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Reduction of Gaseous Microembolism During Aortic Valve Replacement Using a Dynamic Bubble Trap

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Abstract. Serious postoperative psycho-neurological dysfunction is at least partially attributed to the occurrence of gaseous microbubbles in the arterial line of extracorporeal circulation (ECC). Therefore, we investigated in a prospective randomized double blind study whether the usage of dynamic bubble trap (DBT) will reduce microbubble load of patients undergoing aortic valve replacement.

Patients ($n = 41$) were divided into group I (GI, $n = 22$) with DBT introduced into the arterial line of ECC and group II (GII, $n = 19$) with placebo-DBT instead. Doppler ultrasonography was used for detection of microbubbles before and after DBT, and for detection of high intensity transient signals (HITS) within the middle cerebral artery. The recording time during ECC was divided into period 1 (P1, until aortic clamp removal) and period 2 (P2, clamp removal until the end of ECC).

A significant reduction of microbubble load was found in GI only ($p < 0.0001$ for ECC; $p < 0.0001$ for P1; $p < 0.0025$ for P2). A significant difference in number of HITS between the groups was observed in P1 only ($p < 0.002$ left middle cerebral artery, $p < 0.005$ right middle cerebral artery), since in P2 the trapped air in left chamber can go to the supraaortal vessels without passing ECC.

In conclusion the use of DBT cannot substitute careful venting after aortic declamping. Nevertheless, reduction of HITS in the cross-clamped period of ECC justifies the use of DBT in patients undergoing open chamber surgery.

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Introduction

Serious postoperative psycho-neurological dysfunction occurs in 2–8 % of all patients undergoing cardiopulmonary bypass (CPB) (Hogue et al. 1999; Wolman et al. 1999; van Dijk et al. 2000). Besides most serious adverse cerebral outcomes (e.g. stroke or death), these patients may suffer from memory depression, comprehension, attention and perception impairment. In some cases it could take even months until their psycho-neurological status returns to normal (Pugsley et al. 1994). These complications could be at least partially attributed to the occurrence of gaseous microemboli in the cerebral circulation of the patients. Intervention of surgeon, anesthesist or perfusionist (Kurusz et al. 1995; Taylor et al. 1999), blood warming (Geissler et al. 1997), assisted venous drainage (Rider et al. 1998), and other reasons like spontaneous gas bubbling in microporous oxygenators (Karichev et al. 1999) were identified as possible sources for such gaseous microemboli. Despite several technical improvements, e.g. introduction of modern microporous oxygenators or insertion of arterial filters into the arterial line of extracorporeal circulation (ECC), the presence of microbubbles still remains an important issue in extracorporeal perfusion systems. Recently, a new method using a dynamic bubble trap (DBT) in the arterial line of ECC was also introduced (Taborski et al. 2003). This method is based on biophysics of blood flow through the arterial line of ECC. A tubular DBT consists of a 3/8-inch inlet, a tube with a 3/8 outlet, a site for collecting microbubbles and diffuser chamber. A three-channel spiral is integrated into the diffuser chamber. As blood passes through the spiral, it is converted into a rotating stream. The shape of the diffuser chamber causes the centrifugal forces to direct air microbubbles to the centre of the flow line. After the blood passes through the tube, the process stabilizes with the largest proportion of bubbles being now in the central blood flow line. The collection site situated in the centre of the distal end of the tube diverts the central blood flow line with the majority of microbubbles and returns it to the cardiotomy reservoir. The special hydrodynamic characteristics of the diffuser allow a constant diversion of flow at 400–450 ml/min. As recently reported, the DBT was able to significantly reduce the number of air microbubbles entering the circulation of the patients and was shown to be advantageous for the postoperative outcome of patients undergoing coronary artery bypass surgery. However, it is clear that the majority of air embolic events happen during the open chamber interventions. Therefore, we aimed to investigate whether the use of DBT is of additional advantage also for this group of patients.

Materials and Methods

A total of 41 patients undergoing an aortic valve replacement were recruited for a prospective randomized double blind study. In group I (GI, $n = 22$), a DBT was introduced into the arterial line of ECC system between a common 40 μm arterial filter and the aortic cannula. In group II (GII, $n = 19$), a placebo-DBT was used and placed in the same position. Exclusion criteria were: age more than 75 years, combined procedures, ejection fraction less than 35 %, severe arteriosclerosis of the carotid arteries, severe lung, renal or cerebral diseases, drug or alcohol abuse, insulin dependent diabetes mellitus, emergencies and early postoperative complications requiring prolonged respiratory support and sedation. The investigation interval was 15 months. The protocol was approved by the state ethics Committee. All participating patients gave signed informed consent.

Transcranial Doppler sonography

A bilateral transcranial detection of high intensity transient signals (HITS) within the proximal middle cerebral artery was performed continuously from beginning to end of CPB with a 2-MHz pulse-wave Neuroguard-Plus transcranial Doppler system (Medasonics Inc., Fremont, CA, USA) as described previously (Marcus 1993; Laas et al. 2003; Schoenburg et al. 2003). The recording time was determined by the duration of ECC and divided into two periods: period 1 (P1) – start of ECC until aortic clamp removal, period 2 (P2) – clamp removal until the end of ECC.

Arterial line embolus detection

A two-channel Doppler ultrasonography device UBC (Convergenza, Vaduz, Liechtenstein) was used to detect microbubbles before and after the DBT. The device counts microbubbles ranging from 10 to 120 μm (Jenderka et al. 1998; Urbanek and Tiedtke 2002). Solid microparticle emboli do not influence the count result.

Dynamic bubble trap

The DBT (HPmedica, Augsburg, Germany) was placed in the arterial line between the arterial filter and arterial cannula. In the placebo group, a DBT without the helix, but with collection site and recirculation line in order to ensure the blindness of the study for the investigators, was analogically utilized.

Bypass technique

The DBT or placebo-DBT was integrated into a standard ECC tubing set (HMT Medizintechnik, Fürstenfeldbruck, Germany) containing a 40 μm heparin-coated arterial line filter AF 1040 Gold (Baxter, Irvine, CA, USA). Extracorporeal perfusion was performed with a roller pump (Stoeckert Instrumente, Munich, Germany) and a hollow fiber-membrane oxygenator with hard-shell venous reservoir (Biocor 200 IHS, Minntech Corp. Minneapolis, USA) at a nonpulsatile flow rate of 2.4 $\mathrm{l \cdot min^{-1} \cdot m^{-2}}$.

Statistical analysis

Statistical analysis was performed with the Program R, version 1.9.1. (Free Software Foundation). All values are expressed as mean $\pm$ standard deviation. Statistical significance regarding the differences between groups, defined as $p < 0.05$, was determined with a two sample Student's t-test.

Results

Overall 33 men and 8 women were included in both groups. According to our study design and exclusion criteria, one male patient of GI was excluded from the study because of not planned mitral valve repair and one female patient of GII was excluded because of prolonged cardiac arrest. Postoperative records of all patients were uncomplicated and comparable. They were extubated within 12 h and left intensive care unit (ICU) after approximately 1 day (mean stay on ICU was 1.45 days). Standard neurological examination of all patients on the second and third postoperative day confirmed normal neurological status. The biometric data concerning gender and key body figures did not differ statistically between the groups (Table 1).

ECC duration and length of P1 and P2 were in both groups almost identical with no statistically significant differences between both groups (Table 2). Similarly, the difference in microbubble counts before placebo-DBT and DBT did not reached statistical significance (Table 3).

As our measurements reveal, most of the microbubbles in the arterial line

Table 1. Biometric data and key body figures

Enrollment criteria	GI – DBT		GII – placebo-DBT	
	Mean	SD	Mean	SD
Age	59.00	11.31	57.89	11.02
Weight (kg)	84.45	11.61	79.33	17.32
BSA (m^2)	1.98	0.17	1.90	0.23
ECC time (min)	67.40	19.19	66.33	11.91
Cross-clamp (min)	50.40	16.46	50.33	11.43
Hbg before ECC (g/l)	127.10	11.97	127.33	13.23
Hbg ECC (g/l)	74.10	9.22	72.17	9.27
Bodytemp. (℃)	27.46	0.64	27.21	0.67
Flow ECC (l/min)	4.72	0.38	4.55	0.54

DBT, dynamic bubble trap; SD, standard deviation; BSA, body surface area; Hbg, hemoglobin; ECC, extracorporal circulation; Bodytemp., mixed venous blood temperature after aortic crossclamping; Flow ECC, mean flow of extracorporal circulation.

Table 2. ECC, periods P1 and P2 duration

Surgery time	GI – DBT		GII – placebo-DBT		p
	Mean	SD	Mean	SD	
ECC time	67.4	19.2	66.3	11.9	0.4424
Aorta closed – P1	50.4	16.5	50.3	11.4	0.4959
Aorta reopened – P2	17.0	2.7	16.0	3.6	0.2682

Table 3. Microbubble counts before DBT and placebo-DBT

Before DBT and placebo-DBT	GI – DBT		GII – placebo-DBT		p
	Mean	SD	Mean	SD	
During ECC time	15.594	8.603	12372	10299	0.1639
During aorta closed – P1	13.376	7.365	11188	9726	0.2311
During aorta opened – P2	2.218	1.238	1184	573	0.0732

Table 4. Microbubble counts after DBT

GI – DBT	Before DBT		After DBT		p
	Mean	SD	Mean	SD	
During ECC time	15.594	8.603	4.875	3.539	<0.0001
During aorta closed – P1	13.376	7.365	4.381	3.317	<0.0001
During aorta opened – P2	2.218	1.238	494	222	0.0025

Table 5. Number of high intensive transient signals (HITS) in the right and left middle cerebral artery

HITS left	GI – DBT		GII – placebo-DBT		p
	Mean	SD	Mean	SD	
During ECC time	269	181	283	158	0.4481
During aorta closed – P1	36	28	96	80	0.0020
During aorta opened – P2	233	153	187	78	0.4461

HITS right	GI – DBT		GII – placebo-DBT		p
	Mean	SD	Mean	SD	
During ECC time	248	206	315	195	0.1637
During aorta closed – P1	35	32	109	110	0.0051
During aorta opened – P2	213	174	206	85	0.1586

before DBT and before placebo-DBT were counted during P1 (13376 in GI, 11188 in GII). In contrast, in P2, representing 25% of the total CPB time, only a low percentage (14% GI, 10% GII) of the total amount of microbubbles were observed (2218 in GI, 1184 in GII; Table 3). A significant reduction of microbubbles after DBT was observed in P1, P2 as well as during the complete duration of ECC ($p < 0.0001$, $p < 0.0025$, and $p < 0.0001$, respectively; Table 4).

In P1, the numbers of HITS detected in the left and right middle cerebral artery in GI were significantly lower than those detected in GII (36 *vs.* 96 in the left, $p < 0.002$; and 35 *vs.* 109 in the right, $p < 0.005$; Table 5). However, the vast majority of HITS was detected in P2 with no statistically significant differences between the DBT and the placebo group ($p < 0.4461$ in the left, $p < 0.1586$ in the right middle cerebral artery; Table 5).

Discussion

The occurrence of air microbubbles in the arterial line of extracorporeal perfusion systems with its subsequent infusion into the patient's circulation is believed to be one of the culprits for psycho-neurological dysfunction of the patients undergoing CPB-assisted surgical procedures. Various components of the ECC circuits are currently being used for the elimination of microbubbles. Cardiotomy and venous reservoirs with their built-in filter components, as well as additional arterial filters in the arterial line, together with the air trapping ability of membrane oxygenators were proofed to have significant impact on the bubble removal from ECC circuits (Mitchell et al. 1996, 1997; Mueller et al. 1998; Padayachee et al. 1998). However, despite these technical improvements, the presence of microbubbles still remains an important issue in extracorporeal perfusion systems. Therefore, based on the hydrodynamic characteristics of the blood flow in the arterial line we used an additional DBT in order to increase the efficacy of bubble removal. Since the majority of air embolic events occur during an open chamber intervention, we aimed to evaluate the potentially advantageous effect of bubble load reduction in patients undergoing aortic valve replacement.

For this purpose, 41 patients undergoing aortic valve replacement were randomly divided into two groups – GI, and GII. In GI, a DBT was introduced into the arterial line of ECC system between a common 40 μm arterial filter and the aortic cannula. In GII, a placebo-DBT was used and placed in the same position. We measured the number of microbubbles before and after DBT, and before and after placebo-DBT, respectively. Additionally, we measured the numbers of HITS as a reflection of gaseous microemboli in the cerebral circulation of the patients. The total recording time was determined by the duration of ECC and divided into two periods: P1 and P2.

During the P1 all blood passes through the DBT. As revealed by our measurements, the microbubble load of patients was strongly reduced in patients with DBT compared to patients with placebo-DBT. Consequently, the decrease in the amount microbubbles was mirrored by high reduction of HITS in GI in comparison to GII. However, most HITS, approximately two third of the total count, were detected during P2. In this period we did not find anymore statistically significant differences between both groups. In contrast to P1, in this period the cross-clamp is removed and the heart starts to work in parallel to the CPB. The trapped air in the left chamber can now go straight to the supraaortal vessels without passing through the CPB. Consequently, these gaseous microemboli cannot be scavenged by the DBT and are registered as HITS in the brain. Therefore, the use of DBT in patients undergoing aortic valve replacement cannot substitute careful venting after aorta declamping. Nevertheless, the substantial reduction of microbubbles and thereby reduction of the number of HITS in the cross-clamped period of cardiopulmonary bypass time appears to justify the use of DBT in this group of patients.

In conclusion, we believe that DBT possess the potential to combat at least partially the detrimental effects of gaseous microembolism on the postoperative psycho-neurological outcome of patients after valve replacement procedures. However, further studies, including the postoperative mid-term follow-up with evaluation of the psycho-neurological status, are needed to finally confirm the benefit of this low-cost biophysical method for the patients undergoing open chamber surgical interventions.

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