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Changes in cerebral blood flow induced by balloon test occlusion of the internal carotid artery under hypotension

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Abstract. Balloon test occlusion (BTO) of the internal carotid artery (ICA) combined with cerebral blood flow (CBF) study has proved to be a sensitive test for prediction of the outcome of permanent vessel occlusion. In this study, we evaluated the acute changes in regional CBF during BTO under hypotension in order to examine the possible risk of cerebral ischaemia after surgical treatment. Eleven patients in whom surgical carotid sacrifice was planned underwent BTO combined with CBF studies using technetium-99m hexamethyl-propylene amine oxime single-photon emission tomography under hypotension by decreasing the systemic blood pressure by about 50 mm Hg using a ganglion blocking agent. All patients showed a mild to severe decrease in CBF in the ipsilateral ICA territory relative to the contralateral side. A decrease in CBF of greater than 20% was observed in nine patients (82%), and two of them showed a decrease exceeding 40%. However, no ischaemic symptoms were demonstrated during scanning with hypotensive BTO. Our results suggest that in many patients with negative normotensive BTO, a considerable reduction in CBF would occur during hypotension. This procedure may predict a possible risk of hypotensive accident during and/or after surgery.

Key words: Balloon occlusion – Cerebral blood flow – Hypotension – Single-photon emission tomography – Ischaemia

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Introduction

Balloon test occlusion (BTO) is the temporary occlusion of the internal carotid artery (ICA) with an inflatable balloon while monitoring neurological symptoms. This procedure is used to identify those patients who might develop cerebral ischaemia and/or infarction after permanent arterial occlusion, which is performed for treatment of inoperative aneurysms or extensive tumours involving the neck and the skull base. However, 5%–20% of the patients without clinical signs of ischaemia during BTO develop cerebral infarction following permanent occlusion [1].

Recently, BTO combined with cerebral blood flow (CBF) study has been proven to be a sensitive means of predicting tolerance to carotid sacrifice [1–8], but false-negative cases are still found, with some patients experiencing a hypotensive accident during the postoperative course. In this study, we evaluated the acute change in CBF during BTO under hypotension in order to predict the possible haemodynamic risk after permanent carotid occlusion.

Materials and methods

Patient population. Eleven patients in whom surgical carotid sacrifice was planned were included in this study (Table 1). Nine patients suffered from vascular lesions, including eight ICA aneurysms and one middle cerebral artery (MCA) aneurysm. The other two patients had neoplasms, including one skull base meningioma and one extensive parapharyngeal neurinoma.

Scanning procedure (Fig. 1). BTO was performed at the C5 portion of ICA. During BTO, systemic blood pressure, electroencephalogram (EEG) and neurological status were monitored. First, the clinical test occlusion was performed for 15 min in the normotensive state. Hypotension was applied in patients who passed the normotensive clinical test occlusion by means of intravenous drip

Table 1. Patient population

Case	Age/sex	Diagnosis	CBF study	
			SPET	PET
1	68/F	ICA cavernous aneurysm	Yes	No
2	40/F	Parapharyngeal neurinoma	Yes	No
3	60/M	Clinoidal meningioma	Yes	No
4	33/M	MCA-M1 giant aneurysm	Yes	No
5	38/F	ICA cavernous aneurysm	Yes	No
6	47/F	ICA giant aneurysm	Yes	No
7	69/F	ICA cavernous aneurysm	Yes	No
8	79/F	ICA giant aneurysm	Yes	No
9	60/F	ICA cavernous aneurysm	Yes	No
10	64/F	ICA terminal aneurysm	Yes	No
11	63/F	ICA cavernous aneurysm	Yes	Yes

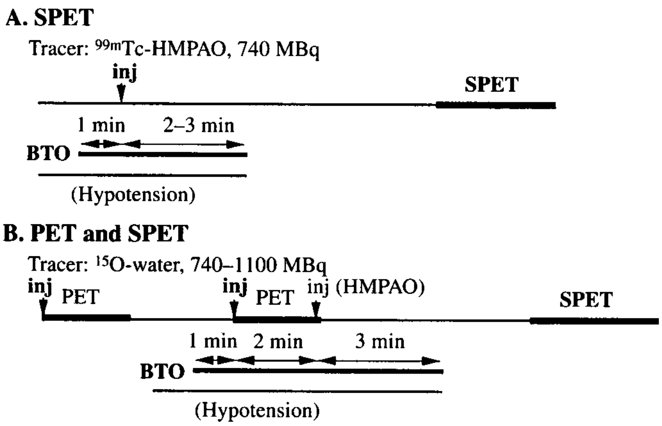


Fig. 1A, B. Scanning procedure for CBF study during hypotensive BTO. **A** ^{99m}Tc-HMPAO was injected 1 min after the balloon inflation and the total occlusion time was 3–4 min. SPET scanning was started about 3 h later. **B** One patient (case 11) underwent both PET and SPET examination. Following the normotensive baseline PET scan, under hypotension ^{15}O-labelled water was injected 1 min after the balloon inflation. HMPAO was injected immediately after the PET measurement for SPET imaging. The PET scan had a duration of 2 min and the total occlusion time was 6 min.

infusion of a ganglion blocking agent, trimetaphan, which decreased the systemic blood pressure by about 50 mmHg. The balloon was to be deflated immediately if the patient developed worrying symptoms during BTO. CBF studies during BTO under hypotension were performed in those patients who passed the 15-min hypotensive clinical test occlusion. Total occlusion time was 3–4 min for single-photon emission tomographic (SPET) scan and 6 min for the patient who underwent both positron emission tomography (PET) and SPET studies. SPET imaging was performed using a multi-detector ring-type scanner (SET-030W; Shimadzu Co., Kyoto, Japan) (cases 1–4, 7, 10, 11) or a triple-head SPET scanner (PRISM3000; Picker International, Highland Height, USA) (cases 5, 6, 8, 9). The SET-030W provided only three transaxial slices at 30-mm intervals and two consecutive SPET scans were performed to acquire six tomographic planes at 15-mm intervals. Because of the poor axial sampling of the SET-030W, the aforementioned four cases were studied with the PRISM3000 following its installation in March 1993; this scanner provided contiguous multiple images of 7 mm thickness. One minute after balloon inflation, patients were injected with 740 MBq (20 mCi) of technetium-99m *d,l*-hexamethyl-propylene amine oxime (HMPAO) intravenously. SPET imaging was carried out about 3 h later.

In order to perform the quantitative evaluation, PET scan was performed in the control state and under BTO before the SPET study in one patient (case 11). The PCT-3600W system (Hitachi Medical Co., Tokyo, Japan) was used to obtain PET images. This scanner simultaneously acquires 15 slices with an interslice distance of 7 mm. CBF was measured following bolus injection of approximately 1110 MBq (30 mCi) of oxygen-15 labelled water, using the autoradiographic method [9] with serial arterial blood sampling data. Following the control PET study, BTO was applied and the second dose of ^{15}0-labelled water was injected 1 min later. Immediately after the end of PFT measurement, ^{99m}Tc-HMPAO was injected for SPET imaging.

All patients underwent a baseline CBF SPET study (normotension, non-occluded) within 2 weeks. CBF changes during BTO were assessed using both SPET and PET images and clinical observation of the patient's response.

Data analysis. All SPET images were analysed semi-quantitatively by means of Lassen's linearization procedure, with the ipsilateral cerebellum serving as a reference region having a CBF of 55 ml/100 g per min [10]. The semi-quantitative CBF values of SPET images and the absolute values of quantitative PET images were used for the data analysis. Sixteen symmetrical, irregularly shaped regions of interest (ROIs) were placed as shown in Fig. 2. An additional ROI was defined in the area with the most profound decrease in CBF in the ICA territory of the occluded side on BTO images, and a symmetrical ROI was placed on the non-occluded side. The size of each ROI was approximately 7 cm^2. Unilateral decrease in CBF was calculated as % decrease in CBF on the BTO side (CBF ips) relative to the non-occluded side (CBF contr):

$$\%\text{decrease}=100[(\text{CBFcontr}-\text{CBFips})/\text{CBFcontr}].$$

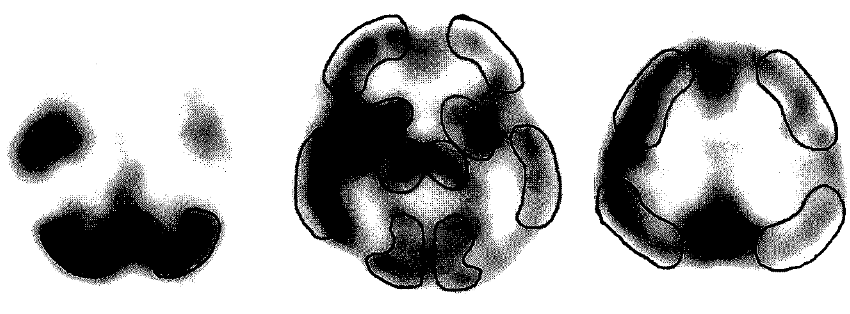


Fig. 2. Definition of the regions of interest in the axial slices

Table 2. Monitoring during 15 min BTO with and without hypotension

Case	Normotension			Hypotension		
	Systemic BP (mmHg)	EEG findings	Neurological findings	Systemic BP (mmHg)	EEG findings	Neurological findings
1	150/80	None	Negative	100/78	None	Negative
2	110/	None	Negative	93/	NA	Negative
3	180/100	None	Negative	113/68	None	Negative
4	145/74	None	Negative	119/71	None	Negative
5	156/98	None	Negative	98/72	None	Negative
6	120/	None	Negative	80/	None	Mildly restless
7	180/	None	Negative	125/	None	Negative
8	150/	None	Negative	90/	None	Mildly restless
9	119/55	None	Negative	80/44	None	Negative
10	113/	None	Negative	74/50	None	Negative
11	178/89	None	Negative	104/62	None	Negative

BP, Blood pressure; EEG, electroencephalographic; NA, not available

Table 3. CBF values at baseline and during BTO under hypotension

Case	CBF (mL/100 g per min)		% decrease[a]	CCD	Symptom
	Baseline Ips./contr.	BTO Ips./contr.			
1	44/42	40/44	(9%)	–	–
2	43/43	38/44	(14%)	–	–
3	46/44	39/47	(17%)	–	–
4	53/56	37/46	(20%)	(+)	–
5	41/48	39/49	(20%)	–	–
6	49/48	45/57	(21%)	–	–
7	56/59	47/60	(22%)	–	–
8	48/52	38/50	(24%)	–	–
9	47/57	36/49	(27%)	–	–
10	51/54	29/60	(52%)	–	–
11	54/58	31/54	(43%)	+(11%)	–
	46/47[b]	24/52[b]	(55%)[b]	+(8%)[b]	–

Ips./contr., Ipsilateral/contralateral; CCD, crossed cerebellar diaschisis

[a] Decrease in CBF relative to contralateral side

[b] Measured by PET

Results

Ten CBF studies were performed by means of SPET and one with both SPET and PET. All patients passed the 15-min clinical test occlusion under both normotension and the hypotensive state, and hypotensive BTO-CBF studies were carried out. Table 2 summarizes monitoring data in respect of systemic blood pressure, electroencephalographic (EEG) findings and neurological findings during 15 min BTO under both normotension and hypotension. During the hypotensive 15-min clinical test, two patients (cases 6 and 8) were mildly restless but had neither ischaemic symptoms nor EEG changes during the hypotensive BTO-CBF study for 4 min.

None of the baseline CBF images demonstrated apparent asymmetry in cerebral perfusion. Case 4 showed mild hypoperfusion in the contralateral cerebellar hemisphere, but there was no remarkable change between the baseline and the hypotensive BTO image.

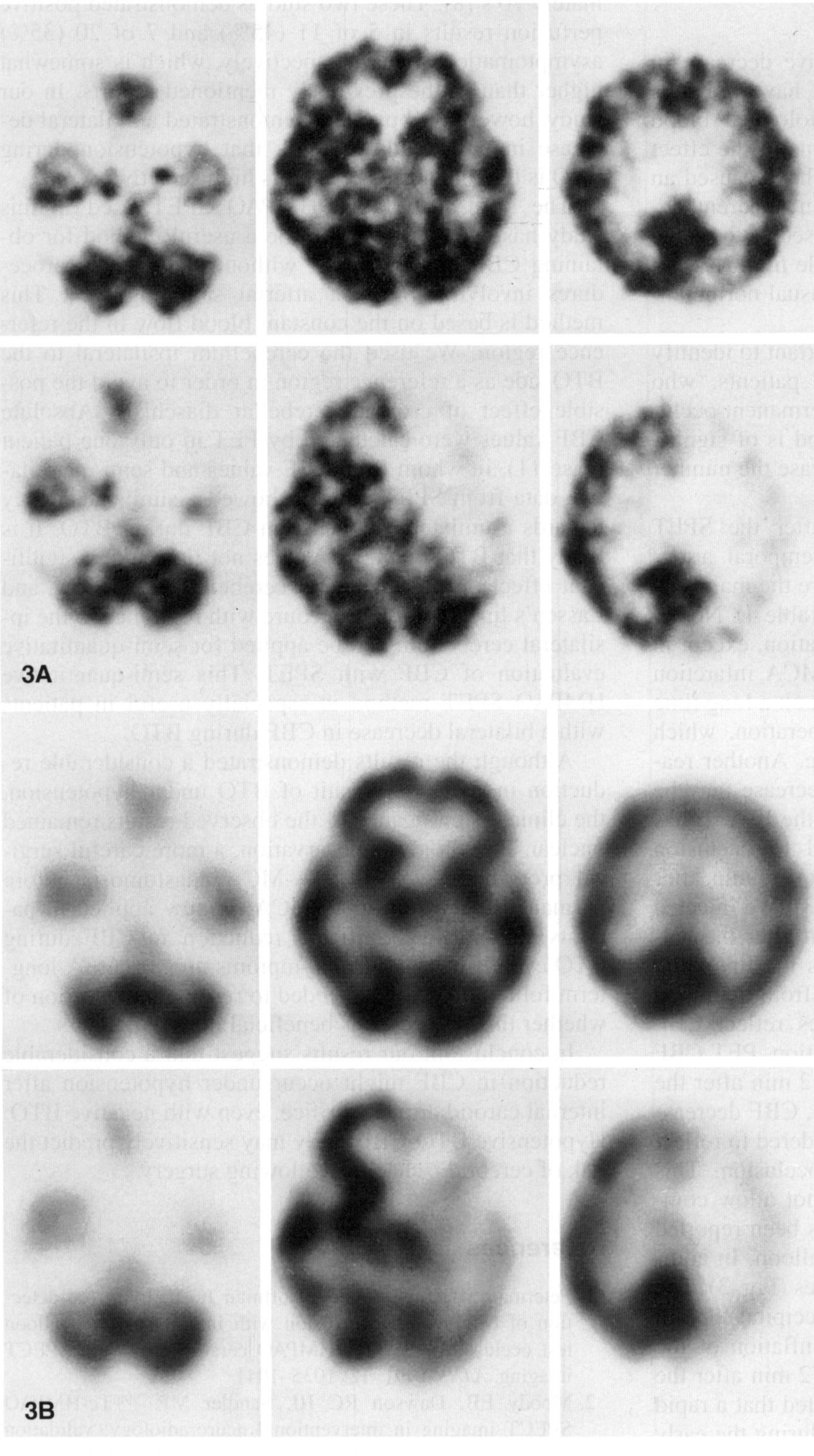
During hypotensive BTO, all 11 patients showed a mild to severe decrease in CBF. Table 3 shows CBF values acquired from both baseline and hypotensive BTO images. SPET and PET showed a 9%–55% decrease in

Table 4. Surgical treatment and postoperative course

Case	Diagnosis	Surgical treatment	Outcome (infraction)
1	ICA cavernous aneurysm	STA-MCA anastomosis, ICA balloon occlusion	(–)
2	Parapharyngeal neurinoma	Removal of tumour, ICA not sacrificed	(–)
3	Clinoidal meningioma	STA-MCA anastomosis, removal of tumour	(–)
4	MCA-M1 giant aneurysm	STA-MCA anastomosis, trapping of aneurysm	MCA infarction
5	ICA cavernous aneurysm	STA-MCA anastomosis, ICA ligation	(–)
6	ICA giant aneurysm	None	Died[a]
7	ICA cavernous aneurysm	STA-MCA anastomosis, ICA balloon occlusion	(–)
8	ICA giant aneurysm	STA-MCA anastomosis, ICA balloon occlusion	(–)
9	ICA cavernous aneurysm	STA-MCA anastomosis, ICA balloon occlusion	(–)
10	ICA terminal aneurysm	ECA-RAG-MCA bypass, trapping of aneurysm	MCA infarction
11	ICA cavernous aneurysm	None	Unchanged

[a] Death due to rupture of the aneurysm before any surgical treatment

ICA, Internal carotid artery; STA, superficial temporal artery; MCA, middle cerebral artery; ECA, external carotid artery; RAG, radial artery graft


3A

3B

Fig. 3A, B. PET and SPET images obtained in a patient with left ICA cavernous aneurysm (case 11). **A** PET CBF images at baseline (*top*) and under hypotensive BTO (*bottom*). During BTO of the left ICA, a marked decrease in CBF in the ipsilateral ICA territory and mild hypoperfusion in the contralateral cerebellum were demonstrated. **B** ^{99m}Tc-HMPAO SPET images at baseline (*top*) and under hypotensive BTO (*bottom*), demonstrating that the area of hypoperfusion extended to the left occipital lobe

CBF in the occluded ICA territory relative to the contralateral side. None of them showed any neurological symptoms during the hypotensive BTO-CBF study, including two patients with a reduction of more than 40%. Figure 3 shows baseline and hypotensive BTO images of case 11. During hypotensive BTO, both SPET and PET showed marked CBF decrease in the occluded ICA territory and mild crossed cerebellar diaschisis. The remaining nine patients showed a mild decrease in CBF of between 9% and 27% without any neurological symptoms.

Discussion

The present study demonstrated a positive decrease in CBF during BTO more frequently than have previous studies carried out under normal physiological blood pressure [1–8]. This difference may be due to the effect of hypotension during BTO, which may have caused an autoregulatory impairment, leading to an apparent decrease in CBF. Therefore, this procedure seems to be the most sensitive means of detecting possible high-risk patients who show negative results on the usual normotensive test [11].

From the clinical viewpoint, it is important to identify preoperatively the borderline group of patients, who might develop cerebral infarction after permanent occlusion. For this purpose, the present method is of significant clinical value although it might increase the number of false-positive cases.

Surgical operation was performed after the SPET studies in nine cases, and superficial temporal artery (STA)-MCA bypass was carried out before the main surgical treatment in eight of nine patients (Table 4). No cerebral infarction occurred after ICA operation, except in two patients who developed ipsilateral MCA infarction (cases 4 and 10). In case 10, however, it took a long time to clip the MCA during the surgical operation, which might have had an effect on the outcome. Another reason for this high positive rate of CBF decrease may be the short time interval after clamping of the ICA. It has been reported that ICA pressure distal to occlusion shows a gradual increase during the first 5–6 min after the initial fall caused by clamping [12, 13]. We injected the radioactive tracer intravenously 1 min after the balloon inflation. In SPET measurement, as the lipophilic component of HMPAO is rapidly cleared from the blood circulation, the measured brain activities reflect CBF within a couple of minutes after the injection. PET CBF measurement was also performed within 2 min after the injection of ^{15}O-labelled water. Therefore, CBF decreases observed in the present study are considered to reflect the early changes (2–3 min) after the occlusion. This short interval after the occlusion might not allow complete collateral opening, although this has been reported to occur 1–2 min after inflation of the balloon. In addition, our case 11 showed interesting images (Fig. 3). The hypoperfused area extended to the left occipital lobe in the BTO-SPET image (3 min after the inflation of the balloon) but not in the BTO-PET image (2 min after the inflation of the balloon). This fact suggested that a rapid change in CBF distribution might occur during the early period of BTO.

In most of the previous reports [1–6], the injection was performed after a minimum of 15 min of BTO, and 10%–45% of patients showed a CBF decrease following BTO. On the other hand, Simon et al. reported an HMPAO SPET study in which injection was performed 2 min after BTO [7], and Barker et al. reported a PET CBF study which required balloon inflation for approximately 70 s [8]. These two studies demonstrated positive perfusion results in 5 of 11 (45%) and 7 of 20 (35%) asymptomatic patients, respectively, which is somewhat higher than in the previously mentioned reports. In our study, however, all patients demonstrated a unilateral decrease in CBF, and we think that hypotension during BTO is the major reason for this high sensitivity.

The semi-quantitative HMPAO SPET used in this study has been suggested to be a useful method for obtaining CBF images easily, without complicated procedures involving frequent arterial sampling [10]. This method is based on the constant blood flow in the reference region. We used the cerebellum ipsilateral to the BTO side as a reference region in order to avoid the possible effect of crossed cerebellar diaschisis. Absolute CBF values were calculated by PET in only one patient (case 11), in whom PET CBF values and semi-quantitative data from SPET images showed a similar tendency towards a unilateral decrease in CBF during BTO. It is likely that BTO of the ICA does not induce any significant effect on the ipsilateral cerebellar blood flow, and Lassen's linearization procedure with reference to the ipsilateral cerebellum can be applied for semi-quantitative evaluation of CBF with SPET. This semi-quantitative HMPAO SPET method is especially useful in patients with a bilateral decrease in CBF during BTO.

Although the results demonstrated a considerable reduction in CBF as a result of BTO under hypotension, the clinical significance of the observed results remained unclear. Based on this observation, a more careful surgical procedure, such as STA-MCA anastomosis before permanent occlusion of the ICA, is now applied in patients showing a significant reduction in CBF during BTO even if neurological symptoms are absent. A long-term follow-up study is needed to resolve the question of whether this procedure is beneficial in such patients.

In conclusion, our results suggest that a considerable reduction in CBF might occur under hypotension after internal carotid artery sacrifice, even with negative BTO. Hypotensive BTO-CBF study may sensitively predict the risk of cerebral ischaemia following surgery.

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