The dynamic bubble trap reduces microbubbles in extracorporeal circulation and high intensity transient signals in the middle cerebral artery: a case report

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Microemboli during extracorporeal circulation (ECC) might be a reason for postoperative neuropsychological dysfunction. This case report shows that reduction of microbubbles in the arterial line, as well as high intensity transient signals (HITS) in the middle cerebral artery (MCA), could be accomplished by use of a dynamic bubble trap (DBT) during routine coronary artery bypass graft (CABG) surgery in a 63-year-old male. The DBT was placed after the arterial filter, an ultrasound Doppler device was used for detection of microemboli before and after the DBT. HITS were measured by a transcranial ultrasound Doppler in both MCAs. For first 32 min of ECC, the DBT was excluded; 54,916 microbubbles and 507 HITS were counted. In the next 30 min, blood flow was directed through the DBT. This led to a significant reduction of microbubbles from 55,888 to 1,8237; accordingly, only 120 HITS were recorded. A DBT, integrated in ECC for routine CABG, effectively reduces air bubbles, thus protecting the cerebrovascular system from microembolization, as demonstrated by lower HITS counts.

Introduction

The impairment of neurocognitive function appears to be a common finding after open-heart surgery. Gaseous and/or corpuscular microembolization to the brain have been considered to be responsible. Microembolic signals (MES) or high intensity transient signals (HITS) induced by extracorporeal circulation (ECC) can be detected using a transcranial Doppler ultrasound (TCD) over the middle cerebral artery (MCA), irrespective of their gaseous or corpuscular nature.

Reduction of microembolization induced by the ECC system promises to be beneficial. Regarding ECC, it has been shown that corpuscular particles are eliminated after passing the cardiotomy reservoir and the arterial filter, but gaseous bubbles are not. These bubbles can be measured with the help of an ultrasound device over the arterial line tubing. Usually thousands of these bubbles can be observed in the ECC tubing.

The cerebrovascular system consumes about one-fifth of the cardiac output. Accordingly, a huge number of these bubbles will reach the cerebral circulation, representing a potential risk factor for postoperative neurocognitive dysfunction.

Recently, there have been several excellent reports describing a significant correlation between microembolization, as detected by Doppler ultrasound, and postoperative neurocognitive dysfunction.

In this single-patient observation, microbubbles were measured in the arterial outflow of ECC with and without the installation of a DBT. Simultaneously, HITS were detected in both MCAs.

Materials and methods

A DBT (HPmedica, Augsburg, Germany) was designed to reduce the number of bubbles when placed between the aortic cannula and arterial filter of the ECC (Figure 1).

The DBT is tube shaped and has a helix tightly built into it. Blood flows through the helix and is converted into a rotating stream. As a result of...
centrifugal force, the more buoyant microbubbles concentrate in the centre of the blood-flow line. These bubbles then pass through the recirculation line into the cardiotomy reservoir (Figure 2).

A previous study has already revealed a significant reduction of air bubbles when a DBT was used during routine coronary artery bypass grafting (CABG). However, we also wanted to know if this also goes along with a reduction of HITS in the MCA. Therefore, simultaneous detection of HITS was performed by TCD monitoring.

**Patient**

One male patient, 63 years old, with coronary three vessel disease, normal left ventricular function, sinus rhythm, no record of cerebrovascular accident, with both carotids free of stenoses as proven by preoperative Doppler evaluation, underwent CABG (lima-lad, two single venous grafts). Informed consent was obtained prior to the investigations.

**Anaesthesia**

After premedication with oxazepam, general anaesthesia was induced with pancuronium bromide, fentanyl, etomidate and midazolam and maintained with fentanyl, midazolam and enfluran (0.6–1.0 vol%). After tracheal intubation, the patient was on normocapnic ventilation with standard monitoring during cardiac anaesthesia.

**Extracorporeal circulation**

For venous drainage, a standard two-stage cannula was advanced into the inferior vena cava via the right atrial appendage. Cannulation of the ascending aorta was performed with our routinely used aortic cannula (Jostra HK46 SE: diameter 0.24 in, length 8 in, 3/8-in connector; Jostra, Hirrlingen, Germany). Perfusion was established with the help of a roller pump (Jostra HLM20), a membrane oxygenator (Jostra Quadrox) and a venous reservoir (Jostra). After heparinization (300 U/kg) ECC was started. The linear flow rate was 2.6 L/min/m². For priming of the ECC, 1000 mL of glucose 5%, 1000 mL of Ringer lactate and 5000 U of heparin were used. The left ventricle was drained with a vent cannula (diameter 14 G, length 5.6 in; Jostra, Germany) in the aortic root and mild hypothermia was established (34°C).

Distal to the standard 40 μm filter (Jostra Quart, Jostra, Germany), the DBT was integrated into the arterial tubing of the ECC (Jostra).

**Operative course**

Cardiac arrest was accomplished after crossclamping and application of cardioplegic solution (Calafiore). The distal anastomoses \( n = 3 \) then were performed. The crossclamp was released after 32 min, and the proximal anastomoses \( n = 2 \) were sewn. ECC was gradually reduced after reperfusion and rewarming and terminated after 62 min.
**Micrububble detection in the ECC**

The two-channel Doppler ultrasonography device UBC (HPmedica, Augsburg, Germany) was used to detect the microbubbles before and after the DBT. A special feature of the device is the automatic set up of sensitivity to measurement conditions (ultrasound attenuation of the tube, coupling condition of the probe). Air microbubbles ranging from 10 to 120 μm are counted by the device; particles (blood elements, microthrombi) do not influence the results. Since the device enables the user to record raw data on a hard disc, it is also possible to evaluate the files offline after the investigation.

The UBC is calibrated in a circulation model with a water flow rate of 4 L/min. Calibration was performed by air microbubbles generated in a specific procedure. About 10 cm before the calibrated probe, within 60 seconds and a frequency of 10 bubbles per second, these microbubbles were introduced into the centre of the flow line. The exact size and number of microbubbles were recorded with a video camera and measured by using computer software (compared with a wire with a diameter of 25 μm). This procedure was applied for the two microbubble sizes of 20 and 80 μm.

**Transcranial Doppler/HITS measurement**

For the detection of HITS during the complete period of ECC, the MCA was monitored bilaterally for 30 min with 2-MHz probes (Nicolet 2MHz probe; Nicolet, Estenfeld, Germany) through the temporal bone window. The probes were connected with a Doppler sonography device (Pioneer TC 4040; Medilab, Würzburg, Germany) allowing online recording by applying the FS1 algorithm. Through a second independent investigator, data confirmation was obtained by a subsequent offline run of the recorded visual and acoustic signals.

Only unidirectional signals within the Doppler velocity spectrum with an intensity of 3 dB HTL higher than the background flow signal, lasting less than 300 ms were counted as HITS. All signals were saved on a hard disc.

**Results**

Priming and starting of ECC appeared uneventful. Average blood flow was 4.6 L/min. In order to obtain a baseline of microbubbles occurring during cardiopulmonary bypass, the DBT was excluded during the first run (t = 32 min). Shortly after crossclamping, increasing numbers of bubbles could be detected in the arterial line, with an amount of about 30 bubbles/second. No significant increase of microbubbles resulted from different surgical manipulations during the cardiac operation (preparation, suturing, luxation).

Table 1 shows the distribution of bubbles of different sizes during the first 32 min of bypass.

These figures represent cumulative data for each bubble that passes through the UBC probe within 15 seconds; however, the bubble size is discrete.

Within this period, we detected 507 HITS (276 on the left and 231 on the right). In the following 30 min, the blood flow was allowed to pass the DBT after the arterial filter. Table 2 shows the number of bubbles, with special emphasis on the reduction of microbubbles after passing through the DBT.

In this period, 120 HITS were recorded (64 on the left and 56 on the right). At the end of cardiopulmonary bypass, with blood flow being reduced to 1.6 L/min, a significant decline of microbubbles became evident, and by reducing the flow to 1.4 L/min, the generation of microbubbles stopped completely.

With the use of the DBT, the amount of microbubbles could be reduced by about 67%; accordingly, by using the DBT, the number of HITS declined from 507 to 120 (reduction rate ≈ 76%).

**Discussion**

Neurological and neurocognitive dysfunctions after open-heart surgery with ECC are frequently reported.\(^{19,20}\) Such an injury may affect almost any level of the central nervous system, ranging from neurocognitive impairment to manifest stroke. Authors agree that stroke is one of the most devastating complications of cardiac surgery, leading to longer hospitalization, increased costs and increased morbidity and mortality. However, one is not allowed to underestimate the problem of perioperative cognitive decline with all its medical, social and financial implications for the patient and their family.

Excellent studies have shown that perioperative neurocognitive impairment significantly correlates with long-term cognitive dysfunction, and this subsequently goes along with reduced quality of life.\(^{21,22}\) Despite major advances in surgical techniques and anaesthesia management, for the patient, cardiopulmonary bypass – even with today’s technology – still represents an unphysiological-like condition with several hazards, such as hypothermia, hypoperfusion, hypothermia and most seriously, embolism.

Thinking about neuroprotection, one has to pay particular attention to improving the technical aspects of cardiopulmonary bypass, especially...
with respect to the reduction or avoidance of micro- and macroembolism. With the integration of the DBT into the arterial line of a standard set up of ECC, we were able to reduce the number of microbubbles from 55 888 to 18 237, representing a highly effective reduction rate of 67%.

Simultaneous detection of HITS in the MCAs revealed a similar reduction of signals when the DBT was used: the number of HITS declined from 507 to 120 (reduction rate of 76%). This observation is consistent with the hypothesis on the composition of HITS: they seem to be a conglomerate of gaseous and solid particles leading to cerebral microembolization. They seem to be a conglomerate of gaseous and solid particles leading to cerebral microembolization. Which have shown a striking association between perioperative microembolization and postoperative neurocognitive dysfunction.

The DBT proved to be an effective tool to significantly reduce the number of microbubbles during ECC, leading to decreased microembolization to the brain. With respect to the protection of their neurocognitive abilities, this could be beneficial for patients.

However, the etiological contribution of cardio-pulmonary bypass to neurocognitive dysfunction still must be considered as hypothetical. Reducing the incidence of perioperative neurocognitive complications will require a multidisciplinary approach on the basis of a perioperative randomized trial.

References

15 Bowles BJ, Lee JD, Dang CR et al. Coronary artery bypass performed without the use of cardiopulmonary

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<th>Table 1 Distribution of microemboli without DBT</th>
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<td>Bubble count after arterial filter</td>
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<td>Range (μm)</td>
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<td>Before DBT (= after arterial filter)</td>
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<td>Reduction (%)</td>
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