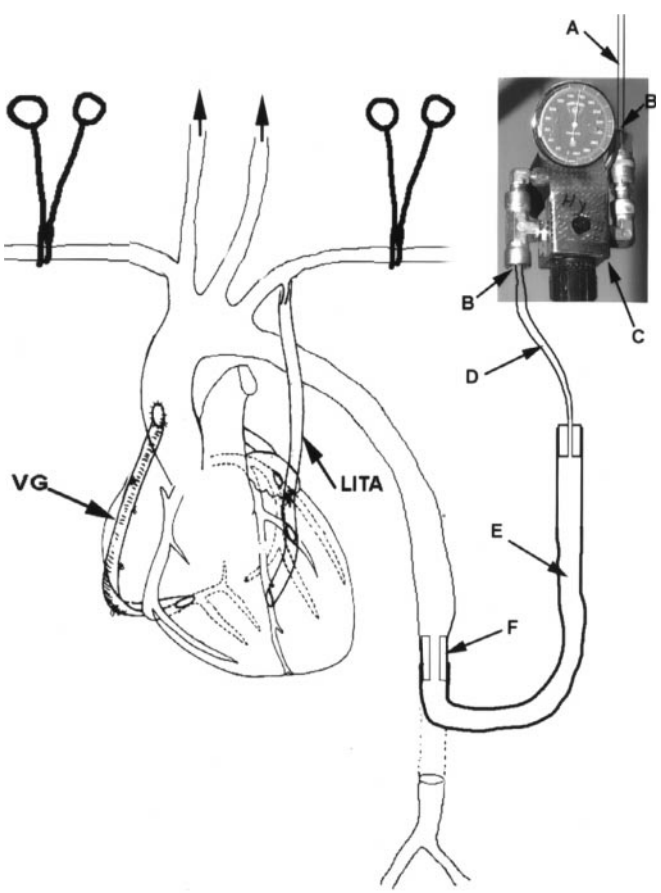

Fig. 1 The portable perfusion device (C) equipped with a blood-pressure manometer for imaging of the coronary arteries and grafts. The perfusion device is connected with quick couplings (B) to a compressed air line (A) and to a plastic pressure tube (D) connected to the contrast medium container (E). The disposable container is attached to the abdominal aorta via a mouthpiece (F). Axillar arteries are clamped with forceps. Arteries of the neck and brain are simultaneously filled. (VG = vein graft, LITA = left internal thoracic artery)

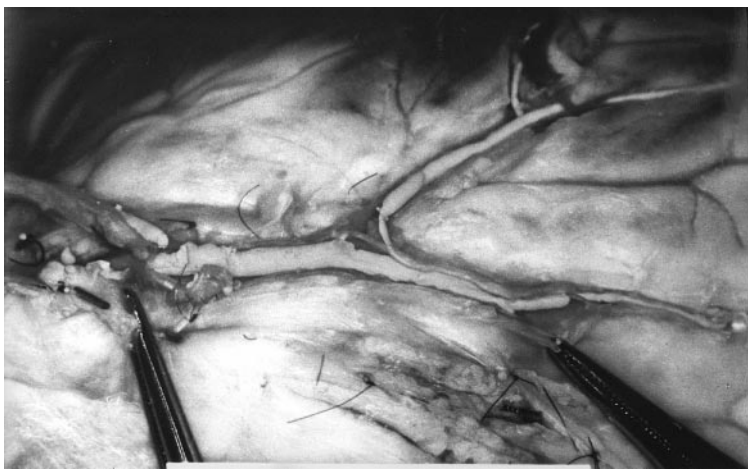

Fig. 2 Silicone rubber cast demonstrating normal coronary anastomosis of a vein graft

Fig. 3 Silicone rubber cast filling the coronary arteries

Fig. 4 Normal post-mortem angiography with three vein grafts and left internal thoracic artery graft (LITA) imaged. All grafts are open and anastomoses clearly visible

The abdominal aorta or brachiocephalic trunk was transsected and the contrast medium container connected to the blood vessel via a plastic mouthpiece. The axillary arteries were clamped distal to the base of the internal mammary arteries. No preperfusion with saline was used. The contrast medium used was liquid vulcanizable silicone rubber made radiopaque with lead oxide. For angiography, 1000 g of liquid rubber (Silikon Kautschuk RTV-Vergussmasse K, Wacker, Munich, Germany) was made radiopaque with 210 g of lead oxide, and 80 ml silicone oil (Silicon – oel AK 100, Wacker) was added. The mass was divided into ten portions to prevent premature solidifying. Immediately before use, a 100 g portion was thoroughly mixed with 2 ml of solidifier (Wacker Catalyst T). Without delay, the liquid mixture was poured into the PVC contrast – medium container attached to the aorta, and the physiological pressure (120–180 mmHg) was adjusted. A needle was inserted in the uppermost part of the aorta to allow air to escape. When the container was about to run out of contrast medium, the next portion was similarly prepared and used. This process of perfusion took about 30 min to accomplish. Grafts and coronary arteries were thus perfused with this silicone rubber suspension, which solidified to a cast within 2–3 h under physiological pressure. In the beginning of the perfusion, the aortic valve normally closed by itself due to the retrograde pressure. Carotid arteries as well as the circulus Willisi were also simultaneously perfused with contrast medium. Radiographs were taken at a distance of 100 cm and a power of 55 kV and 300 mA with a convential Siemens x-ray machine and Agfa-Gevaert Scopix CR3B film. The views used were antero-posterior and lateral.

Diagnosis of graft and anastomosis complications

The angiographic x-rays were available for the forensic pathologist before autopsy dissection. At autopsy, the aorta, coronary arteries and grafts were longitudinally opened by a bend scalpel and scissors, following the course of the rubber model of the graft (Fig. 2), and locations of possible complications were examined. The whole elastic cast model of the grafts and coronary arteries (Fig. 3), or informative parts of the model including the complication site, can also be removed and filed for possible later use.

Aortal anastomoses, the graft itself, and coronary anastomoses were each re-evaluated on angiographies (Fig. 4) by two of us (US and SW) unaware of the autopsy findings. The number and type of grafts used was obtained from the patients records and the types and sites of complications were recorded. The graft was assessed to be open if it was filled with contrast medium. The graft was considered to be occluded by thrombosis if the flow of contrast medium in the graft had stopped or the graft did not visualize at all. Cases in which the coronary anastomosis was open only distally were also considered graft complications. This diagnosis could be

Table 3 Sensitivity and specificity of post-mortem angiography and autopsy dissection in the evaluation of complications in 660 grafts of 223 patients with fatal outcome following CABG

Graft complication type	*n* = 600	Angiographic diagnosis *n*	Sensitivity[a] %	Specificity[a] %	Dissection finding *n*	Sensitivity %	Specificity %
Open	552	429	82	100	552	100	100
Occluded	79	177[b]	100	84[b]	79	100	100
Narrowed	11	11	100	100	5	65	100
Twisting	7	7	100	100	3	64	100
Dissection	1	0	0	0	1	100	100
Undefined	10	36	–	–	20	–	–

[a] Sensitivity of diagnosis obtained by angiography and dissection was calculated by dividing the number of true positive findings (TP) with the sum of true positives and false negatives (FN). The formula for sensitivity % = (TP/(TP + FN)) × 100. Specificity was obtained by dividing the number of true negative diagnoses by the sum of true negatives (TN) and false positives (FP). Formula for specificity % = (TN/(TN + FP)) × 100

[b] mainly caused by "empty" grafts

Table 4 Sensitivity and specificity of post-mortem angiography and autopsy dissection in the evaluation of 517 aortal anastomoses in 223 patients with fatal outcome within 30 days of CABG

Aortal anastomosis complication	*n* = 517	Angiographic diagnosis *n*	Sensitivity %	Specificity %	Dissection finding *n*	Sensitivity %	Specificity %
Open	468	141	59	100	468	100	100
Occluded	13	53	100	93	13	100	100
Narrowed	12	12	100	100	7	71	100
Undefined	24	311	–	–	29	–	–

Sensitivity and specificity percentages calculated as in Table 3

made when contrast medium filling the graft entered the distal part of the coronary artery through the anastomosis, but the proximal part of the coronary artery was not visualized.

The re-evaluated angiograph findings were retrospectively compared to autopsy dissection findings documented on routine autopsy reports. Preliminary assessment of angiography and dissection had been routinely done by forensic pathologists who performed routine general autopsies on the patients of this series. A combination of the results of re-evaluated angiography and dissection findings gave the total number of patients with graft complications.

The sensitivity of each method in detecting a particular type of complication was calculated by dividing the number of true positive findings by the sum of true positive and false negative diagnoses, whereas specificity was obtained by dividing true negatives by the sum of true negatives and false positives (see formula in Table 3).

Results

Frequency of graft complications

Complications of graft or anastomosis were found in 122 (54.7%) of the 223 patients. Vein graft complications alone were seen in 90 (40.4%) patients, with 11 (4.9%) having only arterial graft complications. Both vein and arterial graft complications occurred in 21 (9.4%) patients.

Of the total 660 grafts used in these patients, 108 (16.4%) were found to show some complication (Table 3), with 49 (9.5%) complications among the 517 proximal anastomoses (Table 4). Of the total of 838 distal anastomoses, 166 (19.8%) were found to have some type of complication (Table 5).

Diagnostic sensitivity and specificity of angiography compared to dissection in detecting graft complications

Grafts

Of the 660 grafts, 429 (65.0%) were assessed to be open by angiography (Table 3), whereas the true rate of open grafts was 552 (83.6%). The sensitivity of angiography in detecting open grafts was thus 82%. However, the main problem in using angiography was the great difference between post-mortem angiography and dissection in detecting graft occlusion caused by thrombosis, giving 84% specificity for angiography (Tables 3–5). Of the 177 grafts diagnosed to be occluded by angiography, 79 (44.6%) turned out to be actually thrombosed (Fig. 5). Although in angiography, most of these grafts did not visualize and were thus considered to be thrombosed, at dissection they were normally open but devoid of cast and "empty". This finding was considered as a false positive in the diagnosis of graft thrombosis.

Using angiography, the best (100%) sensitivity and specificity were observed in diagnosies of graft narrowings or twisting of the graft. Significant narrowing was retrospectively disclosed in 11 and twisting in 7 grafts (Fig. 6), whereas these findings had been missed in six and four grafts, respectively, in the preliminary analysis of angiographies and at dissection, giving low sensitivity (65% and 64%) for dissection in revealing these kinds of complications. On the contrary, only one case with dissection of the graft was missed by angiography but found at

Table 5 Sensitivity and specificity of post-mortem angiography and autopsy dissection in the evaluation of 838 coronary anastomoses in 223 patients with a fatal outcome within 30 days of CABG

Graft complication type	*n* = 838	Angiographic diagnosis *n*	Sensitivity[a] %	Specificity[a] %	Dissection finding *n*	Sensitivity %	Specificity %
Open	672	439	74	100	672	100	100
Open distally only	16	16	100	100	6	62	100
Open proximally only	28	28	100	100	10	61	100
Occluded	50	134	100	90	50	100	100
Narrowed	42	36	88	100	42	100	100
Dissection of the wall	2	0	0	0	2	100	100
Undefined	28	185	–	–	56	–	–

Sensitivity and specificity percentages calculated as in Table 3

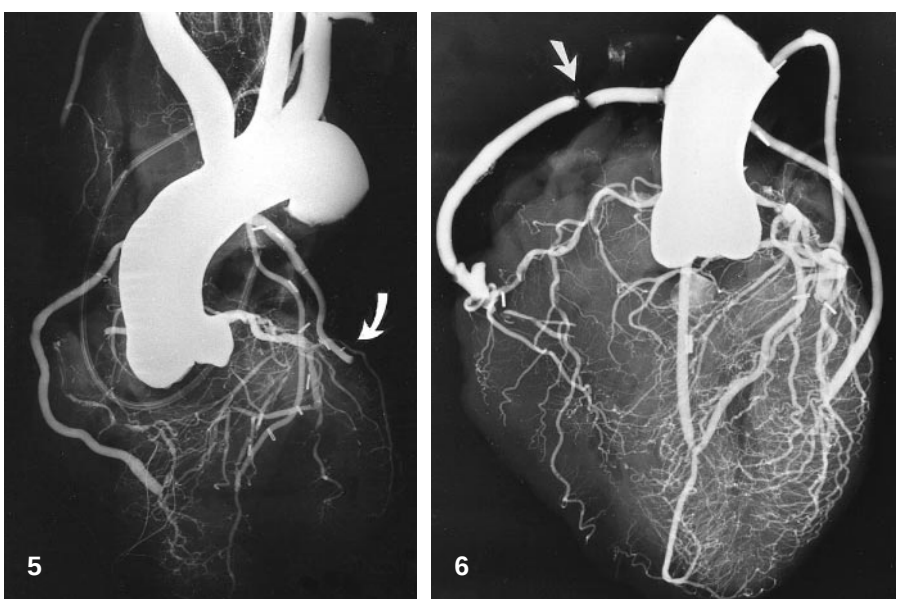

Fig. 5 Occlusion of the vein graft (arrow) following coronary artery bypass grafting (CABG)

Fig. 6 Post-mortem angiography demonstrating twisting of the vein graft to the right coronary artery (arrow) following coronary artery bypass grafting

dissection. Only 36 (5.5%) of the 660 grafts were impossible to assess by angiographic means.

Aortal anastomosis

Of the 517 aortal anastomoses, 311 (60.2%) could not be assessed in the x-rays due to technical reasons (Table 4). This suggests poor applicability of post-mortem angiography in diagnosing complications in aortal anastomoses. Of the remaining 206 anastomoses that could be assessed, 53 (25.7%) were considered to be occluded, whereas the true rate turned out to be 13 (6.3%), giving a 93% specificity for angiographic diagnosis. In contrast, among these anastomosis sites that could be visualized, angiography detected 12 (5.8%) cases with considerable narrowing of the anastomosis, of which only 7 were mentioned in the autopsy dissection reports. Presumably, the true number of narrowings that could have been detected by angiography must have been higher, because 311 anastomosis could not be assessed in the angiographs. Moreover, the fact that all cases with narrowings detected by dissection were already included in cases diagnosed by angiography, suggests that a correct angiographic x-ray available before autopsy had played an important role in directing the dissection, or was utilized when the forensic pathologist decided that the anastomosis was “narrowed”.

Coronary anastomosis

Of 838 coronary anastomoses (Table 5), 653 (77.9%) could be identified in the radiographs, but 185 (22.1%) were inaccessible. Occlusion imaged in 134 coronary anastomoses on x-rays remained unconfirmed at dissection in 84 grafts, indicating lower specificity (90%) for angiography in revealing this complication type. At this location, most false positive diagnoses were caused by technical problems associated with a too low perfusion pressure or an excessive amount of polymeriziser, leading to premature solidifying of the silicone rubber mixture, with slowing and eventually cessation of the flow of the contrast medium mixture before it entered the distal anastomosis. However, angiography was highly specific and sensitive (100%) in detecting distal or proximal occlusion and also imaged most (88%) of cases with narrow anasto-

Table 6 Technical problems in post-mortem angiographic x-rays in 223 patients with fatal outcome following CABG

Type of technical failure	Patients $n = 223$	Grafts $n = 660$
Minor		
Incomplete x-ray projection of aortal anastomoses	146 (65.5%)	311 (47.1%)
Small amounts of contrast medium in left ventricle	99 (44.4%)	–
Air bubbles in grafts	88 (39.5%	183 (27.7%)
Empty grafts	50 (22.4%)	98 (14.8%)
Incompletely filled grafts	41 (18.4%)	57 (8.6%)
Major		
Disturbing amout of contrast medium in left ventricle	21 (9.4%)	
Failure in x-ray techniques	7 (3.1%)	

mosis. Again, both cases with dissection of the distal anastomosis were missed in angiography, but were detected at dissection.

Technical problems with the angiographic method

Some minor technical faults such as air bubbles in the grafts and small contrast medium leaks were commonly seen in post-mortem angiographies (Table 6). As a minor technical failure affecting the angiographic diagnostics, 311 (60.2%) of the 517 aortal anastomoses could not be assessed because the projection of the x-ray did not reveal the anastomosis. In 41 (18.4%) of the angiographies, the grafts did not fill completely with vulcanizing silicone rubber, probably due to too low perfusion pressure or an excessive amount of polymeriziser in the contrast medium mixture, or by trapping of air in the grafts. These minor failures reduced, but did not completely negate the diagnostic sensitivity and specificity of angiography.

Major technical failures such as contrast medium totally filling the left ventricle, faulty x-ray technique, e.g. too high voltages leading to overexposed radiographs, occurred in 28 (12.6%) of the angiographies. These technical failures almost completely invalidated the use of those angiographic x-rays.

Discussion

Cardiac complications of coronary artery bypass grafting (CABG) – myocardial infarction, low cardiac – output syndrome and fatal arrhythmias are considered to comprise most of the causes of postoperative mortality [4, 6, 10, 11]. Most of these cases may be seen as unforeseeable consequences of severe disease of the coronary arteries or myocardium or of certain typical complications of treatment. However, it is difficult to know how many of these cases may be at least partly due to human error or inexperience (acting beyond one's skills) or may be unintended injuries during or after surgery [3]. Because accidents and errors are potentially preventable, the study of such errors and accidents leading to the death of the patient is also an essential part of hospital quality control. Thus, medico-legal autopsies of CABG cases with fatal outcome play an important role in assessment of quality of surgical care, as well as in the gathering of data useful in defending the rights of medical personnel in possible litigation cases. Although occasions with negligence or where the care given falls below the standard level for one reason or another are rare, the rapidly rising rate of claims for payments to patient insurance companies also puts more weight on careful evaluation of the fatalities associated with surgery.

Although graft complictions are known to contribute in many cases to the outcome, the frequency and characterization has not been examined in detail. This may be due to the fact that reporting complications is a distressful and delicate topic partly for the reasons discussed above, but it is at least partly also caused by difficulty in detecting graft complications by meticulous autopsy dissection only. Our novel post-mortem angiography method was developed to simplify the identification of graft complications and to gain more detailed information also concerning the extent of postoperative myocardial ischemia.

Post-mortem angiography has also been used to assess the specificity and sensitivity of pre-operative clinical angiography in patients with fatal outcome following cardiac surgery [12] and to observe atherosclerotic plaques of coronary arteries in necropsy patients [11, 13]. Post-mortem angiography has been combined with planimetry to study coronary arteries [14]. In this study, we present a novel angiographic technique for visualization and characterization of graft complications and assess its applicability and limitations. Previously, this technique has been used in a small preliminary study in revealing vascular complications of CABG patients [4]. This technique has been also used to visualize vascular complications associated with neurosurgery [15], av-malformations of the brain [16], vertebral artery ruptures in traumatic subarachnoid haemorrhage [17], rupture of splenic artery aneurysm [18] and to image stenoses in lumbar spine arteries [19] as well as to visualize esophageal varices [20] and sudden fatal or non-operable bleeding from ruptured intracranial aneurysm [21].

Our method has many benefits compared to methods presented earlier for post-mortem angiography [13, 22–29, 31]. The equipment is simple and mobile and the installation is rapid. The perfusion can be done from the abdominal aorta, distant from the site of surgery and there is no need to disturb the graft or heart before the silicone rubber contrast medium is completely polymerizised. Angiographic pictures can be taken and the dissection accomplished and evaluated after contrast material infusion in only a few hours. In a previous method, dissection of the heart was possible only after 24 h of polymerizing of the cast [25]. Solidifying silicone rubber and lead oxide yield an excellent permanent cast at room temperatures that also serves a guide for examining the arteries and

grafts. Barium contrast media must be mixed with gelatin and heated before infusion and kept in a refrigerator to harden [25, 27] before angiography, and the media is destroyed by dissection. In the present method, physiological pressure from 120 to180 mmHg was used in perfusion to visualize coronary arteries and grafts. We did not use saline as Hubner and Böhm [31], because blood is probably forced into the capillaries by the silicone rubber mass. In imaging of coronary arteries and grafts, we have observed no artifacts caused by post-mortem clots. Our method enables simultaneous imaging of grafts, epicardial and intramuscular coronary arteries. Thus our technique offers more information compared to other methods developed for assessing of myocardial vasculature [32] or to autopsy dissection only [33].

Graft occlusion has been considered a common autopsy finding in the early postoperative period [7] but aside from a report by Järvinen et al. [4], the contribution of graft complications in postoperative mortality has not been studied in detail. In the present study, 54.7% of the CABG patients with a fatal outcome had some kind of graft complication, a figure also including even proximal occlusion of the coronary anastomosis. The criterion of graft complications was thus very strict, because proximal occlusion of a coronary anastomosis is rarely of clinical importance. At autopsy, 12.0% of the grafts were found to be occluded. This differs from the results of a series of 55 patients [7] in which 16 (29.0%) of the grafts thrombosed. The tendency of vein grafts to twist is well known [34]. In the present study, twisting of grafts was imaged in 3.1% (seven patients) post-mortem angiographic pictures, with only three of these detected by dissection. Twisting was thus more reliably identified by angiography than by autopsy dissection. Narrowing of the anastomosis could also be assessed reliably only on angiographic pictures. In contrast, the intimal dissection of the graft, although very rare, was found only at dissection, making dissection always necessary to evaluate the angiographic findings.

The most important advantage of our technique was its ability to demonstrate whether grafts and anastomoses were narrowed and also to reveal all cases with thrombosis, although with lower specificity, giving a large number of false positive findings. It also offered a possibility to locate the complication before dissection, furnishing a land-mark for the pathologist. Thus, the sensitivity and specificity of autopsy dissection would probably have been much lower, had angiographs not been available. The fact that the autopsy pathologist did not diagnose all complications, although they were retrospectively apparent in the x-rays, also demonstrates that assessment of angiographs needs experience, or perhaps should be done in collaboration with an expert radiologist. Nevertheless, in cases of dispute, an angiographic picture also affords documentation of the findings retrospectively. The drawback of the method was that occlusions were falsely diagnosed in the grafts and anastomoses so commonly. This was due to empty grafts, which did not fill with the contrast medium, but were open at dissection. However, we have recently found that the presence of an “empty” graft, when combined with a filling defect of the myocardial vasculature, is often associated with reperfusion injury or perioperative myocardial infarction (Weman et al. unpublished results). Thus, an empty graft may at the same time be a false positive sign of thrombosis and may offer a clue to a postoperative myocardial lesion which leads to obstruction of the capillary bed, halting the flow of contrast medium in the graft supplying that territory of the myocardium.

However, the present post-mortem angiographic technique is not free of technical problems and failures. Some of the x-ray pictures failed technically, being over- or under-exposed. Observation of the course and patency of grafts and coronary vessels was difficult in cases where the contrast medium leaked into the left ventricle in the beginning of the perfusion, due in most cases to slow or incomplete closure of the aortic valve. Because some of these patients had low-grade aortic valve insufficiency, this leaking was thus expected. Aortal anastomoses, very probable sites of graft complications, were impossible to assess in most of the cases, due to incomplete projection. We suggest that an x-ray should be taken perpendicularly from the side of each aortal anastomosis separately to achieve improved diagnosing. In some angiographies, grafts were perfused incompletely, probably due to low perfusion pressure. However, complications of aortal anastomoses were easy to explore at autopsy dissection. The more difficult sites involve coronary anastomoses and most (78.0%) were detectable on the angiographic picture. Air bubbles were sometimes trapped in blood vessels when the contrast medium container became empty under pressure, due to too small an amount of contrast medium. Other reasons for air bubbles were a leak in an accidentally damaged lumbar artery during insertion of the cannula into the abdominal aorta, or when a needle, inserted into the aorta to let air escape, was obstructed or loosened. However, air bubbles generally did not disturb the assessment of the grafts and anastomoses.

Even if aortal anastomoses were impossible to assess in most cases, angiographic pictures were of great use, especially in the evaluation of coronary anastomoses to determine possible narrowing, total occlusion, or only distal or proximal occlusion. Moreover, x-rays helped in directing the dissection to the correct sites. It was also possible to detect coronary artery narrowings that were not bypassed. Both the angiographic picture and the silicone cast greatly facilitated evaluation of the tightness of anastomoses during dissection. The vulcanized and elastic rubber cast was easy to locate during dissection even in cases with severe pericardial adhesions.

The present study suggests that graft complications should be suspected and carefully evaluated in every patient with fatal outcome following CABG. In approximately half of our patients, some type of graft complication obviously contributed to their fatal outcome. Our findings therefore indicate that complete evaluation of coronary arteries and grafts is important, and may even be impossible without the use of a post-mortem angiographic technique. Angiography improves the quality of postopera-

tive autopsies and provides information before the normal dissection. Angiography is the only method to reliably detect twisting of the graft and it is also useful in demonstrating narrowing of an anastomosis. The rubber cast greatly facilitates examination of the course of coronary arteries and grafts. Thus, despite its limitations, the post-mortem angiographic technique should invariably be applied to autopsy dissection to achieve complete evaluation of grafts and the myocardium in patients dying after CABG.

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