Cerebral emboli during left heart catheterization may cause acute brain injury

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Aims Left heart catheterization carries a risk for cerebral complications. The aims of this prospective study were to determine the frequency and composition of catheterization-related cerebral microemboli and to detect cerebral morphological changes and acute cognitive impairment due to catheterization.

Methods and results Forty-seven unselected patients undergoing elective left heart catheterization, either by transradial or by transfemoral access, were monitored for cerebral microemboli using multifrequency transcranial Doppler. Cerebral magnetic resonance imaging (MRI) with diffusion-weighted imaging sequences and neuropsychological assessments were carried out on the day before and the day after catheterization. A median number of 754 cerebral microemboli were detected: 92.1% were gaseous and 7.9% were solid. New cerebral lesions were observed in 15.2% of the transradial, but none of the transfemoral, catheterization patients (P = 0.567). These lesions were significantly associated with a higher number of solid microemboli (P = 0.016) and a longer fluoroscopy time (P = 0.039). There was also a significantly higher number of solid microemboli during transradial than during transfemoral catheterization (P = 0.012). Cognitive impairment following the investigations was associated with the degree of pre-catheterization cerebral MRI injury (P = 0.03).

Conclusion During left heart catheterization, cerebral microemboli, especially those which are solid, may damage the brain. Cardiac catheterization may therefore pose a greater risk for the brain than previously acknowledged.

KEYWORDS Brain injury; Cardiac catheterization; Cerebral ischemia; Magnetic resonance imaging; Microemboli; Transcranial Doppler

Introduction

During the last decade, there has been an increasing interest in the heart–brain relationship of cardiac surgery. The cerebral aspects of cardiac intervention have not, despite its extensive use, been given similar attention. Left heart catheterization with coronary angiography or percutaneous coronary intervention (PCI) is a standard procedure for the evaluation and treatment of patients with ischaemic coronary artery disease. The method is considered to be relatively safe for the brain, with an acute stroke rate of <1%.1–4 Vascular access through a radial artery instead of a femoral artery is increasingly being used due to the advantage of less immobilization time and less bleeding complications.5,6

Patients with ischaemic coronary artery disease often have generalized atherosclerosis. The use of guidewires and catheters may, therefore, cause fragmentation of atherosclerotic plaques with subsequent embolization.1 Transcranial Doppler (TCD) is an established non-invasive method which can detect cerebral microemboli.8,9 Microemboli have been shown to appear frequently during cardiac surgery and invasive cardiovascular procedures.10–15 Recent studies using cerebral magnetic resonance imaging (MRI) with diffusion-weighted imaging (DWI) sequences have shown that new cerebral lesions may be detected immediately after cerebral angiography, catheterization of stenotic aortic valves, and coronary artery bypass surgery.16–18

The aim of this prospective study was to assess cerebral embolization and acute morphological and functional changes in the brain due to left heart catheterization. Multifrequency TCD was used to detect cerebral microemboli. Cerebral MRI with DWI and neuropsychological tests were used to assess possible brain injury.
Table 1: Demographic and previous cardiovascular characteristics of the patient population (n = 47)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>59.3 [9.3]</td>
</tr>
<tr>
<td>Male sex</td>
<td>37 (78.7)</td>
</tr>
<tr>
<td>Education (years)</td>
<td>10.2 [2.6]</td>
</tr>
<tr>
<td>Full scale IQ (WAIS-R test)</td>
<td>101.5 [7.9]</td>
</tr>
<tr>
<td>Hypertension</td>
<td>16 (34.0)</td>
</tr>
<tr>
<td>Hyperlipidemia/statin user</td>
<td>39 (83.0)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>7 (14.9)</td>
</tr>
<tr>
<td>Smoking (last 2 years)</td>
<td>17 (36.2)</td>
</tr>
<tr>
<td>Stroke</td>
<td>1 (2.1)</td>
</tr>
<tr>
<td>NYHA class</td>
<td>2.0 [0.9]</td>
</tr>
<tr>
<td>Myocardial infarct</td>
<td>19 (40.9)</td>
</tr>
<tr>
<td>Coronary artery bypass surgery</td>
<td>5 (10.6)</td>
</tr>
<tr>
<td>PCI</td>
<td>7 (14.9)</td>
</tr>
</tbody>
</table>

Data are presented as mean (SD) or n (%).

Methods

Patients

Forty-seven patients, >18 years of age, with angina pectoris admitted for invasive cardiac investigations were asked and all were included in the study after giving written informed consent. Their demographic and previous cardiovascular characteristics are shown in Table 1. All patients had a relatively long travel distance to our hospital and were therefore assessed as in-patients. This allowed the study program to be carried out during three consecutive days by including the first patient every Monday during working weeks for 1 year. The study was approved by the Regional Ethics Committee and it complied with the Declaration of Helsinki.

Catheterization

All 47 catheterizations were elective and performed by an experienced interventional radiologist or cardiologist following hospital guidelines. A water-soluble, non-ionic, dimeric contrast medium ioxaglate (Visipaque 320 mg/mL, Amersham Health, Oslo, Norway) was used in all procedures. In 37 (78.7%) of the patients, the procedure was carried out with vascular access through the right radial artery, and in 10 (21.3%) of the patients through the right femoral artery. The approach selected depended on the investigator’s preference, except when insufficient ulnar artery collateral circulation excluded radial access. All patients were given acetylsalicylic acid prior to the investigation. When the transradial approach was used, a cocktail containing heparin 5000 IE (Heparin 5000 IE/mL, LEO, Ballerup, Denmark), nitroglycerine 200 μg/mL, and verapamil hydrochloridum 2.5 mg (Isotpin 2.5 mg/mL, ABBOT Scandinavia AB, Solna, Sweden) was administrated as a 15 mL saline bolus through the radial sheath before inserting the guidewire. The heparin effect was not reversed after the procedure. No heparin was given when a pure diagnostic transfemoral catheterization was performed. A water-soluble, non-ionic, dimeric contrast medium iodixanol (Visipaque 320 mg/mL, Amersham Health, Oslo, Norway) was used in all procedures. In 37 (78.7%) of the patients, the procedure was carried out with vascular access through the right radial artery, and in 10 (21.3%) of the patients through the right femoral artery. The approach selected depended on the investigator’s preference, except when insufficient ulnar artery collateral circulation excluded radial access. All patients were given acetylsalicylic acid prior to the investigation. When the transradial approach was used, a cocktail containing heparin 5000 IE (Heparin 5000 IE/mL, LEO, Ballerup, Denmark), nitroglycerine 200 μg/mL, and verapamil hydrochloridum 2.5 mg (Isotpin 2.5 mg/mL, ABBOT Scandinavia AB, Solna, Sweden) was administrated as a 15 mL saline bolus through the radial sheath before inserting the guidewire. The heparin effect was not reversed after the procedure. No heparin was given when a pure diagnostic transfemoral catheterization was carried out.

For both the transradial and transfemoral approaches, 10 cm 6F sheaths (Radifocus Introducer II, 6F Terumo Europe, Leuven, Belgium), 6F diagnostic catheters (Cordis Corporation, Miami, FL, USA) and a standard 0.038 in., 220 cm long fixed core guidewire with ‘J-tip’ (Kimal Scientific Products Ltd., Uxbridge, UK) were used. When introduced transradially the guidewire was advanced to the ascending aorta and selective coronary angiography catheters (Judkins left 3.5 and Judkins right 5) were exchanged over the wire when stationary in the ascending aorta. When the transfemoral procedure was used, the guidewire was normally not advanced beyond the descending aorta. Selective catheterization of the right and left coronary arteries was carried out followed by hand injection of the contrast agent. Five patients previously had coronary artery bypass grafting and their vein grafts and the left internal mammary arteries were selectively catheterized. In five patients, PCI was attempted during the procedure. Three of these patients had successful revascularization with stent implantation in one coronary vessel each. Heparin was given to all patients undergoing PCI in doses calculated to maintain an activated clotting time of ~250 s during the procedure.

After angiography, a pigtail catheter was advanced through the aortic valve into the left ventricle. If this was not possible, a guidewire (Straight Standard Guide Right 0.038 Darg, St Jude Medical Company, Minneapolis, MN, USA) was advanced in front of the catheter. Inside the ventricle, the catheter was aspirated and flushed with ~10 mL heparinized saline (Hepaflex 2.5 IE heparin/mL Baxter Renal, Lessines, Belgium) before pressure measurements were performed. A contrast ventriculography was carried out using a contrast medium injector giving 36 mL contrast at a speed of 12 mL/s. The catheter was again flushed with ~10 mL Hepaflex before a new pressure measurement was performed in the ventricle and during the withdrawal of the catheter into the ascending aorta.

TCD monitoring and clinical neurological examination

Forty-two (89.4%) (33 transradial and 9 transfemoral accesses) of the 47 patients had a cerebral MRI with DWI on the day before and the day after catheterization. Two patients could not complete one of the examinations due to claustrophobia and three patients for practical non-medical reasons. All except one of these 42 patients also completed the neuropsychological assessments. The principles of detection and differentiation of cerebral microemboli using multifrequency TCD instrumentation (EmboDop, DWL, Singen, Germany) were monitored for microemboli using multifrequency Doppler has been described previously. The TCD monitoring was performed continuously from incision of the artery until withdrawal of the intra-arterial introducer.

The neurologist who performed the ultrasound examinations also carefully noted any cerebral symptoms and signs during and within the first hour after catheterization.

Neuroradiological assessment

Forty-two (89.4%) (33 transradial and 9 transfemoral accesses) of the 47 patients had a cerebral MRI with DWI on the day before and the day after catheterization. Two patients could not complete one of the examinations due to claustrophobia and three patients for practical non-medical reasons. All except one of these 42 patients also completed the neuropsychological assessments. The examinations were carried out on a 1.5 T Siemens Magnetom Vision scanner (Siemens, Erlangen, Germany). A standard MRI examination was performed using axial proton-density and T2 weighted turbospin-echo sequence with 5 mm slice thickness and 1.5 mm slice intergap (repetition time 4000 ms and echo time 14 ms for proton-density images and 85 ms for T2 weighted images), coronal fluid attenuated inversion-recovery sequence with 5 mm slice thickness and 1.5 mm slice intergap (repetition time 750 ms and echo time 14 ms) and sagittal T1 sequence with 5 mm slice thickness and 1.5 mm slice intergap (repetition time 570 ms and echo time 14 ms). The DWI axial sequence was done with a single-shot
echoplanar spin-echo pulse sequence with 5 mm slice thickness and 1.5 mm slice intergap (repetition time 5100 or 5700 ms and echo time 137 or 139 ms and 50, 500, and 1000 s/mm for \( b \)-values and apparent diffusion coefficient).

The pre-catheterization MRI examinations were assessed using a modified scale\(^{21}\) as: (i) normal (no cerebral lesions), (ii) borderline (cerebral lesions with a diameter < 5 mm), and (iii) pathological (cerebral lesions with a diameter ≥ 5 mm). The DWI criteria chosen for assessing significant changes from pre- to post-catheterization were one or more new focal high-intensity cerebral lesions with a diameter ≥ 2.0 mm and with low signal on apparent diffusion coefficient. The neuroradiologist was blinded regarding all information about the patients.

**Neuropsychological assessment**

Of the 47 patients, 42 (89.4%) (32 transradial and 10 transfemoral accesses) were assessed with an extensive neuropsychological test battery on the day before and the day after catheterization. During the study, five patients decided not to participate in one or both examinations. All except one of these 42 patients also completed the neuroradiological assessments. The test battery included assessment of motor co-ordination [grooved pegboard test (dominant vs. non-dominant hand)], psychomotor speed/mental efficiency [digit symbol (WAIS-R), trail making test (part A and B)], attention [digit span (forward vs. backward), Stroop colour-word interference test], verbal learning and delayed recall [Rey auditory verbal learning test (AVLT)], verbal abstraction and fluency [vocabulary and similarities (WAIS-R), controlled oral association test (COWAT)], visual memory [Rey Osterrieth’s complex figure test (ROCFT), Taylor’s complex figure test (TCFT)] and visuocostructive abilities [picture completion and block design (WAIS-R)]. Alternate forms of the memory measures (AVLT, ROCFT/TCFT) were used at the second test.\(^{22}\) A reduction of ≥20% on at least 2 of the 12 selected test variables was defined as cognitive impairment for an individual patient. This 20% criterion is a commonly used approach which allows identification of individuals exhibiting a reduction in their test performance at retest. It also allows generalizations across samples and studies.\(^{23}\) A standardized component score (Z) assessing cognitive change across the selected 12 measures was also estimated. The Z score indicates how far and in what direction a single patient’s neuropsychological score deviates from the mean score of all patients. All patients were tested individually and the tests were administered in the same order. The neuropsychologist was blinded for all clinical information and for the results of TCD monitoring and neuroradiological examinations.

**Statistical analysis**

Spearman’s rank order coefficient (two-tailed), the Mann–Whitney U test (two-tailed), and the Kruskal-Wallis test were used to analyse non-parametric data. Comparison of groups for categorical data within four-fold tables was calculated with the Fisher’s exact test (two-sided). Differences among group mean values were tested using one-way analysis of variance (ANOVA) or non-parametric Kruskal-Wallis ANOVA, and post hoc analyses were performed using Tukey and Scheffé corrections. Repeated measures ANOVA were performed for each of the 12 selected neuropsychological tests to compare performance before and after catheterization. Analyses were performed on raw scores, with post-catheterization DWI change as the between-subject factor (new lesions vs. no new lesions) and time (pre- vs. post-catheterization) as the within-subject factor. The test of significance of the interaction between DWI change and time was a direct test of the differential effect attributable to DWI changes post-catheterization. The level of statistical significance was \( P < 0.05 \). The statistical analyses were performed using the SPSS 11.0 program (Chicago, IL, USA).

**Results**

**Catheterization**

All catheterizations were successful regarding assessment of the left and right coronary arteries. There was a mean
number of 1.7 (SD 1.2) coronary arteries with ≥50% cross-sectional stenosis, 10 patients (21.3%) had normal findings, 14 (29.8%) had one-vessel disease, 3 (6.4%) had two-vessel disease, and 20 (42.6%) had three-vessel disease. The median fluoroscopy time was 5.6 min (min–max range 1.4–33.6) and the median contrast volume given was 120.0 mL (min–max range 40.0–360.0). There were no bleeding complications, no major hypotensive episodes, no significant changes in middle cerebral artery blood flow velocities lasting more than a few seconds, and no need for prolonged hospitalization for any of the patients.

Cerebral microemboli

Cerebral microemboli were detected during all catheterizations, with a median number of 754 (min–max range 73–2502) microemboli. Of the microemboli 92.1% were automatically assessed as gaseous and 7.9% as solid. Solid microemboli (Figure 1) were detected in all patients with a median number of 54 (min–max range 12–372) microemboli. Both gaseous and solid microemboli frequently entered the right middle cerebral artery when the catheter passed from the right arm to the aorta in those examined with transradial access. A high number of microemboli were frequently detected during catheter flushings and, in particular, during ventriculography (Figure 2). The majority of these emboli were gaseous. There was a significant correlation (r = 0.34 and P = 0.023) between the number of microemboli and the volume of contrast used. There was no difference in contrast volume used during transradial (median 120 mL, min–max range 40–360) compared with transfemoral catheterization (median 135 mL, min–max range 100–235) (P = 0.246). There was, however, a significantly higher number of solid microemboli during transradial (median 57 solid microemboli, min–max range 18–372) than during transfemoral catheterization (median 36 solid microemboli, min–max range 12–66) (P = 0.012).

Neuroradiology

The pre-catheterization cerebral MRI findings were normal in six (14.3%) patients, borderline in 29 (69.0%) patients, and pathological in seven (16.7%) patients. The degree of MRI pathology was significantly related to increasing age [F(2,38) = 6.65 and P = 0.003].

Out of 33 patients, five (15.2%) had new DWI lesions after transradial catheterization, whereas no lesions were found after nine transfemoral catheterizations (P = 0.567). DWI lesions were found as a single cerebellar hemispheric lesion in three patients, bihemispheric cerebellar lesions in one patient, and both a frontal lobe and a cerebellar hemispheric lesion in one patient (Figure 3). Patients with DWI lesions had a significantly higher number of solid microemboli (median 90 solid microemboli, min–max range 60–372) compared with patients without DWI lesions (median 42 solid microemboli, min–max range 12–246) (P = 0.016). Patients with DWI lesions also had a longer fluoroscopy time (median 11.3 min, min–max range 1.4–33.6) and the median contrast volume given was 120.0 mL (min–max range 40.0–360.0). There were no bleeding complications, no major hypotensive episodes, no significant changes in middle cerebral artery blood flow velocities lasting more than a few seconds, and no need for prolonged hospitalization for any of the patients.

Figure 3 Post-catheterization cerebral DWI (b-values 1000 s/mm) showing a new brain lesion in both (A) the right frontal lobe and (B) the left cerebellar hemisphere of the same patient.
Compared with those without DWI lesions (median 5.2 min, min–max range 1.4–33.6) \( (P = 0.039) \).

**Neuropsychology**

Neuropsychological assessment of the individual patients showed that 7 (16.7%) of the 42 patients had post-catheterization cognitive impairment. Patients with cognitive impairment did not have a statistically significant higher number of solid microemboli (median 81 solid microemboli, min–max range 24–372) when compared with the other patients (median 42 solid microemboli, min–max range 12–246), \( (P = 0.42) \). Changes in Z score at retest were significantly associated with the degree of pre-catheterization MRI injury \( [F(2,38) = 3.84, \ P = 0.03] \) (Figure 4).

Repeated measures ANOVA on the 12 selected cognitive tests for patients with and without DWI lesions showed significant interaction effects for the two tests placing the highest demands on the capacity for learning and attention: the AVLT \( (P = 0.049) \) and the Stroop test \( (P = 0.019) \). More specifically, patients with new DWI lesions performed less well at retest on these attention demanding tests, not showing the expected improvement in test performance as patients without DWI lesions did.

**Clinical symptoms**

Of the 47 patients, 3 (6.4%) had a transitory cerebral deficit during or within a few minutes after catheterization. These three patients did not have a statistically significant higher number of solid microemboli (median 90 solid microemboli, min–max range 60–372) when compared with patients without symptoms (median 42 solid microemboli, min–max range 12–246), \( (P = 0.458) \). Two patients (one transradial approach and one transfemoral approach) experienced amaurosis fugax but no new DWI lesions were detected. One patient (transradial approach) had transient bilateral scotomas and a new DWI lesion in one of the cerebellar hemispheres. No patients suffered a stroke.

**Discussion**

This study is the first to demonstrate that left heart catheterization may cause cerebral morphological changes and acute cognitive impairment. Catheterization caused a high number of cerebral microemboli, both gaseous and solid, in all patients. Cerebral injury on DWI appeared to be, in particular, due to the number of solid microemboli. Transradial catheterization gave rise to a higher number of solid cerebral microemboli than transfemoral catheterization. Cognitive impairment following catheterization was correlated with the degree of pre-catheterization MRI injury.

Cerebral microemboli did not appear randomly during left heart catheterization. They were predominantly detected during catheter advancement, catheter flushing, contrast injection, and ventriculography. Clusters of microemboli often entered the brain within a few seconds after initiation of catheter flushing or ventriculography. The vast majority of microemboli appearing in such clusters were gaseous, caused by the entry of microbubbles during the injection of contrast and saline. Single solid microemboli were often detected during catheter advancement, but also appeared during other stages of catheterization together with gaseous microemboli. Solid microemboli are most likely due to mechanical fragmentation of atherosclerotic plaques or clots from the tip of the catheter.

The number of microemboli, in particular gas bubbles, was probably underestimated. When clusters of microemboli enter the Doppler sample volume at the same time, it is at present impossible for the Doppler instrumentation to count each single embolus. This is often the case during contrast injection where we found an association between the number of microemboli and the volume of contrast used. This has also been described by Gerraty et al. \(^{24}\) during carotid angiography. Contrast volume, catheter flushing, and procedure time should therefore be kept to the minimum necessary and the contrast agent degassed before use, in order to reduce the number of microemboli.

DWI is a sensitive and specific technique used to detect acute cerebral ischaemic lesions. \(^{25}\) The correlation between DWI lesions and the number of solid microemboli emphasizes the clinical significance of embolus differentiation. Solid microemboli are probably more dangerous for the brain than gaseous microemboli, because they are more likely to occlude the cerebral microvasculature. However, it has been shown that larger volumes of intra-arterial air may disturb brain metabolism. \(^{26}\) We were, on the other hand, unable to find autopsy evidence of cerebral microinfarctions or injury of the cerebral microvasculature in rat brains after increasing amounts of air. \(^{27}\)

In our clinical catheterization study, brain injuries due to episodes with decreased cerebral perfusion would seem to be excluded because there were no episodes with significant systemic hypotension or reduced cerebral blood flow velocities during the investigations. It is also unlikely that a non-ionic contrast agent such as iodixanol, which is isotonic to blood, could induce small focal cerebral ischaemic lesions. Follow-up MRI examinations to determine the duration of DWI lesions were not carried out. However, Omran et al. \(^{17}\) found, after catheterization of stenotic aortic valves, that every acute cerebral DWI lesion was still present as a similar low-intensity lesion on conventional MRI sequences 3 months later. This strongly suggests that they represented irreversible ischaemic injury.

Microembolus differentiation allows us to gain information not only about the composition but also about the potential size of an embolus. An embolus in the middle cerebral artery which causes an increase of Doppler power of 14 dB, which was not uncommon during catheterization, may either be due to a 4 \( \mu \)m microbubble or a 130 \( \mu \)m solid microembolus. \(^{20}\) A 4 \( \mu \)m gasbubble may be expected to travel through the brain microvasculature (7–10 \( \mu \)m), or dissolve, whereas this could seem more difficult for a 130 \( \mu \)m solid microembolus.

Although MRI is the most sensitive non-invasive cerebral anatomical examination method available, it is reasonable to suppose that morphological abnormalities smaller than an MRI pixel size, which is \( \sim 2.0 \times 1.8 \) mm\(^2\), will not be detected. It is, therefore, probable that the degree of acute cerebral injury may be more extensive than that visualized by DWI. This view is supported by the findings of Brown et al. \(^{28}\) who performed neuropathological examinations in patients who died after cardiopulmonary bypass, where there are also frequent microembolization to the brain. They found extensive cerebral pathological findings with...
thousands of small capillary and arteriolar dilatations caused by microembolization. In our study, the majority of DWI lesions were located in the cerebellum. Barbut et al.²⁹ have postulated that a given embolic load might be more prone to occlude the vasculature in the posterior than in the anterior part of the brain due to less regional vascularization and perfusion.

More solid microemboli entered the cerebral circulation during transradial than during transfemoral catheterization. When introduced from the right arm, the guidewire has to pass the apertures of the right vertebral and the right common carotid arteries. The guidewire may, at least in some cases, cause some mechanical force upon atherosclerotic plaques located near these apertures. Smaller or larger particles of solid material may therefore be detached and carried to the brain. Solid emboli generated during guidewire advancement from the femoral artery will not travel to the brain, but will be carried in the blood stream to the abdominal viscera or the lower limbs. Although the present study was not primarily designed to compare cerebral aspects of transradial vs. transfemoral catheterization, the findings suggest that further studies should be carried out to determine the relative risk to the brain of these two methods.

Patients with most cerebral MRI lesions before catheterization had a significant decrease in neuropsychological function compared with those with a normal MRI. This suggests that the individual patient’s tolerance for cerebral microemboli may depend on the degree of previous cerebrovascular injury.

In this prospective study, transient neurological symptoms were present with a higher incidence than usually reported during cardiac interventions. However, most studies which have reported the complication risk of cardiac catheterization have either had a retrospective or a multi-centre design,¹⁻³ or have been solely based on the interventionist’s own reporting.⁴ Our relatively high incidence of TIA is most likely due to the continuous clinical observation performed by an independent neurologist throughout the investigations.

Conclusions

This study has shown that cerebral microemboli, especially those which have a solid composition, may damage the brain during left heart catheterization. Careful patient selection and great care should therefore be taken during catheterization in order to reduce embolization, especially if there is evidence of previous cerebral ischaemic injury or severe generalized atherosclerosis.

Acknowledgements

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