INTRAOPERATIVE TRANSCRANIAL DOPPLER ULTRASONOGRAPHY MONITORING OF CEREBRAL BLOOD FLOW DURING CORONARY ARTERY BYPASS GRAFTING

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SUMMARY – Perioperative neurologic events in heart surgery are the most devastating complications. Brain is the only organ not routinely monitored by any direct method during the administration of anesthesia. Brain monitoring with transcranial Doppler is of particular value when the brain is at risk of cerebral hyper- or hypoperfusion, gaseous or particulate embolization, or their combined effects. The main aim of this study was to assess cerebral blood flow differences and patterns during off-pump *versus* on-pump coronary artery bypass grafting (CABG). This prospective study was performed using transcranial Doppler ultrasonography (TCD) monitoring in 30 patients aged 39-81 undergoing elective coronary bypass surgery with or without cardiopulmonary bypass: 15 patients undergoing off-pump and on-pump CABG each. The two groups did not differ according to age, sex, risk factors, cerebrovascular disease, comorbid disease and NYHA class. Study results clearly demonstrated significant differences in blood flow velocity between off-pump and on-pump procedures (P=0.0001). The duration of hypoperfusion was longer in on-pump group, whereas shorter periods of more profound hypoperfusion were observed in off-pump group. Brain monitoring with TCD during CABG proved to be a useful tool to detect cerebral hypotension as it provided unique information on cerebral perfusion. Such monitoring may improve the safety of surgical procedures, allowing for hemodynamic interventions to perform rationally and without interruption of surgical procedure.

Key words: *Coronary artery bypass, off-pump; Cardiopulmonary bypass; Ultrasonography, Doppler, transcranial; Monitoring, intraoperative – methods*

Introduction

Coronary artery bypass surgery (CABG) with cardiopulmonary bypass (CPB) carries a significant risk of perioperative brain injury. At least 1% to 5% will suffer a stroke, and at 3 months postoperatively approximately 30% are reported to have cognitive impairment assessed by neuropsyhological testing. In off-pump surgery, CPB is not used and instrumentation on the ascending aorta is reduced[1,2]. The cerebral blood flow pattern may be severely changed during both on-pump and off-pump surgery. During CPB, cerebral perfusion is nonpulsatile with delivery of a fixed flow rate by the artificial bypass pump. Nonpulsatile cerebral perfusion may lead to diffuse brain edema, which may be avoided by using the off-pump technique where cerebral perfusion is pulsatile[3]. Theoretically, the normal pulsatile cerebral flow pattern present during off-pump surgery should be advantageous for the brain. In off-pump surgery, however, manual cardiac manipulation during the grafting

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stages causes intermittent reductions in cardiac output and cerebral perfusion pressure with the risk of significant cerebral hypoxia[4].

Caplan and Hennerici have also suggested that cerebral microemboli may be potentially more dangerous when cerebral perfusion pressure is too low to wash microemboli through the microvasculature[5]. Therefore, it is possible that sudden reduction and continuous variations in cerebral perfusion pressure and cerebral oxygenation during off-pump surgery may at least partly explain why similar cognitive outcomes may be found after off-pump and on-pump surgery.

Intraoperative cerebral microembolization is not the only pathophysiological factor, which may be implicated as a cause of brain injury during cardiac surgery. Combined events may impact the brain to varying degrees, ranging from temporary confusion states to stroke, from which meaningful recovery may be impossible.

In addition to interventions to maintain balance between oxygen demand and supply, we frequently rely on intermittent hypotensive anesthesia while performing distal and proximal coronary anastomoses. Hypotension may lead to inadequate oxygen supply to the brain, so brain monitoring becomes mandatory[6].

The main aim of this study was to assess cerebral blood flow differences and patterns when performing CAPG off-pump and on-pump. For this purpose, transcranial Doppler ultrasonography (TCD) was used during on-pump and off-pump surgery in order to assess blood flow changes as well as the occurrence of carotid plaque changes and the signs of cerebral microembolization. Cerebral microemboli (High Intensive Transient Signal, HITS) were identified online by a single observer and the time of occurrence was noted by direct observation of various stages of the operation.

Patients and Methods

Patient population

This prospective study was performed using TCD monitoring in 30 patients aged 39-81 undergoing elective coronary bypass surgery with or without extracorporeal circulation. Only patients undergoing their first cardiac revascularization were included. Fifteen patients were undergoing off-pump and on-pump CABG each. The selection criteria for patients undergoing either of the two treatments were not predefined. The two groups did not differ according to age, sex, risk factors, cerebrovascular disease, comorbid disease and NYHA class (Table 1).

Transcranial Doppler technique

Blood flow velocity in basal cerebral arteries was monitored using Translink 8000 Rimed ultrasonic device with 2 MHz probes that were placed on temporal acoustic window for intraoperative recording of blood flow in middle cerebral artery (MCA) (Fig. 1). Prior to operation, mean flow velocity (MFV) was evaluated in all basal arteries (TCD evaluation). Intraoperative cerebral flow monitoring was, however, performed in the initial segment (M1) of MCA at a depth of 55 to 60 mm from the temporal bone, considering the normal values of MFV in MCA of 62±12 cm/s[7] cerebral flow. In most cases, manual fixation of the probe onto the temporal acoustic window was required, thus already slight head movement could cause the optimal signal loss despite fixation of the probes in the special head band. Due to the need of anesthe-

Table 1. Sex (M = male; F = female) and age distribution of patient population

Patient No.	Sex	On-pump	Off-pump
		Age (yrs)	Age (yrs)
1	M	54	77
2	M	81	57
3	M	73	65
4	M	78	67
5	M	66	70
6	M	73	70
7	M	63	64
8	M	39	56
9	M	51	68
10	M	62	72
11	F	75	73
12	F	63	49
13	F	55	67
14	F	73	58
15	F	63	65
x_{mean} ± SD		64.6±11.4	65.2±7.4

siologic access on the right side of the patient, cerebral flow was followed on the left side. TCD monitoring was continuously performed from incision of the pericardium until chest wall closing.

Cerebral microemboli (HITS) were identified online by a single observer and the time of occurrence was noted by direct observation in various stages of the operation. Preoperative 3D ultrasonography monitoring of plaque structure in carotid bifurcation and in the initial segment of internal carotid artery (ACI) was performed. All patients had varying degrees of carotid artery atherosclerosis but there was no reduction in artery diameter of 50% or more.

Surgical technique

Surgery was performed in balanced anesthesia with opiates and barbiturates together with inhalation anesthesia and propofol at the end of the operation. Sternotomy was performed in all patients.

In the off-pump group, heparin (1 mg/kg body weight) was administered after left internal thoracic artery mobilization. Activated coagulation time was maintained above 250 seconds. Distal anastomoses were performed with the use of Octopus stabilizers and intraluminal shunts (Medtronic Inc., Minneapolis, MN, USA). Partial aortic clamp was used for proximal anastomoses.

In the on-pump group, CABG was performed using standard CPB technique with mild hypothermia. Heparin (3 mg/kg body weight) was administered before the onset of CPB. Cardiac arrest and myocardial protection were achieved with both antegrade and retrograde cold blood potassium cardioplegia. On pump CABG was performed with a roller pump System 1 Heart-Lung Machine, Terumo and Capiox RX25 Hollow Fiber Oxygenator, Terumo.

Flow rates were maintained at 1.9-2.4 L/min/m^2, with a minimum mean perfusion pressure of 60 mm Hg. Proximal anastomoses were sewn on arrested heart with aortic cross clamp.

Neuropsychological tests

Patients were assessed with neuropsychological tests 1 day before surgery, then on days 7-15 and 1 month postoperatively.

Statistics

Fisher's exact test for the analysis of variance and Student's t-test were used on statistical analysis of differences in measurement results between two patient groups. The level of statistical significance was set at $P \leq 0.01$.

Results

Typical intraoperative TCD measurements are presented in Figures 1 to 3. Figure 1 illustrates the appearance of TCD MCAV during cardiopulmonary bypass. The left panel of the figure depicts typical nonvarying TCD spectrum. HITS and velocity falls associated with declamping aortic cross clamp are shown in the central part of the spectrum.

The normal appearance of TCD flow velocity spectrum during off-pump CABG just before declamping aortic partial occlusion clamp is presented in Figure 2. Because of their large acoustic impedance, the emboli produce HITS on TCD display, here seen as an intense white spot on the right side of the spectrum display. HITS occurred immediately after the release of aortic partial occlusion clamp.

Marked hypoperfusion on manipulation and cardiac verticalization during off-pump CABG is illustrated in the left part of Figure 3. Restoration and normal appearance of TCD flow velocity spectrum upon stabilizing the heart in proper position are seen in the right part of the scan.

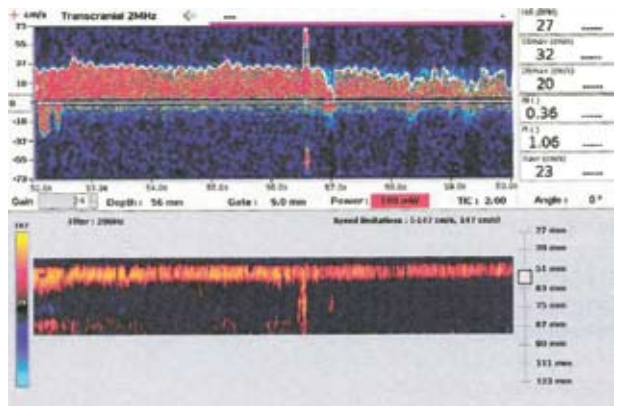

Fig. 1. Transcranial Doppler middle cerebral artery blood flow velocity (MCAV) during cardiopulmonary bypass. Hypoperfusion (mean flow velocity below 23 cm/s) and one High Intensive Transient Signal (HITS) after declamping cross clamp of aorta.

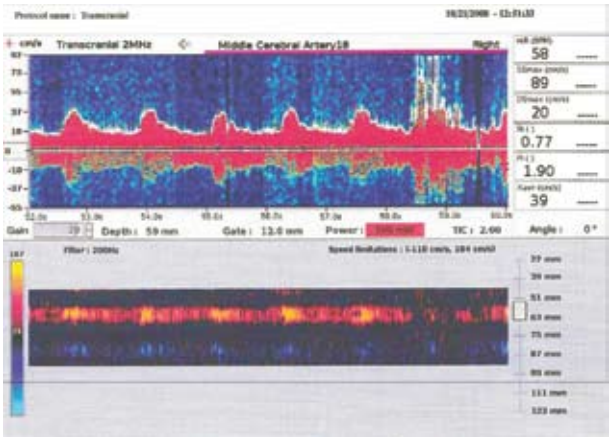

Fig. 2. Transcranial Doppler middle cerebral artery blood flow velocity (MCAV) during off-pump coronary artery bypass grafting (OPCABG): High Intensive Transient Signals (HITS) after release of partial aortic clamp.

Table 2 shows results on the length of hypoperfusion during on-pump and off-pump CABG, monitored by TCD. The mean numbers of bypasses and their variances were equal in the two groups (P=0.03 and P=0.63, respectively). In the on-pump group, hypoperfusion was recorded in 9 of 15 patients, whereas it did not occur in 6 cases. In this group, hypoperfusion lower than 27 cm/s lasted for 4-49 minutes.

In the off-pump group, hypoperfusion with the mean flow velocity of 5-10 cm/s was recorded in all 15 patients and lasted for less than 1 minute. There was significant difference in the mean duration of hypoperfusion between on-pump and off-pump groups (P=0.0001).

There was no mortality. One ischemic stroke occurred in the on-pump group with permanent left side hemiparesis. There were no cerebrovascular accidents in the off-pump group.

Considerably more HITS were observed in the on-pump group, distributed from the start to the end of CPB showing highest rate during clamping and removal of aortic cross clamp. In the off-pump group, HITS were only detected (depending exclusively) during side aortic clamp removal.

Discussion

Coronary artery bypass grafting is the most frequently performed surgical procedure in the Western world. Despite evolving technologies, morbidity still occurs, where adverse neurologic outcomes are most devastating[8].

Stroke or other neuropsychological deficits in CABG patients can result from a multitude of individual or combined factors: cerebral hyper- or hypoperfusion, micro- and macroembolization (gaseous, lipoid, atheromatous, or thrombotic), preexisting intracranial or extracranial cerebrovascular disease with compromised autoregulation, ineffective collateral intracranial circulation, compromised intracranial reserve, inhomogeneous cooling and warming of the brain, or catastrophic events such as cardiac arrest, hemor-

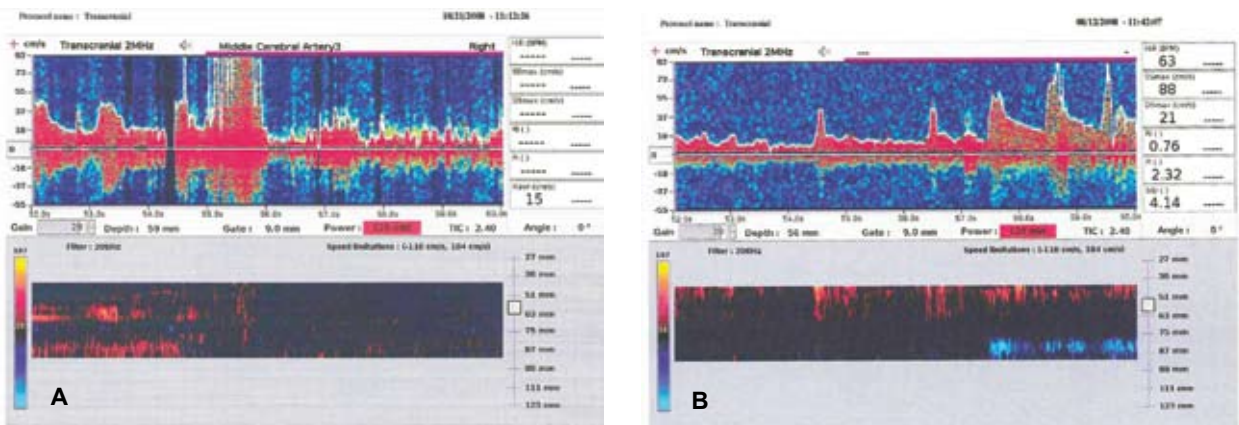

Fig. 3. Transcranial Doppler middle cerebral artery blood flow velocity (MCAV) during off-pump coronary artery bypass grafting (OPCABG): (A) temporary cessation of blood flow during lifting and manipulation of the heart; (B) restoration of blood flow after stabilization of the heart.

Table 2. Results of intraoperative TCD monitoring of mean flow velocity and duration of hypoperfusion in on-pump and off-pump patient groups

Hypoperfusion	On-pump			Off-pump		
Mean flow velocity (cm/s)	Sex (M/F)	Bypass (n)	Duration (min)	Sex (M/F)	Bypass (n)	Duration (min)
20-27	M	3	4			
	M	3	49			
	F	3	13			
15-20	M	4	14			
	M	2	18			
10-15	M	5	32			
	F	4	3			
	F	3	17			
5-10	M	3	2	M	4	0.3
				M	3	0.3
				M	2	0.3
				F	3	0.3
				F	2	0.3
				M	1	0.5
				M	3	0.6
				F	3	0.6
				M	3	0.9
				F	3	0.9
				F	2	0.9
0-5				M	2	0.1
				M	2	0.2
				F	3	0.3
				M	2	0.5
n		9	9		15	15
x_{mean} ± SD		3.3±0.87	16.9±15.3		2.6±0.8	0.5±0.3

rhage or massive air embolism. One factor in common to the study and understanding these mechanisms of injury is cerebral blood flow[9,10]. During operation, anesthesiologists rely primarily on indirect physiologic evidence provided by blood pressure, peripheral pulse oximetry, heart rate and respiratory and anesthetic gas concentrations to determine that brain blood flow and oxygenation are adequate[9]. In such conditions, TCD is a useful tool to detect cerebral hypotension.

Some studies showed significantly lower incidence of neurologic complications compared to the impact of high mean arterial pressure (80 to 100 mm Hg) *versus* low mean arterial pressure (50 to 60 mm Hg) during CPB[11].

Our study clearly demonstrated significant differences in blood flow velocity during off-pump compared with on-pump CABG. The duration of hypoperfusion was more pronounced in the on-pump group, whereas short periods of profound hypoperfusion mainly dependent on lifting and manipulation of the heart were observed in the off-pump group.

One ischemic stroke occurred in the on-pump group with permanent left side hemiparesis. There were no cerebrovascular accidents in the off-pump group; however, the difference did not reach statistical significance.

We also observed by far more HITS in the on-pump group, distributed from the start to the end of

CPB, showing highest rate during clamping and removal of aortic cross clamp. In the off-pump group, HITS were only detected (depending exclusively) during side aortic clamp removal.

Multiple studies with TCD have suggested higher rates of cerebral embolization in CPB patients than in OPCAB patients[10-13]. Most studies investigating neurocognitive functions showed a slightly more pronounced decline among CPB patients relative to OPCAB patients in the short term (2 to 3 months) but failed to show significant differences after 1 year[14-16]. The authors presumed the composition of embolic materials to be important, but also considered several alternative mechanisms through which patients undergoing off-pump surgery may still be at risk of brain injury.

Cardiopulmonary bypass seems to be a major cause of both intraoperative microemboli and cerebral hypoperfusion[10]. Our findings are consistent with a large number of similar studies demonstrating that changes in flow velocity and pulsatility play an important role in postoperative neurologic outcome[3,11,19].

However, the number of patients included in the present study was rather small to draw any definite conclusions on neuropsychological functions in these patients. Despite changes in the cerebral blood flow pattern, difference between the two surgical methods with regard to postoperative neurologic outcome could not be definitely assessed in this patient population.

Conclusive evaluation of neurocognitive functions in both patient groups would require larger studies with a higher number of patients included. Only large, prospective multicenter randomized trials will help elucidate the controversial genesis of neurologic complications secondary to CABG procedures.

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Sažetak

INTRAOPERACIJSKO PRAĆENJE MOŽDANOG PROTOKA KRVI TRANSKRANIJSKIM DOPPLEROM TIJEKOM UGRADNJE PREMOSNICE KORONARNE ARTERIJE

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Perioperacijski neurološki događaji su u srčanoj kirurgiji najrazornije komplikacije. Mozak je jedini organ koji se ne prati rutinski izravnom metodom za vrijeme anestezije. Praćenje mozga transkranijskim Dopplerom (TCD) je od osobite važnosti kad je mozak ugrožen od povećane ili smanjene prokrvljenosti, embolizacije česticama ili zrakom ili od njihovih kombiniranih učinaka. Glavni cilj ove studije bio je procijeniti razlike protoka krvi u mozgu kad se pri izvođenju koronarne premosnice upotrebljava stroj za izvantjelesnu cirkulaciju u usporedbi sa zahvatom bez njega. Ova prospektivna studija provedena je uz primjenu TCD kod 30 bolesnika podvrgnutih planskoj operaciji koronarnih premosnica uz uporabu stroja za izvantjelesnu cirkulaciju ili bez njega. Po 15 bolesnika u dobi od 39 do 81 godine operirano je pomoću stroja za izvantjelesnu cirkulaciju i bez njega. Dvije skupine se nisu razlikovale u odnosu na dob, spol, rizične čimbenike, cerebrovaskularne bolesti, pridružene bolesti i klasifikaciju NYHA. Naša studija je jasno pokazala kako postoje znatne razlike u brzini protoka krvi za vrijeme upotrebe stroja za izvantjelesnu cirkulaciju u usporedbi sa zahvatom bez njega (P=0,0001). Trajanje smanjene prokrvljenosti bilo je istaknutije kod skupine s upotrebom stroja za izvantjelesnu cirkulaciju. U skupini bez upotrebe stroja za izvantjelesnu cirkulaciju opažena su kraća, ali izrazitija razdoblja smanjene prokrvljenosti. Praćenje rada mozga pomoću TCD za vrijeme operacije koronarne premosnice dokazano je kao korisna metoda za otkrivanje moždane hipotenzije, jer daje jedinstvene informacije o prokrvljenosti mozga. Takvo praćenje bi moglo voditi ka sigurnijoj kirurgiji, dozvoljavajući da se hemodinamični zahvati izvode racionalno i bez prekida kirurške intervencije.

Ključne riječi: *Premoštenje koronarne arterije (Aortokoronarno premoštenje); Izvantjelesna cirkulacija; Ultrasonografija, Dopplerova, transkranijska; Praćenje, intraoperacijsko – metode*