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CASE REPORT

Detection of cerebral hypoperfusion with bispectral index during paediatric cardiac surgery

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Background. The bispectral index (BIS) may indicate changes in cerebral activity when the cerebral circulation is affected by acute hypotension.

Methods. We measured BIS and cerebral haemoglobin saturation (Sr_{O_2}) by near-infrared spectroscopy in 10 children undergoing cardiac surgery.

Results. We noted 14 episodes of simultaneous decreases in Sr_{O_2} and BIS during acute hypotension in five children. An acute decrease in BIS, which coincided with a decrease in Sr_{O_2} suggesting a reduction in cerebral blood flow, was associated with acute slowing of the raw EEG waveforms.

Conclusions. Our findings suggest that an acute decrease in BIS during acute hypotension indicates cerebral hypoperfusion, and that cerebral hypoperfusion caused by hypotension may occur frequently during paediatric cardiac surgery.

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Recent studies show that the bispectral index (BIS) is a useful monitor of hypnotic state during general anaesthesia in adults[1] and also in children.[2–4] We have measured BIS in children undergoing non-complex cardiac surgery, whose tracheas were to be extubated immediately after surgery and in whom intraoperative awareness was of some concern. We report our initial experience with BIS monitoring in the first 10 children.

Case reports

After institutional approval and informed consent, we applied BIS monitoring (A-1050, Aspect Medical Systems, Natick, MA, USA) to 10 consecutive children aged 2–11 yr undergoing corrective surgery for non-cyanotic heart disease (Table 1). We also measured regional cerebral haemoglobin oxygen saturation (Sr_{O_2}) by near-infrared spectroscopy (NIRS) (PSA-3N, Biomedical Science, Kanazawa, Japan). Anaesthesia was maintained with sevoflurane in oxygen-enriched air and intermittent doses of fentanyl and midazolam (Table 1). The priming solution for the cardiopulmonary bypass (CPB) circuit consisted of balanced salt solution with the addition of mannitol and albumin. Blood was not added to the system. Mild or moderate hypothermia was induced during CPB. After surgical correction, dobutamine and dopamine were infused i.v. to facilitate weaning from CPB.

In five children aged 3 yr or less, and not in five children older than 3 yr, we noted unusual decreases in BIS as follows (Table 1).

Case 4: at the start of, during and immediately after CPB, four episodes when Sr_{O_2} and BIS decreased at the same time during acute hypotension (Fig. 1);

Case 5: before CPB, two episodes when Sr_{O_2} and BIS decreased at the same time as blood pressure decreased (Fig. 2);

Case 6: at the start of CPB, both Sr_{O_2} and BIS decreased acutely with hypotension (Fig. 3);

Case 7: at the start of and during CPB, three episodes of acute reduction in both Sr_{O_2} and BIS immediately after acute hypotension (Fig. 4);

Table 1 Patient details and episodes of changes in BIS and Sr_{O_2} in 10 children.

Case	Age (yr)	Sex	Weight (kg)	Diagnosis	Operation time (min)	Anaesthetic agents used for		Cerebral hypoperfusion associated with acute hypotension
						Induction	Maintenance (including CPB)	
1	5	F	13.2	VSD	180	GOS	S 1.0–3.0%, M 8 mg, F 200 μg	No
2	6	M	23.0	ASD	130	T + S	S 1.0–5.0%, M 12 mg, F 140 μg	No
3	7	F	21.8	ASD	155	T + S	S 0.8–3.0%, M 4 mg, F 260 μg	No
4	2	F	8.4	VSD	195	GOS	S 0.5–2.0%, M 4 mg, F 200 μg	Yes (4 times)
5	3	M	12.4	ASD	180	GOS	S 0.5–3.0%, M 5 mg, F 200 μg	Yes (2 times)
6	3	M	13.8	PS	190	T + S	S 1.0–3.0%, M 7 mg, F 180 μg	Yes (1 time)
7	3	F	15.0	ASD	120	GOS	S 1.0–3.0%, M 8 mg, F 200 μg	Yes (3 times)
8	11	M	35.4	ASD	158	T + S	S 1.0–3.0%, M 7 mg, F 350 μg	No
9	6	M	22.8	VSD	180	GOS	S 1.0–5.0%, M 5 mg, F 300 μg	No
10	2	F	9.2	VSD	225	T + S	S 1.0–2.0%, M 7 mg, F 200 μg	Yes (4 times)

VSD = ventricular septal defect; ASD = atrial septal defect; PS = pulmonary stenosis; GOS = slow induction with sevoflurane in nitrous oxide; T + S = rapid induction with thiopental and sevoflurane; S = sevoflurane; M = midazolam; F = fentanyl; CPB = cardiopulmonary bypass.

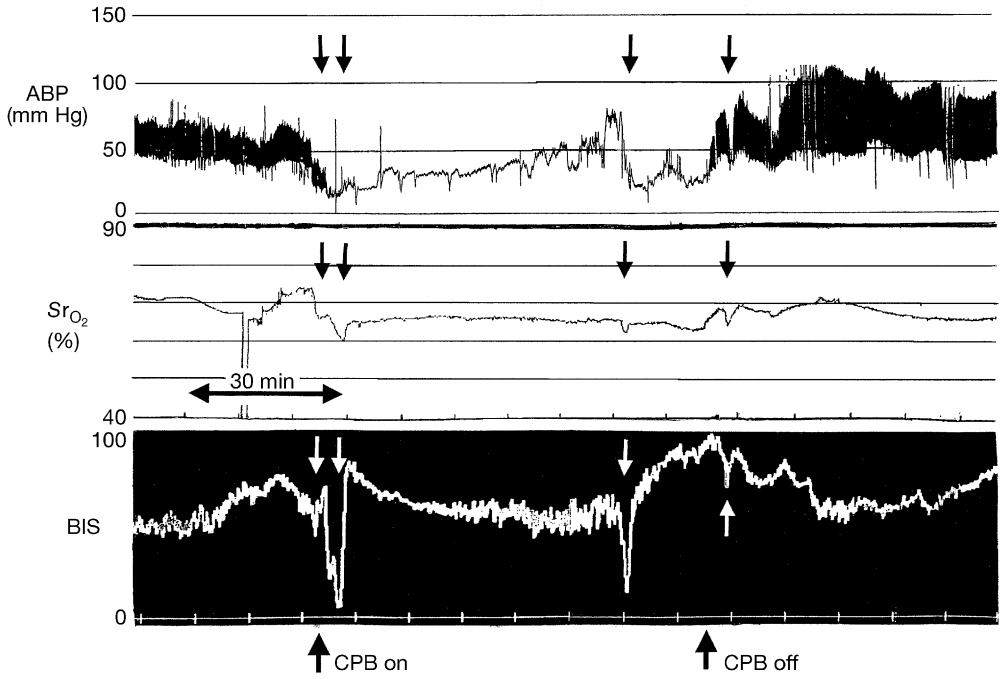

Fig 1 Arterial blood pressure (ABP), cerebral regional oxygen saturation (Sr_{O_2}), and bispectral index (BIS) in a 2-yr-old girl undergoing patch closure of a ventricular septal defect (Case 4). Cerebral hypoperfusion is indicated by arrows. CPB, cardiopulmonary bypass.

Case 10: at the beginning of and during CPB, four episodes of acute reduction in Sr_{O_2} and BIS at the same time as hypotension (Fig. 5).

Acute decreases in BIS were associated with acute slowing of the raw EEG frequency (Figs 4 and 5). All episodes of simultaneous decreases in Sr_{O_2} and BIS were associated with clinically important acute hypotension. There was no change in anaesthetic administration at these times. Reductions in BIS lasted for no longer than 3 min even when arterial pressure did not return to a normal level (Figs 1 and 4). In five children aged 3 yr or less in whom decreases in BIS occurred at the same time as acute hypotension, Sr_{O_2} tended to change in parallel with changing arterial pressure throughout surgery (Figs 1–5). In five children older than 3 yr, a hypotension-induced decrease in BIS did not occur while Sr_{O_2} remained almost constant throughout surgery, although BIS decreased only slightly and transiently during acute hypotension. We did not find neurological deficits in any of the patients after surgery.

Discussion

We used BIS monitoring in children undergoing cardiac surgery to assess possible intraoperative awareness with our anaesthetic methods. We were struck by unusual decreases in BIS rather than increases in BIS that might suggest light anaesthesia.

In five of the 10 children, we found simultaneous acute decreases in Sr_{O_2} and BIS during acute hypotension. An acute decrease in Sr_{O_2} suggests an acute reduction in cerebral blood flow (CBF) or cerebral oxygen supply unless cerebral oxygen consumption changes acutely.[5] Acute

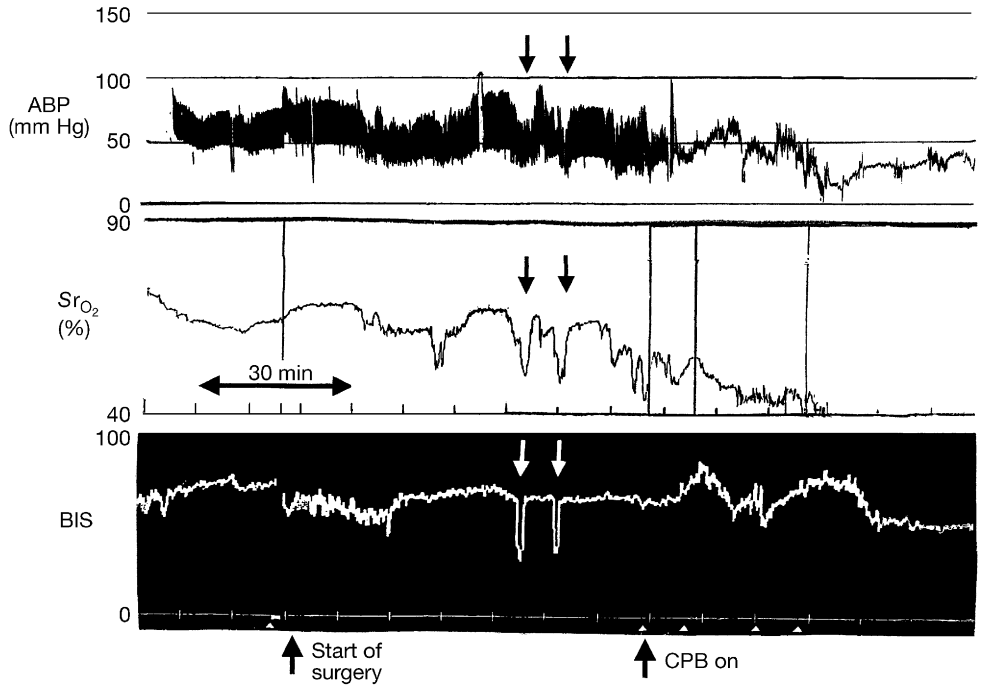

Fig 2 Arterial blood pressure (ABP), cerebral regional oxygen saturation (Sr_{O_2}), and the bispectral index (BIS) in a 3-yr-old boy undergoing direct closure of an atrial septal defect with transxiphoid approach (Case 5). Hypoperfusion is indicated by arrows. CPB, cardiopulmonary bypass.

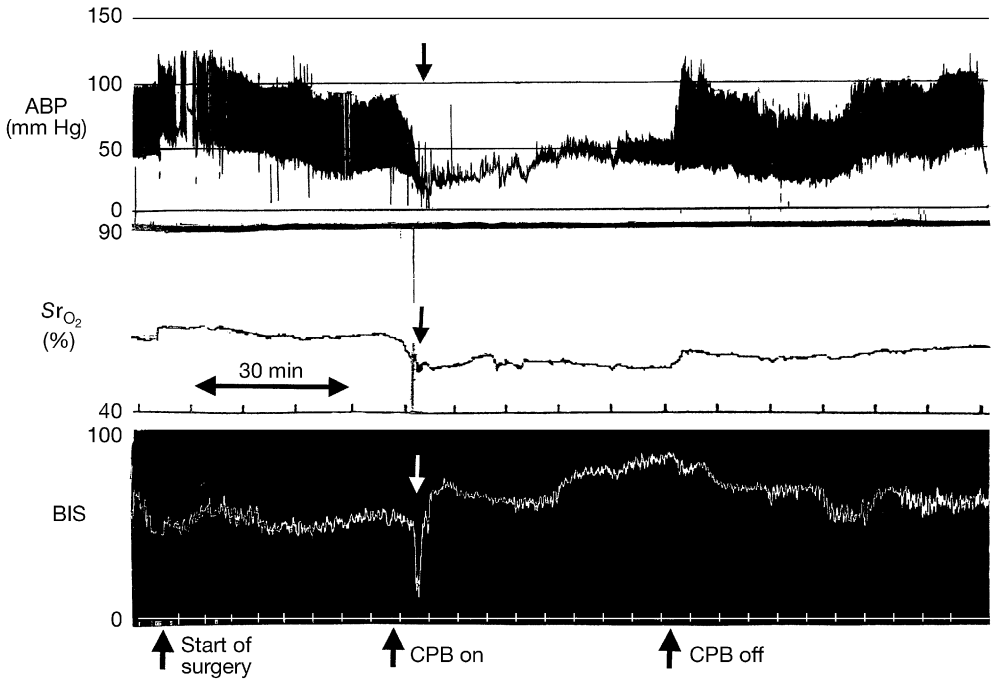

Fig 3 Arterial blood pressure (ABP), cerebral regional oxygen saturation (Sr_{O_2}), and the bispectral index (BIS) in a 3-yr-old boy undergoing plasty of the pulmonary valve (Case 6). Hypoperfusion is indicated by arrows. CPB, cardiopulmonary bypass.

decrease in BIS in our patients occurred with acute slowing of the EEG. The acute EEG slowing is a sign of cerebral hypoperfusion, and can be detected within seconds of severe hypotension, cardiac arrest or carotid occlusion using other processed EEG methods.[6–10] Our findings suggest that if a change in BIS is not drug induced, an acute decrease in BIS indicates cerebral hypoperfusion, particularly when it accompanies acute hypotension and a decrease in Sr_{O_2}.

A decrease in jugular venous haemoglobin saturation (Sj_{O_2}) to less than 50% is generally considered to indicate cerebral hypoperfusion.[11] Values of Sr_{O_2} remained above 60% in most of our patients, however, even when cerebral

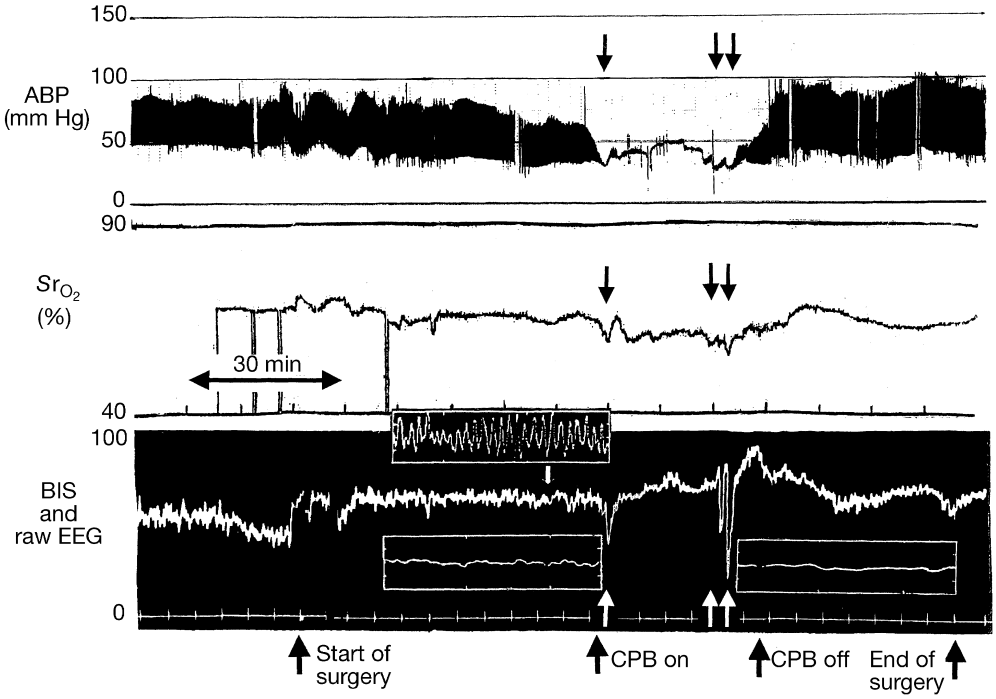

Fig 4 Arterial blood pressure (ABP), cerebral regional oxygen saturation (Sr_{O_2}), and the bispectral index (BIS) in a 3-yr-old girl undergoing direct closure of an atrial septal defect (Case 7). An acute decrease in BIS and acute slowing of the raw EEG waveform are seen. Hypoperfusion is indicated by arrows. CPB, cardiopulmonary bypass.

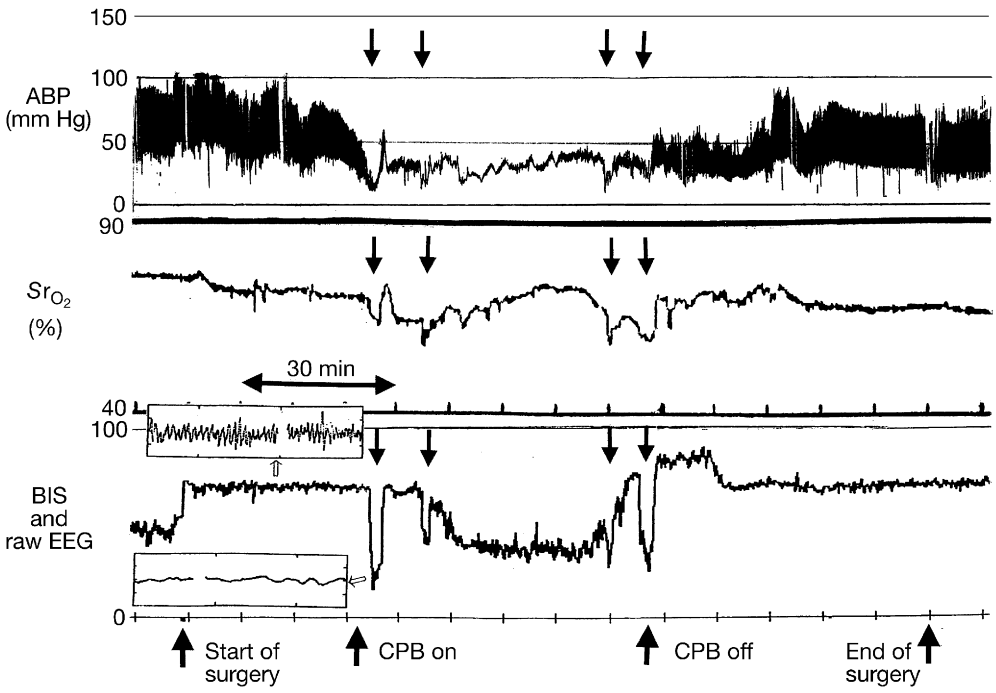

Fig 5 Arterial blood pressure (ABP), cerebral regional oxygen saturation (Sr_{O_2}), and the bispectral index (BIS) in a 3-yr-old girl undergoing patch closure of a ventricular septal defect (Case 10). An acute decrease in BIS and acute slowing of the raw EEG waveform are seen. Hypoperfusion is indicated by arrows. CPB, cardiopulmonary bypass.

hypoperfusion was indicated by acute EEG slowing or a decrease in BIS. The relatively high Sr_{O_2} values during cerebral hypoperfusion might result in part from the lack of calibration of the NIRS oximeter in children, since an absolute value of Sr_{O_2} can be obtained only after calibration based on some assumptions. The clinical value of an NIRS oximeter is thus limited to tracking trends of Sr_{O_2}.[12 13] In addition, Sr_{O_2} may remain higher than Sj_{O_2} because Sr_{O_2}

represents the weighted average of haemoglobin saturation of arterial, capillary and venous blood within a volume of tissue whereas Sj_{O_2} indicates venous haemoglobin saturation.[13 14] For example, even when Sj_{O_2} is 50%, Sr_{O_2} can be 62.5% if Sa_{O_2} is nearly 100%, assuming that blood in the cerebral vasculature is three-quarters in the venous bed and one-quarter in the arterial bed ($Sr_{O_2}=0.75\times Sj_{O_2}+0.25\times Sa_{O_2}$).[12] For these reasons, cerebral hypoxia may be present when the Sr_{O_2} value is relatively greater than the Sj_{O_2} value.

Cerebral hypoperfusion indicated by acute EEG slowing or an acute BIS reduction occurred most commonly at the start of CPB. Acute haemodilution might contribute to development of cerebral perfusion at this time point because of reduced arterial pressure and reduced oxygen carrying capacity associated with haemodilution. More directly, bloodless prime being flushed through the brain could decrease electrical activity at the onset of CPB.

Cerebral hypoperfusion caused by acute hypotension occurred often in the five children aged 3 yr or younger but not in the five older children. Only in the younger children did Sr_{O_2} change in parallel with changing arterial pressure throughout surgery, suggesting that CBF depended on arterial pressure in these younger children. Although data regarding the development of cerebral autoregulation in humans are lacking,[15] our findings suggest that cerebral autoregulation is immature during infancy. With an abrupt reduction in cerebral perfusion pressure, blood flow will decrease for a brief period (1–2 min) before autoregulation restores CBF.[16] The immature autoregulatory system may take more time to restore CBF, and thus a decrease in CBF that is long and severe enough to cause decreased cerebral electrical activity can occur more easily in younger children. Even in younger children, however, Sr_{O_2} tended to return towards a normal level, and decreases in BIS lasted no longer than 3 min, even when arterial pressure remained at a reduced level. Therefore, it was likely that cerebral autoregulation acted slowly to restore CBF and EEG during persistent hypotension in the younger children.

One case report described an acute profound reduction in BIS following hypovolaemic cardiac arrest during adult cardiac surgery.[17] We found that in children undergoing cardiac surgery, cerebral hypoperfusion can occur not only following severe haemodynamic changes such as cardiac arrest but also following less severe changes in arterial pressure such as hypotension at the onset of CPB.

We cannot determine the saturation level at which cerebral ischaemia will occur with an NIRS oximeter alone.[13 14] By combining Sr_{O_2} and BIS, we can establish if a reduction of CBF indicated by a decrease of Sr_{O_2} is sufficient to slow the EEG by following BIS. Conversely, we can determine whether a decreased BIS value is caused by decreased CBF rather than other causes (e.g. deepened anaesthesia or hypothermia) by noticing changes in Sr_{O_2}.

The manufacturer of the device notes clearly that BIS is not intended as a monitor of ischaemia. Further studies are required to assess the adequacy of such use.[17] In our patients, however, development of and recovery from cerebral hypoperfusion could be conveniently monitored with the BIS EEG monitor. This simple-to-use monitor of brain function may indicate hypoxia and recovery of cerebral electrical activity in response to circulatory changes during anaesthesia and surgery, especially when used in combination with an NIRS oximeter.

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