

Case Report

A Dynamic Bubble Trap Reduces Microbubbles During Cardiopulmonary Bypass: A Case Study

Markus Schönburg, MD;* Petr Urbanek;† Gunther Erhardt, CCP;* Uwe Taborski, MD;* Hans Plechinger;† Stefan Hein, MD;* Michael Roth, MD;* Wolf-Peter Klövekorn, MD*

*Thoracic and Cardiovascular Surgery, Kerckhoff-Klinik, Bad Nauheim, Germany; †Convergenza AG, Vaduz, Liechtenstein

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ABSTRACT

Microemboli passing to the cerebral circulation during cardiopulmonary bypass can contribute to postoperative neurologic dysfunction. Many studies conclude that air microbubbles predominantly are responsible for this problem. A dynamic bubble trap (DBT) was developed to diminish the number of microbubbles in the arterial line of extracorporeal circulation. The DBT is able to substantially reduce the number of air microbubbles, as shown in two patients undergoing coronary artery bypass grafting, where a high number of microbubbles was assessed. Although a 40- μm arterial filter was used, many bubbles larger than 40 μm occurred in the arterial line. The DBT reduced the number of large microbubbles from 2,267 to 67 in patient 1 and from 897 to 61 in patient 2.

Address Correspondence to:
Markus Schönburg, MD
Thoracic and Cardiovascular Surgery
Kerckhoff-Klinik GmbH
Benekestr. 2-8
61231 Bad Nauheim Germany

INTRODUCTION

Microemboli passing to the cerebral circulation during cardiopulmonary bypass (CPB) can contribute to postoperative neurologic dysfunction. Several studies have reported that 70% of the patients suffer from cognitive deficits in the first week after coronary artery bypass grafting (CABG) (1–4). The microemboli are either solid microparticles or air microbubbles. An arterial filter is usually positioned in the arterial line of the CPB circuit to eliminate particles and bubbles larger than 40 μm . All microparticles smaller than 40 μm and, in some instances, microbubbles larger than 40 μm can pass through the filter with the blood flow into the circulation of the patient. Taylor et al. confirm this occurrence in their paper (5). Recently, there has been an increasing number of studies concluding that air microbubbles are predominantly responsible for the appearance of psycho-neurological dysfunction (6, 7).

METHOD

The dynamic bubble trap^a (DBT) was developed to reduce the number of microbubbles in the arterial line (8). This device, which efficiently removes microbubbles, was placed in the arterial line between the arterial filter and arterial cannula (Figure 1).

The tube-shaped DBT has an inlet, a separation chamber, a site for collecting microbubbles, where a recirculation line is connected, as well as an outlet. Inside the separation chamber, there is a helix that is tightly integrated in the chamber (Figure 2). As blood passes through the helix, it is converted into a rotating stream. The shape of the separation chamber causes the centrifugal forces to direct air microbubbles to the center of the flow line. After the blood passes through the tube to the collection site, the process stabilizes and the bubbles are now in the central blood flow line. The collection site diverts the

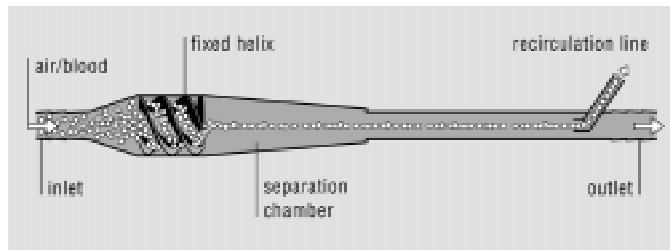


Figure 2: Construction and the working principle of the dynamic bubble trap.

central blood flow line through the recirculation line and returns it together with all bubbles to the cardiotomy reservoir. The diversion of flow to the cardiotomy reservoir is approximately 350–450 mL/min, with a pressure drop of about 35 mmHg at a blood flow of 4 L/min.

The materials used for the DBT construction are stainless steel (tube and collection site) and Ultem^b (helix and separation chamber). Before clinical use, the biocompatibility of the DBT was tested in an in vitro study. Two identical measurement circuits filled with human blood (800 mL) were set up. A DBT was integrated in the first circuit, and the second was a reference. Fifteen different parameters of hemocompatibility, including hemostasis, cell activation, complement activation, cytokines, hemolysis, and electrolytes were evaluated. There was no significant difference in the evaluated blood parameters between the two test circuits (9).

CASE STUDY

To prove the efficiency of the DBT, the outcome of two patients undergoing CABG, where a high number of microbubbles occurred during surgery, was assessed. Patient 1 (55 years old, weight 84 kg, BSA 2.04 m²) received five grafts (LIMA, RIMA, radial artery, saphenous vein graft 2 \times). Cannulation was performed using a 20F aortic cannula^c and a venous two-stage 34/39F cannula^d. Antegrade and retrograde blood cardioplegia were given during cardiopulmonary bypass. A vent was placed into the aortic root with a suction flow rate of 10–15 mL/min. A heart–lung machine^e, an oxygenator^f, and an arterial filter^g (40 μm) were used. A DBT was placed in the arterial line between the arterial filter and arterial cannula. Two ultrasound probes, positioned proximal and distal to the DBT, were used to detect microbubbles. Cardiopulmonary bypass was performed using moderate hypothermia with a minimum venous temperature of 32.1°C. The total CPB time was 70 min, the aortic cross-clamp time was 46 min.

^a Convergenza AG, Vaduz, Liechtenstein

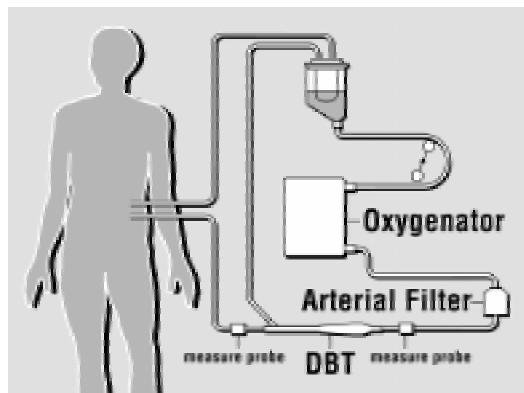


Figure 1: Position of the DBT in the arterial line of the ECC circuit.

^b General Electric Co, Pittsfield, MA

^c Stöckert Instrumente, Munich, Germany

^d Medos Medizintechnik GmbH, Stolberg, Germany

^e Stöckert S3, Stöckert Instrumente, Munich, Germany

^f Biocor 200 IHS, Minntech, Minneapolis, MN

^g AF1040, Baxter Healthcare Corp., Irvine, CA

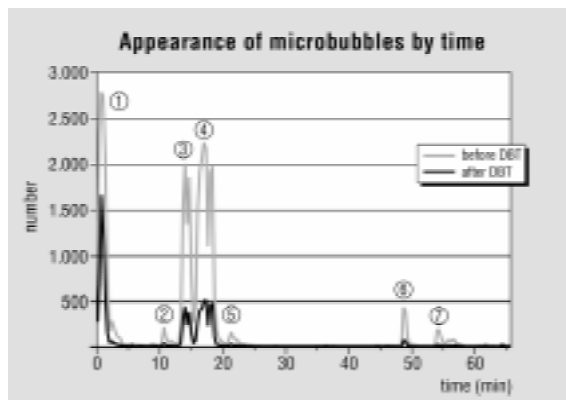


Figure 3: Appearance of microbubbles over time, patient 1, CBP introducing; 2, vent opening; 3, blood cardioplegia; 4, heart manipulation; 5, blood cardioplegia; 6, blood cardioplegia; 7, aortic clamp opening.

No problems or complications were noticed during CPB, whereas the evaluation of microbubble appearance over time (Figure 3) showed a high number of microbubbles at seven points. Bubbles were measured 2 min after introducing CPB (1). This may be attributed to the air volume that remained in the venous line after connecting the venous cannula with the venous line. The next time microbubbles occurred was at 11 min (2), which coincided with the vent being opened. Between 14–16 min, blood cardioplegia was given. The aspiration of air around the retrograde cannula can most likely be referred to a leaky purse-string suture (3). Between 16–20 min, during manipulation of the heart, air was aspirated around the venous cannula; this may have been due to a leaky purse-string suture (4). Twenty-two minutes into the procedure, blood cardioplegia was given again, which caused a slight increase in the number of microbubbles (5). At 50 min, the last hotshot blood cardioplegia was given, which again contributed to microbubble appearance (6). The last event was registered at 55 min (7), during the aortic clamp opening.

A three-dimensional figure (Figure 4) shows how frequently the bubbles appear proximal and distal the DBT during extracorporeal circulation (ECC), with the corresponding distribution of bubble sizes in diameters of 5–60 μm . Figure 4 shows how efficiently the DBT removed larger microbubbles. Microbubbles were measured in diameters of 5–120 μm . Table 1 shows the number of microbubbles as well as the size of microbubbles for each group. The number of microbubbles measured before the DBT was 40,639 and 10,271 microbubbles after DBT. Most of the bubbles had diameters of 5–17 μm . In this range 24,313 bubbles before and 8,533 after (60%, resp. 83% of the total volume) were counted. The removal efficiency was 65% in this range. The DBT removed two-thirds of the very small microbubbles. With the larger microbubbles (18–120 μm), 13,975 microbubbles before the DBT and only 1,738 after the DBT were found, which means a reduction by 88%. Although a 40- μm arterial filter was used, bubbles larger than

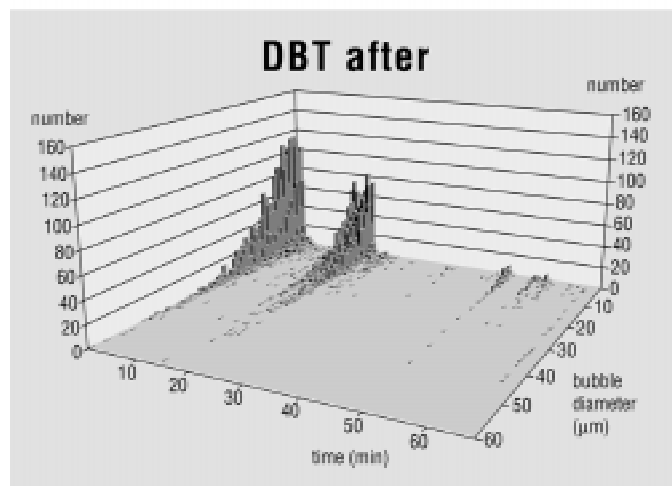
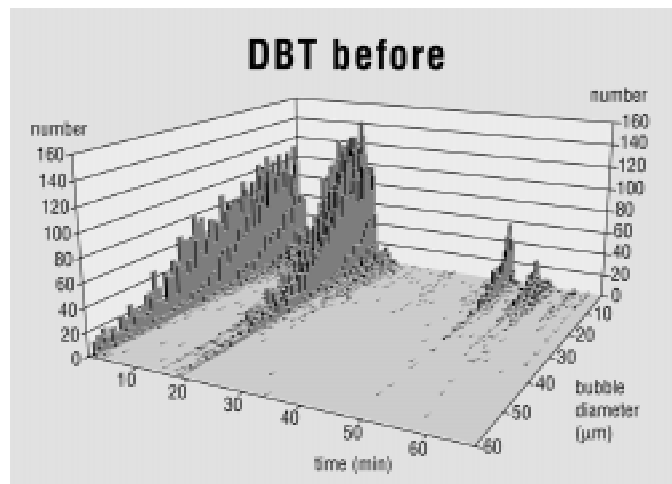


Figure 4: Three-dimensional presentation by size and time, patient 1.

40 μm were always measured before the DBT. In this patient, the 2,267 microbubbles measured before the DBT were reduced to 67 bubbles after the DBT (97%). Table 1 shows how efficiently the DBT removed microbubbles. The efficiency rate ranged from 49% in diameters of 5–7 μm up to 97% in bubbles larger than 40 μm . The mean removal coefficient K_{eff} of all microbubbles (defined as the quotient of the sum of the microbubble cross-section before and after the DBT) was $K_{\text{eff}} = 8.42$.

A quite different situation was observed in patient 2 (75 years old, weight 86 kg, BSA 2.12 m^2). The patient was also undergoing CABG (5 \times venae, 1 \times LIMA) with the same technical equipment as the first patient. The surgery was performed using moderate hypothermia (minimum venous temperature 31.6°C). The CPB time was 80 min, with an aortic cross-clamp time of 57 min. Antegrade and retrograde blood cardioplegia were given. Blood flow during CPB was 4.5 to 5.1 L/min. No complications were noticed during CPB. However,

Table 1: Number of microbubbles and size distribution, patient 1

Bubble diameter (µm)	5–7	8–12	13–17	18–23	24–27	28–32	33–40	>40
After DBT	3329	3375	1829	906	454	192	119	67
Before DBT	6518	9913	7882	5662	3684	2462	2251	2267
Efficiency	0.49	0.66	0.77	0.84	0.88	0.92	0.95	0.97

Bubbles after DBT: 10271.
 Bubbles before DBT: 40639.

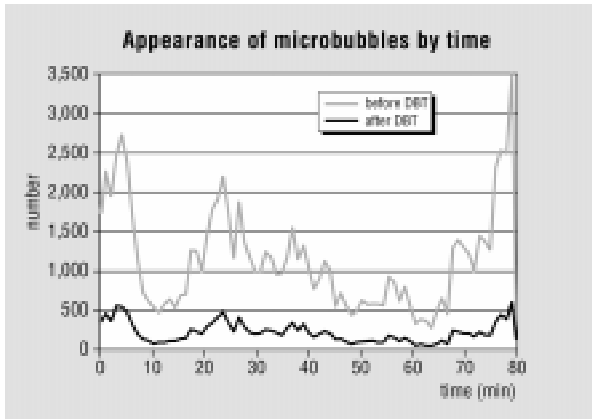


Figure 5: Appearance of microbubbles over time, patient 2.

it was unusual that air was aspirated nearby the two-stage venous cannula. In the arterial line before the DBT, a mean of 1,150 bubbles per minute was measured. Figure 5 shows the microbubble evaluation over time. The high number of microbubbles caused by the aspirated air has covered any other events that could lead to microbubble formation.

A total of 89,522 microbubbles before and 17,436 bubbles after the DBT were measured, most of them in diameters of 5–17 µm (Table 2). In this range, 70,978 microbubbles, resp. 15,043 microbubbles were measured (79%, resp. 86% of the total volume). Before the DBT, 18,544 microbubbles larger than 17 µm were measured; after the DBT only 2,393 (reduction rate 87%). The number of bubbles larger than 40 µm was reduced from 897 to 61 (efficiency rate 92%). The mean removal coefficient K_{eff} was 7.03. Figure 6 shows how efficiently the DBT removed microbubbles.

DISCUSSION

There are many studies that report on microbubble formation during CPB (5,7,8). Neukam et al. (11) conclude that a high number of microbubbles occur at the beginning of ECC and at rewarming. The results in those studies were assessed by measurements in the arterial line. However, the total number of measured microbubbles (mean 780 microbubbles per surgery) was essentially lower. In our previous study (12), the mean number of bubbles that occurred in the investigated 31 patients was 3,990. One reason could be the use of measuring devices

with a different sensitivity, as demonstrated in Mitchell et al. (13). The trends, however, remain unchanged.

We selected two patients, where an abnormal number of microbubbles was measured, for this case report; 40,939 microbubbles (before the DBT) were assessed in the first patient and 89,522 microbubbles (before the DBT) in the second.

The following hypothesis is presented to explain the reason for this microbubble occurrence: The venous two-stage cannula is mostly inserted through the right heart auricle. Air can be aspirated through leak appearances in this place due to the passive blood flow into the reservoir.

The retrograde cardioplegia cannula is inserted into the coronary sinus, which ends at the bottom of the right atrium, where also the venous two-stage cannula is positioned. Since the retrograde cannula is inserted approximately 3–4 cm from the right heart auricle within one purse-string suture, a further possibility for a leak is given. The distance of 3–4 cm from the right heart auricle is equal with that between the upper opening of the venous cannula and the right heart auricle. This may cause that the purse-string suture remains directly on the upper opening, which leads to the suction of air.

The mean removal coefficient is defined as the quotient of the sum of the microbubble cross-section before and after the DBT:

$$K_{eff} = \frac{\sum_{d=5}^{d=120} (n_{d \text{ before DBT}} \times d^2)}{\sum_{d=5}^{d=120} (n_{d \text{ after DBT}} \times d^2)}$$

where

- $n_{d \text{ before DBT}}$ number of microbubble of diameter d before DBT,
- $n_{d \text{ after DBT}}$ number of microbubble of diameter d after DBT,
- d microbubble diameter ($d = \{5;120\}$).

The sum goes over measure range from 5 to 120 µm.

Assuming the microbubble of the diameter d obstructs a capillary cross-section of πd^2 , the sum $\sum d^2$ gives the information, how much of the capillary area is theoretically closed due to air microbubbles. The coefficient K_{eff} indicates how much smaller this closing area is when the DBT was used.

As shown previously, the mean removal coefficient K_{eff} was 8.42, resp. 7.03. This means that the DBT can substantially reduce the danger of brain capillary closing. The use of the

Table 2: Number of microbubbles and size distribution, patient 2

Bubble diameter (µm)	5-7	8-12	13-17	18-23	24-27	28-32	33-40	>40
After DBT	6046	6000	2997	1411	624	237	121	61
Before DBT	24043	29184	17731	9557	4940	2403	1664	897
Efficiency	0.75	0.79	0.83	0.85	0.87	0.90	0.93	0.93

Bubbles after DBT: 17497.
 Bubbles before DBT: 90419.

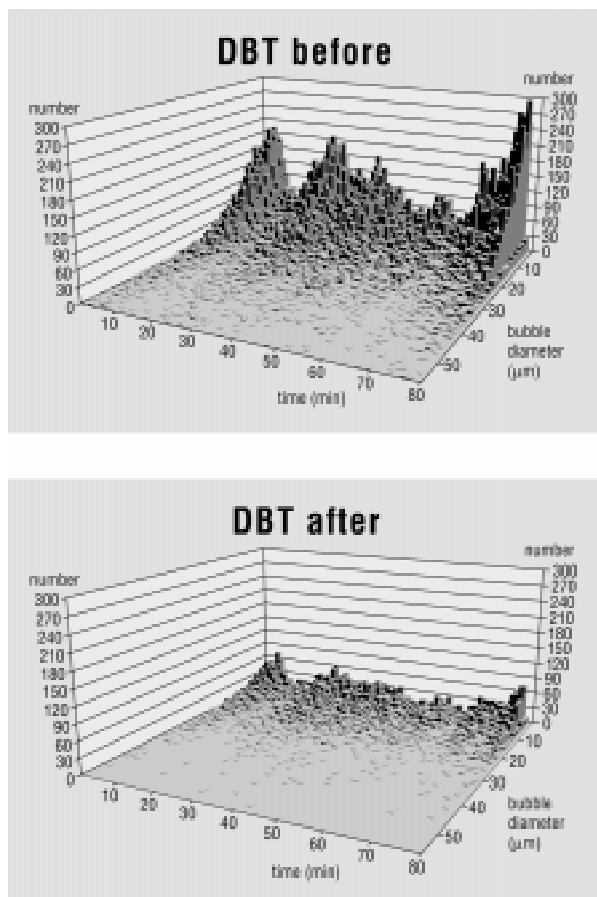


Figure 6: Three-dimensional presentation by size and time, patient 2.

DBT is a suitable technique to significantly reduce the number of microbubbles during extracorporeal circulation. Since the number of bubbles in the arterial line during CABG surgeries is within a range of several hundreds to thousands, a reduction of microbubbles may be beneficial for these patients. We believe this method has the potential to diminish adverse cerebral outcomes related to CPB.

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